GENETIC ANALYSIS OF *STRIGA* RESISTANCE AND LOW SOIL NITROGEN TOLERANCE IN EARLY MATURING MAIZE (*Zea mays* L.) INBRED LINES

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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

Striga hermonthica (Del.) and low soil nitrogen (low N) are among the most important constraints to maize production and productivity in West Africa (WA). Knowledge and understanding of the inheritance of *Striga* resistance and low N tolerance in early maturing maize inbreds are invaluable in developing hybrids adapted to both low N and *Striga*-infested environments in WA. The objectives of the present study were to (i) assess the genetic diversity among the inbred lines using simple sequence repeats (SSR) and single nucleotide polymorphisms (SNPs), (ii) assess the levels of resistance/tolerance of inbred lines to *Striga* and Low N (iii) examine the combining ability of early maturing maize inbreds across low-N, *Striga*-infested and optimum growing environments, and (iv) assess the performance and stability of the hybrids across the stress and non-stress environments.

Genetic diversity among nine CIMMYT and 87 IITA early maturing inbred lines was assessed using 31 polymorphic SSR and 261 SNP markers. SSR and SNP analyses revealed a relatively high level of variability among the lines. One hundred inbred lines (11 CIMMYT and 89 IITA lines) were evaluated under low N and *Striga*-infested environments in 2010 and 2011 in Nigeria. Using the base indices for selection, 27 % of the lines combined resistance to *Striga* and tolerance to low N. Thirty lines were selected based on their performance under low N and *Striga*. The lines were used to generate 150 early single-cross hybrids using the North Carolina design II. The hybrids plus six hybrid checks were evaluated under *Striga*-infested, low-N and optimum growing environments at two locations in Nigeria in 2011 and 2012.

General combining ability (GCA) and specific combining ability (SCA) mean squares were significant for grain yield and other traits indicating that additive and non-additive gene effects were important in the control of the inheritance of grain yield and other traits across the

contrasting environments. GCA mean squares of grain yield, *Striga* damage and number of emerged *Striga* plants were larger than those of SCA, indicating that additive gene action was more important in the inheritance of these traits. Similarly, the contribution of GCA to the total sum of squares was higher than that of SCA for grain yield (52.4%) under low N indicating that additive gene action was more important in the inheritance of low N tolerance. The superior GCA-female effects (GCA_f) for days to silking and GCA-male effects (GCA_m) for ears per plant under *Striga* infestation indicated that maternal and paternal effects modified the expression of the traits under *Striga* infestation. In contrast, there were no maternal or paternal effects on the traits under low-N environments. Inbreds TZEI 173, TZEI 175 and ENT 11 had superior positive GCA_m and GCA_f effects for grain yield under *Striga* infestation. These can be used to improve germplasm for *Striga* resistance. The lines ENT 11, ENT 12, ENT 16 and TZEI 32 with outstanding positive GCA effects for grain yield under low N environments can be used to improve germplasm for low N tolerance. Grain yield of the hybrids ranged from 1254 kg ha^{-1} for TZEI 173 X TZEI 175 to 5541 kg ha^{-1} for ENT 16 x TZEI 32 under low N, 775 kg ha^{-1} for TZEI 168 x TZEI 54 to 4735 kg ha^{-1} for ENT 11 x ENT 12 under *Striga* infestation. The polymorphic information content (PIC) from the SSR marker data ranged from 0.10 to 0.87 with an average of 0.58. The PIC values for SNP ranged from 0.01 to 0.38 with an average of 0.25.The number of alleles per locus identified by SSR markers ranged from 2 to 8 with an average of 3.7. Cluster analysis based on genetic distance (GD) from SSR and SNP classified the lines into five and three groups respectively. The lines clustered predominantly according to their pedigree. ENT 11 x TZEI 4 and TZEI 65 x ENT 11 identified as the most stable and high yielding hybrids should be extensively tested and promoted for adoption and commercialization. This would contribute to improved maize productivity and food security in the sub-region.

DEDICATION

To my husband - Idolo Ifie

To my children - Oyinbrakaemi Efemena Jeremiah and Tamaratonye Efeturi

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LIST OF ABBREVIATIONS

SSA	sub-Saharan Africa
FAO	Food and Agriculture Organization
WA	West Africa
WCA	West and Central Africa
CIMMYT	International Maize and Wheat Improvement Center
IITA	International Institute of Tropical Agriculture
Low N	Low soil nitrogen
DNA	Deoxyribonucleic acid
AFLP	Amplified fragment length polymorphism
RAPD	Randomly amplified polymorphic DNA
RFLP	Restriction fragment length polymorphism
SSR	Simple sequence repeats
SNP	Single nucleotide polymorphisms
UPGMA	Unweighted pair group method with arithmetic average
NJ	Neighbor-joining trees
NC II	North Carolina design II
PIC	Polymorphic information content
GGE	Genotype plus genotype by environment interaction
GD	Genetic distance
WAP	Weeks after planting

CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.) is a major staple food in sub-Saharan Africa (SSA). It is the third most important cereal after wheat and rice (FAO, 2011). There is an increasing demand for the crop for food, feed and raw materials for industrial purposes. Its production in West Africa (WA) over the years has increased with increase in area under cultivation. For example, the area devoted to maize in Nigeria increased from 3.8 million hectares in 2008 to 5.2 million hectares in 2012 while, production increased from 7.5 million tonnes in 2008 to 9.4 million tonnes in 2012 (FAO, 2012). The increase in production was as a result of increase in area cultivated. The production of adequate food in SSA is threatened by a number of factors including declining soil fertility (Bekunda *et al*., 2010; Sanchez 2010). Grain yield of maize in WA where the soils are nutrient deficient has remained stagnant for the past 10 years hovering around 1.6 tonnes (FAO, 2012). Despite the implementation of structural adjustment programmes to enhance agricultural production in SSA, the slow increase in yield per hectare in agricultural production is not enough to keep pace with the rapid population growth (Heerink, 2005). It is therefore important to improve grain yield without expanding the area under production in SSA. This can be achieved by the development of hybrids with improved grain yield under low input conditions and with outstanding performance under high input conditions.

The savanna agro-ecology of Nigeria has the highest potential for maize production and productivity because of its high solar radiation, low night temperatures and low incidence of pests and diseases. As a result, maize has been adopted extensively in the zone, replacing the traditional crops such as sorghum and millet (Fakorede *et al*., 2003). However, production and productivity are hampered by a number of biotic and abiotic factors including *Striga hermonthica* (Del.) Benth. parasitism and low soil nitrogen (low N).

S. hermonthica is a parasitic weed which attacks maize, sorghum and other cereal crops. It is the largest single biological constraint to food production in SSA (Ejeta, 2007a). Its prevalence in the lowland savanna and mid altitude agroecologies, where yield potentials are greatest, imposes severe limitations on productivity (Rodenburg *et al*., 2006; Yallou *et al*., 2009). Impacts are greatest on nutrient-depleted soils, particularly those low in N and the poorest subsistence farmers are the most severely affected (Sauerborn *et al*., 2003). Therefore, maize varieties targeted to the *Striga* endemic areas of Africa should also be tolerant to low N. Grain yield losses due to *Striga* infestation are estimated to range from 30–90% (Van Ast *et al.*, 2005). This however depends on the *Striga* seed bank in the soil, level of resistance or tolerance of the crop to *Striga*, soil fertility status and environmental factors particularly drought. *Striga* infestation can be so severe that farmers are forced to abandon their fields (Ejeta, 2007a). *Striga* control options are available but none of the methods achieve complete control of the parasite, thus necessitating the combination of two or more methods (Yallou *et al*., 2009). The use of *Striga* resistant/tolerant varieties is the most feasible and sustainable approach for minimizing the losses caused by this parasitic weed (De Vries, 2000; Badu-Apraku *et al*., 2005; Menkir *et al*., 2005).

Declining soil fertility is a major abiotic constraint to cereal production in Africa (Hartemink, 2006; Sanchez, 2010). Decades of farming without adequate use of fertilizer has resulted in the depletion of essential soil nutrients required to support plant growth in SSA (Sanchez, 2010). Soil nitrogen depletion is also caused by extensive removal of crop residues for use as animal feed and fuel (Zambezi and Mwambula, 1997). The estimated annual loss of maize yield due to low N stress varies from 10 to 50% (Wolfe *et al.*, 1988). Although current estimates of yield loss as a result of low N are not available, low N is still a major constraint to production (Abe et *al*., 2013). The fertilizer application rate in Africa is low (8 kg ha^{-1}), and this is far below the 50 kg ha^{-1} target set by the Africa Fertilizer Summit (2006) as reported by Vanlauwe *et al*. (2010). In order to increase grain yield, the use of 120 kg N ha^{-1} is recommended for maize production in SSA. However, fertilizer application rates in the sub-region are still far below the recommended dose due to high prices of inorganic fertilizer and its unaffordability by resource poor farmers. Breeding crops with tolerance to low N offers the most appropriate and sustainable approach for increased maize yields for small scale farmers in SSA where low agricultural inputs are utilized.

Studies have shown that recurrent selection is effective in improving maize for *Striga* resistance (Badu-Apraku and Menkir, 2006; Menkir and Kling, 2007; Badu-Apraku *et al*., 2009). Recurrent selection for *Striga* resistance under artificial infestation in two early and two extra-early maize populations resulted in selection gains under low and high N environments as well as reduction in *Striga* damage and emergence (Badu-Apraku *et al*., 2009). In West Africa (WA), selection for improved grain yield under *Striga* infestation is done under low N fertilizer, 30 kg N ha^{-1} instead of the recommended 120 kg N ha^{-1} for production. Similarly, the low dose of nitrogen is used in the recurrent selection programme for low N tolerance in WA. Therefore, it was hypothesized that genotypes selected for *Striga* resistance may also show tolerance to low N. On the other hand, direct selection under low N and indirect selection under high N for low N target environments have been employed by International Maize and Wheat Improvement Center (CIMMYT) in selection for low N tolerance. In the direct selection for low N tolerance, N fertilization is not used. However, Karaya *et al*. (2012a) found *Striga* resistance in the CIMMYT inbreds that were not intentionally selected for *Striga* resistance suggesting that selection for tolerance to drought and low N could confer an appreciable degree of tolerance to *Striga*. The *Striga* resistance identified in the CIMMYT inbred lines may be due to the presence of *Striga* resistant alleles in the lines but not as a result of selection under drought, low N or other stresses but *Striga*. Hence there is a need to identify genotypes with combined resistance to *Striga* and tolerance to low N. The use of hybrids with resistance/tolerance to *Striga* and low N would be appropriate and more sustainable to small scale farmers in areas where low agricultural inputs are utilized and *Striga* problems are endemic. This will contribute to food security and improve incomes of farmers in WA.

Phenotypic classification of inbred lines is of great value in the selection of parental lines for the development of heterotic populations and the introgression of desirable genes from diverse sources into the available genetic base (Thompson *et al.*, 1998). Over 200 early maturing inbred lines have been developed in the International Institute of Tropical Agriculture (IITA) maize breeding programme. However, there is limited information on the performance of the inbred lines under low N, *Striga* infestation and optimum environments. Furthermore, the extent of diversity among them has not been ascertained. This information, when obtained, will be useful in selecting lines that may combine well to produce superior hybrids across stressed and non-stressed environments. It has been generally assumed that crosses involving parents of diverse origin produce higher grain yield than those involving closely related parents (Melchinger, 1999; Lu *et al.*, 2009). This is however not always the case. The use of molecular markers has been useful in clustering inbred lines based on relatedness, kernel type and color. However, information on the relationship of genetic distance determined using molecular markers and hybrid performance is not consistent. While some authors such as Mohammadi *et* *al*. (2008) and Makumbi *et al*. (2011) reported a correlation between genetic distance and grain yield of hybrids, others such as Menkir *et al.* (2010) and Badu-Apraku *et al*. (2013a) found no relationship between genetic distance of inbred lines and grain yield of hybrids. Assessment of the genetic diversity among early maturing inbred lines using molecular markers and examination of its relationship with grain yield of hybrids across low N and *Striga*-infested environments would be useful in selecting potential parents with diverse genetic backgrounds for developing productive hybrids with resistance to *Striga* and tolerance to low N.

The objectives of this study were to:

(i) Assess the genetic diversity in selected IITA and CIMMYT inbred lines using molecular markers.

(ii) Determine the levels of resistance/tolerance of inbred lines to *Striga* and Low N.

(iii) Determine the gene action conditioning *Striga* resistance and tolerance to low N in early maturing maize inbreds

(iv) Assess the performance and stability of the hybrids under low N, *Striga*-infested and optimum environments.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Maize taxonomy

Maize (*Zea mays* L.) is a diploid (2n=20) belonging to the family Poaceae (Grass family). There are five species in the genus *Zea* (*Z. mays, Z. perennis, Z. nicaraguensis, Z. luxurians* and *Z. diploperennis*) but *Z. mays* is the only cultivated species. The others are wild grasses commonly referred to as teosintes and are native to Mexico and Central America (Doeblay, 1990). Maize is predominantly an outcrossing species, the reason for its exceptional genetic diversity, making it highly adaptable and responsive to selection pressure. Maize is a versatile crop and can be grown across a wide range of environments with diversity in soil type and composition, climate, day length, and elevation (Neuffer, 1982; Paliwal 2000).

2.1.1 Maize production and productivity

Maize has a wide range of uses as food, feed and raw materials for industrial purposes. Maize is the third most important cereal in the world after wheat and rice (FAO, 2011) and a major staple food crop in SSA. In Nigeria, it is the second most important cereal after rice. The global maize production is estimated at 883 million tonnes (FAO, 2011). West Africa contributes approximately 16 million tonnes out of which 9.2 million tonnes is produced in Nigeria. In West Africa, the average grain yield of maize is 1.6 tonnes per hectare (FAO, 2012). This is far below the potential of the crop. For example, in the US, average yield of maize is about 7 tonnes per hectare and it is 4 tonnes per hectare in South Africa. Several biotic and abiotic factors affect the production and productivity of maize in sub-Saharan Africa. Low soil fertility (particularly low soil nitrogen) is one of the major abiotic constraints while *Striga* infestation constitutes the largest single biological constraint to maize production in West and central Africa.

2.2 Low soil nitrogen

Nitrogen, an essential component of all enzymes is needed for plant growth and development. It constitutes about one-sixth of the weight of proteins, and is a basic element of nucleic acids (Bänziger *et al*., 2000). The maize plant requires 50-60 kg N and 30 kg P ha^{-1} in plant available forms for one tonne of grain produced (Weber *et al.*, 1996). Nitrogen uptake, biomass production, and grain yield are strongly correlated, indicating that there is a relationship between N requirement and grain yield (Greenwood, 1976; Pandey *et al.*, 2000; Bänziger *et al.*, 2000).

Fertilizer use in Africa is low, with an average of 8 kg ha^{-1} (Heisey *et al.*, 2007; Vanlauwe *et al*., 2010). This is far below the 50 kg ha^{-1} target set by the Africa Fertilizer Summit (2006) as reported by Vanlauwe *et al*. (2010). The low amount of fertilizer used by small holder farmers in Africa is associated with the high price of fertilizer. The inadequate transportation and distribution infrastructure contribute to higher prices (Mosier *et al*., 2005). Low soil nitrogen (low N) is one of the major abiotic constraints to maize production in the tropics where fertilizer is seldom used and organic matter is rapidly mineralized (Lafitte and Bänziger, 1996; Bänziger and Lafitte, 1997a; Abe *et al*., 2013). Factors that affect the availability of N include leaching (Bennet *et al.*, 1989) and removal of crop residues as feed and fuel (Zambezi and Mwambula, 1997). Nitrogen stress before flowering reduces leaf area development, photosynthesis rate, and the number of ear spikelets (potential grains) while stress during flowering results in kernel and ear abortion, and stress during grain-filling accelerates leaf senescence and reduces crop photosynthesis and kernel weight (Bänziger *et al*., 2000).

2.2.1 Breeding for low N tolerance

Approaches used in the development of improved maize cultivars for tolerance to low N environments include selection for improved yield under high N and specific mechanisms expected to confer tolerance to low N (Lafitte and Bänziger, 1996). Selection under optimum nitrogen levels increased grain yields more under high than low N conditions (Castleberry *et al.*, 1984). However, selection gains under low N are predicted to be higher when selection is conducted under both low and high N (Bänziger and Lafitte, 1997a). In assessing the relative efficiency of direct selection under low N vs indirect selection under high N for improving tropical maize for low N target environments Bänziger *et al.* (1997) found indirect selection under high N to be less efficient than selection under low N when yield reduction due to low N exceeded 43%. Thus, concluded that maize breeding targeting low N environments should include low N environments to maximize selection gains. Selection gain for grain yield was reported to be higher under low soil N in a single cycle of selection among half-sib families of a tropical maize population while a yield reduction was observed under high N (Muruli and Paulsen, 1981). Because the heritability for grain yield under low N is low, secondary traits such as ears per plant, delayed leaf senescence, and anthesis-silking interval are used in combination with grain yield for selecting low N tolerant genotypes (Bänziger and Lafitte, 1997b; Bänziger *et al.*, 1999). Several studies have reported good performance of tropical maize genotypes selected for drought tolerance under low N conditions (Lafitte and Edmeades, 1995, Lafitte and Bänziger, 1997, Logrono and Lothrop, 1997; Bänziger *et al.*, 1999, Meseka *et al.*, 2006).

2.2.2 Genetic studies on low N tolerance in maize

Several genes control tolerance to low soil N in maize with a preponderance of additive gene action (Rizzi *et al.*, 1993; Lafitte and Edmeades, 1995; Beck and Betran, 1997; Below *et* *al*., 1997; Kling *et al*., 1997). On the contrary, several authors (Katsantonis *et al*., 1988; Betrán *et al*., 2003b; Meseka *et al*., 2006; Makumbi *et al*., 2011) reported that non-additive genetic effects conditions grain yield of maize hybrids under low N. The differences observed in gene action conditioning tolerance to low N may be due to the germplasm used in different studies.

2.3 The parasitic weed *Striga* (Witchweed)

Over 4000 species of angiosperms are able to invade and parasitize other plants (Nickrent *et al*., 1998) but only a few are weedy and parasitize cultivated plants (Joel *et al*., 2007). These weedy parasites pose a tremendous threat to the world economy (Gressel *et al*., 2004). They belong to various plant families and attach to host roots, shoots, or branches. *Striga* belongs to Scrophulariaceae group. Many parasitic Scrophulariaceae species, including those of the genera *Pedicularis*, *Rhinanthus*, *Agalinis*, and *Triphysaria*, are facultative parasites that can reach maturity without parasitizing a host but members of the *Striga* genus are obligate parasites. They must attach to the roots of suitable host soon after germination in order to survive. They are photosynthetically competent and are therefore termed hemiparasites. Obligate parasites generally have more specific host requirements than facultative parasites.

The genus *Striga* (witchweeds) consists of about 28 described species, some of which parasitize monocots and others dicots (Estep, 2011). Members of the genus *Striga* are vascular plant parasites of sorghum, millet, maize, cowpea and sugar cane in the savannas of Africa. *S. hermonthica* (Del.) Benth., *S. aspera*(Willd.) Benth, *S. asiatica* (L.) Kuntze, *S. forbesii* Benth. infect cereal crops, while *S. gesneriodes* (Willd.) Vatke parasitizes only cowpea and tobacco (Estep, 2011). The witchweeds are menacing root parasites of significant importance in much of Africa and parts of Asia (Mohamed *et al*., 2001, Ejeta, 2007a).

2.3.1 Biology and Life Cycle of *Striga hermonthica*

Striga is a Latin word for "witch" referring to the host symptoms which appears before the parasite emerges (Rich and Ejeta, 2008). *S. hermonthica* is an outcrossing species with strain variation between environments (Kim, 1994). It has lavender flowers and is common in East and WA, and in the Sahel (Mohamed *et al.*, 2001). *Striga* seeds are very small and possess limited energy reserves compared to those produced by facultative parasites or free-living angiosperms. *Striga* plants produce large amounts of tiny seeds (0.3 x 0.2 mm) that may exceed 200,000 per plant (Parker and Riches, 1993), and its seed bank builds up on continuous cultivation of a host plant (Kunisch *et al.*, 1991). The build-up of *Striga* seed in the soil seed bank results in serious losses in crop yields (Parker and Riches, 1993). Seeds of *S. hermonthica* may remain viable for more than 10 years in the soil (Gbèhounou, *et al*., 2003; Hearne, 2009). Therefore, an effective control method should include strategies that will deplete the *Striga* seed bank.

The life cycle of *Striga* is intimately linked to that of its host and depends on a complex exchange of chemical signals (Scholes and Press, 2008). Strigolactones (secondary metabolites) are potent germination stimulants for *Striga* and some other parasitic weeds (Joel *et al.*, 1995; Bouwmeester *et al.*, 2003). The life cycle of *Striga* begins with germination of seeds which occurs only in response to strigolactones in the root exudates of host and some non-host plants (Matusova *et al*., 2005). The adaptation of the parasitic weeds to respond to these germination stimulants is of evolutionary significance (Butler, 1995). The tiny seeds of *Striga* cannot survive for more than a few days after germination unless a host root is invaded hence the need for the penetration of host roots to tap nutrients.

The *Striga* shoot emerges above ground, flowers and sets seed approximately six weeks after penetration. Although *Striga* species perform limited photosynthesis after emergence, the bulk of fixed carbon in the parasite is obtained from the host (Press, 1995). Successful parasitism results from a number of interactive processes between the host and parasite conditioned by a number of genetic and physiological events which are also influenced by environmental factors (Ejeta, 2007b). Reduction in host biomass is explained by the phytotoxic effects that change the partitioning of host photosynthate from shoot to root and an overall reduction in photosynthetic rate (Ransom *et al.*, 1996).

2.3.2 Impact of *Striga hermonthica* on crop production and productivity

Striga prevalence in the lowland savanna and mid altitude zones, where cereal yield potentials are greatest, imposes severe limitations on crop productivity (Yallou *et al.*, 2009). The small holder farmers are the most affected (Estep, 2011). Among the numerous species of *Striga* that are endemic to the savannas of Africa, *S. hermonthica* is the most widespread and destructive species affecting cereals, with maize being the most susceptible (Berner *et al.*, 1995; Yoshida, *et al.*, 2010). Over 6 million ha of land cultivated to maize in East, West and Southern Africa, representing about 24% of the overall maize area is *Striga* infested (de Groote *et al.*, 2008). Approximately 64% of the total land area cultivated to cereals in WA is severely infested with *Striga* (Gressel *et al.*, 2004) while 70% of the arable land in Nigeria is *Striga* infested (Hartman and Tanimonure, 1991). *S. hermonthica* infects maize, sorghum, pearl and finger millets and upland rice causing severe stunting and average yield losses of 30 - 90% (Van Ast *et al.*, 2005; Ejeta, 2007a). Grain yield losses in maize from *S. hermonthica* infestation in WCA average 68% (Kim *et al.*, 2002), but losses can reach 100% in susceptible maize cultivars under severe field infestation in areas of marginal production (Ransom *et al.*, 1990; Haussmann *et al.*, 2000). *Striga* infestation can become so severe that farmers are forced to abandon their fields (Ejeta, 2007a).

Striga is an increasing problem for small-scale subsistence farmers in SSA, and represents the most serious biotic constraint to cereal production in resource-limited agriculture in Africa (Ejeta, 2007a). The problem of *Striga* is intensifying across regions of Sub-Saharan Africa due to soil fertility deterioration, shortening of fallow period, expansion of production into marginal lands with little nutrient input and an increasing trend towards continuous cultivation of crops in place of traditional rotation and inter-cropping systems (Menkir *et al.*, 2001). Infestation is less severe where water and soil fertility are optimal for crop growth (Rich and Ejeta, 2008) which is hardly the case in Africa. The extent to which *Striga* reduces host growth and photosynthesis is affected by nitrogen supply (Kureh *et al.*, 2006; Kabambe *et al.*, 2007; Kamara *et al.* 2007).

2.3.3 *Striga hermonthica* control methods

The extent to which *Striga* affects maize is dependent on the host's ability to tolerate the parasite, inoculum density of *Striga* seed in the soil, time of N application, and the level of soil N (Kim and Adetimirin, 1997a; Kim and Adetimirin, 1997b). There are several available *Striga* control methods. The most common methods include practices such as hand weeding (Akobundu, 1991), crop rotations, trap cropping (Egley *et al.*, 1990), improving soil fertility such as the use of high nitrogen fertilizer (Oswald, 2005; Van Ast *et al.*, 2005; Joel *et al.*, 2007) and the use of resistant/tolerant cultivars Badu-Apraku *et al*. 2004; Menkir *et al*., 2012, Badu-Apraku *et al.*, 2013a). Other control strategies involve the use of the forage legume *Desmodium uncinatum* as an intercrop (Khan *et al.*, 2007) and herbicide coating on seeds of herbicide resistant maize (Kanampiu *et al.*, 2003). All the control methods have limitations and none has provided a complete control for *Striga* (Oswald, 2005). Cultural practices such as crop rotation, intercropping, and prolonged fallow improves soil fertility and exert some control to *Striga*

(Kureh *et al.*, 2000). However, increasing human population has resulted in intensive land use with shortened or no fallow (Webb *et al.*, 1993), and in some areas continuous cereal cropping with little or no fertilizer or manure application (Van Ast *et al.*, 2005). This has resulted in the depletion of soil fertility and therefore decreased effectiveness of cultural control methods (Berner *et al.*, 1996). Trap and catch crops which involve the use of non-host crops such as cotton and soybean produce germination stimulants that induce suicidal germination of *Striga* seeds in previously infested fields, thereby reducing the *Striga* seed bank in the soil. The removal of mature *Striga* plants before they set seed by hand weeding will reduce the amount of *Striga* seeds in the soil, but will not significantly increase the crop yield during the early years of weeding (Verkleij and Kuiper, 2000) because damage to the maize crop would have been seriously inflicted before the *Striga* plant emerges from the soil (Parker and Riches, 1993). Furthermore, hand weeding is laborious, time consuming and impracticable to use for *Striga* control in large farm land. The use of imazapyr and an imidazolinone-resistant maize in Kenya increased the harvest index by 17% when maize plants were grown in *Striga*-infested soils (Abayo *et al.*, 1998). Dicamba, when applied at the time of *Striga* attachment, kills *Striga* before it emerges and provides some yield protection (Odhiambo and Ransom, 1993; Ransom *et al.*, 1990). However, dicamba does not provide the persistent, continual control necessary to make it cost effective (Abayo *et al.*, 1998). Although, the use of herbicides that inhibit acetolactate synthase (ALS) activity is effective for control of parasitic weeds, there is the risk of mutation of traits conferring resistance to ALS-inhibiting herbicide. Application of ethylene gas to *Striga*-infested soil before planting of crops is another *Striga* control method. Ethylene induces germination of *Striga* seeds in the absence of a host, which then causes death because they cannot survive without a host (Parker and Riches, 1993). Ethylene gas is effective but expensive and certainly beyond the reach of the resource poor farmer in the tropics.

2.3.4 *Striga* infestation and nitrogen fertilizer

The problem of inherent low nitrogen status of soils in WA, and the low application of N fertilizers by smallholder farmers in the region further aggravates the problem of *Striga* infestation on maize productivity (Badu-Apraku *et al*., 2013b). Pieterse and Verkleij (1991) reported that the incidence of *Striga* is negatively correlated with soil fertility, particularly nitrogen availability. Yield losses due to *Striga* vary from 10 to 100% depending on the cultivars grown, climatic conditions, soil fertility status and level of infestation (Kroschel, 1999). Nitrogen affects *Striga* germination and attachment to the host root system and thus the partitioning of photosynthates (Parker, 1984; Raju *et al.*, 1990; Cechin and Press, 1993). The effect of nitrogen fertilizer on *Striga* infestation, emergence and grain yield has been extensively reported by several authors in maize and sorghum (Farina *et al.*, 1985; Ogborn, 1987; Smaling *et al*,. 1991; Mumera and Below, 1993; Kim *et al.*, 1997; Kim and Adetimirin, 1997a; Kureh *et al.*, 2006; Kabambe *et al.*, 2007; Kamara *et al.* 2007). Reports on the effect of adequate N on *Striga* infestation and damage have been conflicting. Farina *et al.*, (1985), Mumera and Below (1993), Kim and Adetimirin (1997a) and Kim *et al.* (1997) reported that adequate N reduced *Striga* infestations. On the other hand, Smaling *et al.* 1991 and Kamara *et al.* (2007) reported that adequate N had no effect on *Striga* infestation. Although, adequate N application rates of 120 kg ha^{-1} and 280 kg N ha^{-1} had effects on grain yield, *Striga* infestation and *Striga* emergence, these rates are too high for the smallholder or resource poor farmers who apply N at suboptimal levels. Furthermore, the conflicting results on the effect of nitrogen fertilizer on *Striga* infestation and damage to host plants are a limitation to its effectiveness as a control measure.

2.3.5 Resistance as a control measure

The use of host plant resistance/tolerance is considered the most economically feasible and sustainable approach for reducing the effects of the parasitic weed (DeVries, 2000; Badu-Apraku *et al.*, 2004). Sources of resistance to *Striga* have been identified from *Zea diploperennis,* landraces and elite tropical germplasm (Menkir *et al*., 2001). Several tolerant maize populations, open-pollinated varieties, hybrids, and inbred lines with *Striga* resistance/tolerance have been developed in WCA (Kim *et al.*, 1985; Badu-Apraku *et al.*, 2004; Badu-Apraku *et al*., 2005; 2007a; Menkir *et al*., 2012). A high level of resistance was found in *Z. diploperennis* and the resistance genes have been introgressed into cultivated maize of tropical adaptation (Menkir, 2006; Amusan *et al*., 2008). *Striga* resistant varieties stimulate the germination of *Striga* seeds, prevent the attachment of the parasite to its roots or kill the attached parasite resulting in significantly fewer *Striga* plants and higher yield than a susceptible genotype. On the other hand, *Striga* tolerant genotypes support as many *Striga* plants as the susceptible genotypes but produce more grain and stover, and show fewer damage symptoms 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).

2.3.6 Integrated *Striga* control measures

It has been reported that *Striga* control is most effective when a number of individual technologies are combined in an integrated *Striga* control program. This provides sustainable control over a wide range of biophysical and socioeconomic 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% reduction in *Striga* seed bank in the soil and 88% improvement in crop productivity was observed with the integrated *Striga* control approach (Franke *et al.*, 2006). Adequate N fertilizer and herbicide application are effective at reducing crop damage by *Striga* as well as reducing *Striga* emergence (Pesch and Pieterse, 1982; Hess and Ejeta, 1987; Kim, 1991; Mumera and Below, 1993). *Striga* resistant maize grown after a soybean trap crop increased the net benefit over two cropping seasons by over 100% when compared with continuous maize (Ellis-Jones *et al.*, 2004). With all the control methods available the *Striga* problems still persist. The use of maize varieties that are *Striga* and low N resistant/tolerant in an integrated *Striga* control approach will be the most economically feasible and practical approach for the resource poor farmers in WCA.

2.3.7 Breeding for *Striga* resistance in maize

The complexity of interactions between host, parasite, and the physical environment has been a major limiting factor to the development of crop plants with resistance to *Striga* (Ejeta, 2007b). The slow pace of development and deployment of *Striga*-resistant cultivars is mostly attributable to paucity of sources of resistance, the complex genetics 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). Recurrent selection, backcrossing, inbreeding, and hybridization methods have been used to improve levels of resistance to *Striga* (Badu-Apraku *et al.*, 2005). Most studies of grain yield reductions of cereal and legume by *Striga*, as well as breeding efforts to control the parasite, have been conducted under natural infestation of the parasite (Kim, 1991; Mumera and Below,

1993) but the progress was slow due to erratic infestation of *Striga* (Aggarwal, 1991; Ejeta and Butler, 1993). Rapid advances were made using the artificial field infestation techniques. These techniques ensure uniform infestation of *Striga* and facilitate the identification of resistance to *S. hermonthica* from diverse sources of germplasm (Haussmann *et al.*, 2000; Menkir, *et al*. 2012; Badu-Apraku *et al.* 2013a).

2.3.8 Genetics of *Striga* resistance in maize

Striga damage symptom rating is an index for tolerance while *Striga* emergence count and yield performance is used as an index for resistance (Kim, 1994; Badu-Apraku, *et al* 2010). *Striga* resistance in maize is quantitatively inherited (Kim, 1994). Kling *et al.* (2000) reported that heritabilities of host damage and yield loss from *Striga* were moderate, while those for *Striga* emergence were low. Kim (1994) reported relatively high heritabilities for host damage scores, ear rating, and yield under infestation, and estimated that six to nine genes were involved in the inheritance of these traits. Badu-Apraku (2007) reported a moderately low to high narrow sense heritability estimates in an early tropical white maize population after three cycles of recurrent selection for *Striga* resistance. The author also observed that grain yield had a large positive additive genetic correlation with number of ears per plant, a large negative genetic correlation with *Striga* damage ratings, and moderately large negative genetic correlations with flowering traits and *Striga* emergence count. Studies have shown that genetic correlations between *Striga* emergence and host plant damage are low, suggesting that different genes control the two traits in maize (Kim, 1994; Akanvou *et al.*, 1997). Several studies have reported that additive gene action plays major role in the inheritance of *Striga* damage ratings (tolerance) while *Striga* emergence (resistance) is controlled largely by non-additive gene action (Kim, 1994; Akanvou *et al.*, 1997; Badu-Apraku, 2006; Badu-Apraku, 2007; Badu-Apraku and

Oyekunle, 2012). On the contrary, Gethi and Smith (2004), Badu-Apraku (2007), and Yallou *et al.* (2009) reported that non-additive gene action was more important in *Striga* damage ratings while additive gene action was of major importance in the inheritance of *Striga* emergence (resistance). The differences observed in the studies were attributed to the use of lines or germplasm possessing introduced genes with different modes of action. Both additive and non-additive gene actions are important for *Striga* resistance/tolerance in maize.

Farmers in the *Striga* endemic agro-ecologies of sub-Saharan Africa (SSA) are presently demanding for cultivars that possess resistance to multiple stress factors and are unwilling to adopt maize cultivars that do not meet this requirement (Badu-Apraku et al, 2010). It is therefore important to incorporate low N tolerance into maize cultivars for increased productivity under *Striga* infestation.

2.4 Usefulness of molecular markers in studying diversity

Maize has an extremely high level of natural genetic variation at both morphological and molecular level (Yan *et al*., 2010a). The magnitude and type of genetic variability in a population under improvement determines the type of breeding schemes to use for population improvement and the level of progress that could be made (Shahi and Singh, 1985). A major problem confronting a breeder is ensuring sufficient genetic variability in a population for the trait being improved (Badu-Apraku *et al.*, 2007b). Thus, genetic diversity affects the potential genetic gain through selection. This is because without variability progress cannot be made through selection. Information about genetic diversity also permits the classification of germplasm into heterotic groups in hybrid breeding. Genetic distance based on molecular markers has been used to predict hybrid performance but it is not always predictive of good specific combining ability (Makumbi *et al*., 2011). Crosses involving parents of diverse origin produce higher grain yields than crosses among lines with the same genetic background (Melchinger, 1999; Lu *et al.*, 2009) but this decreases in varieties that are assumed to be extremely diverse (Moll *et al.*, 1965). Apparently, beyond a certain level of diversity heterosis does not increase (Dhillon, 1998). Although the genetic mechanisms that explain heterosis are not fully understood, it is known that non-additive genetic variance, especially epistasis and over dominance are the primary mechanisms that control heterosis.

Phenotypic classification of inbred lines is invaluable in the selection of parental inbreds for the development of heterotic populations and the introgression of desirable genes from diverse germplasm sources into the available genetic base (Reif *et al.*, 2003). However, morphological trait expression is strongly influenced by environment (Rao, 2004), maize breeders have therefore developed heterotic groups as an aid in selection of parents for new source populations. Studies have been conducted to classify early inbred lines based on agronomic and morphological traits, using multivariate analysis (Badu-Apraku *et al.*, 2006) and line x tester (Agbaje *et al.* 2008). A study was conducted to classify 42 *Striga* resistant, early maturing white endosperm inbred lines into heterotic groups using two intermediate maturing, white endosperm tester lines (1368 and 9071) under *Striga* infested and *Striga* free environments (Agbaje *et al.*, 2008). Results revealed that 13 of the 42 lines could be classified into heterotic groups based on the SCA effects and testcross mean grain yields under *Striga*-free environment, 12 lines under *Striga*- infested conditions while, only four of the lines from the tester 9071 group maintained their heterotic groups in both *Striga*-free and *Striga*-infested environments. In addition to agronomic and morphological characteristics for assessing genetic diversity among inbred lines, new techniques which analyze diversity at biochemical or molecular level have been introduced to complement conventional breeding. Biochemical and molecular markers are not influenced by environment. Biochemical markers such as isozymes, allozymes and storage proteins although not influenced by the environment are unable to detect low levels of variation (Rao, 2004). Molecular markers are DNA-based techniques effective in assessing genetic diversity at DNA sequence level (Melchinger and Gumber, 1998; Ovesná *et al.*, 2002). The probability of identifying superior hybrids is greater between populations of known heterotic patterns and the most exploited heterotic groups are Reid yellow Dent x Lancaster Surecrop and Stiff Stalk x Lancaster Surecrop (Gerdes and Tracy, 1993). These heterotic groups are still been exploited by breeders for hybrid development (Bidhendi *et al*., 2012; Yong *et al*., 2012). The US hybrid B73 x Mo17 involves a stiff stalk line composed mainly of Reid Dent material and a line that is half Reid in origin.

Molecular markers, such as amplified fragment length polymorphism (AFLP), randomly amplified polymorphic DNA, restriction fragment length polymorphism, and simple sequence repeats (SSR), single nucleotide polymorphism (SNP) have been used to assess the genetic divergence of parental inbred lines (Menkir *et al.*, 2005; Shieh and Thseng, 2006; Benchimol *et al*., 2008; Yu *et al*; 2009; Menkir *et al.*, 2010, Yu *et al.*, 2011; Makumbi *et al.* 2011; JinSun *et al*., 2013; Badu-Apraku *et al.*, 2013a). Liu *et al.* (2003) in assessing the genetic diversity among 260 inbred lines using 94 markers showed that there was clear separation of the non-stiff stalk, stiff stalk and tropical/subtropical lines and concluded that the stiff stalk lines are the most divergent and would typically provide a strong heterotic response in crosses with other maize inbreds. The identification of parental inbred lines that produce superior hybrids is the most costly and time-consuming phase in maize hybrid development (Betrán *et al.*, 2003a), therefore maize breeders have developed heterotic groups to aid in the selection of parents for new source populations. Per se performance of maize inbred lines does not predict the performance of maize hybrids for grain yield (Hallauer and Miranda, 1988). The relationship between genetic distance and heterosis was first reported long before the development of genetic markers (Moll *et al.*, 1965). However, reports on the relationship between genetic distance (GD) of inbred lines and grain yield of hybrids have been conflicting. Mohammadi *et al.* (2008) and Makumbi *et al*. (2011) reported a correlation between genetic distance of inbred lines and grain yield of hybrids. Makumbi *et al*. (2011) found a weak correlation between GD and grain yield of hybrid, as well as mid-parent heterosis suggests that GD in this set of maize inbred lines is of limited value in predicting grain yield of hybrid. Mohammadi *et al*. (2008) found significant correlation between genetic distance values of parental lines and hybrid performance in a diallel study. Genetic distance was significantly correlated with total grain yield per ear and was not with specific combining ability. On the other hand Menkir *et al*. (2010) and Badu-Apraku *et al*. (2013a) found no relationship between genetic distance of inbred lines and grain yield of hybrids. Differences obsereved could be a result of evaluating different types of materials. In addition, marker-based GD estimate may not be sufficiently associated with grain yield of hybrid and heterosis. Menkir *et al*. (2005) used 20 AFLP and 31 SSR markers to assess the genetic diversity among 41 *Striga* -resistant maize inbred lines and found that both marker types grouped the inbred lines according to their source population. SSR markers detected higher levels of genetic diversity among the *Striga*-resistant inbred lines than the AFLP markers. Cluster and principal component analysis of genetic similarity estimates with the two marker types revealed clear differentiation of the *Striga* resistant inbred lines into groups according to their source populations and maturity (a clear separation between early- and late-maturing *Striga*-resistant inbred lines). Makumbi *et al.* (2011) assessed genetic diversity in fifteen drought and low N tolerant inbred lines using AFLP, RFLP and SSR markers. Clustering based on genetic distance across all marker data grouped lines according to pedigree. Badu-Apraku *et al*. (2013b) examined diversity in 20 extra-early yellow maize inbred lines using 23 polymorphic SSR and reported clustering based on pedigree. SSR markers exhibit great potential for large-scale DNA fingerprinting due to the high level of polymorphism detected, utilizes automated systems, are co-dominant markers and have high accuracy and repeatability (Heckenberger *et al*., 2002; Park *et al*., 2009). The use of both genetic markers and phenotypic variables (morpho-agronomic data) will better classify genotypes compared to using only morpho-agronomic traits or discrete variables (Park *et al.*, 2009). Although molecular markers are useful in assessing genetic diversity, they are not efficient in predicting hybrid performance. Molecular markers would provide information on the variability present within a germplasm that will aid in planned crosses.

CHAPTER THREE

3.0 Genetic diversity of IITA and CIMMYT maize inbred lines using SSRs and SNPs

3.1 Introduction

Knowledge about the genetic diversity and genetic relatedness existing within a germplasm collection could be an invaluable aid in breeding strategies (Semagn, *et al.*, 2012). Molecular markers are useful in assessing the extent of genetic diversity present within breeding materials (Senior *et al.*, 1998). Molecular markers systems are DNA based and are thus not affected by the environment or developmental stage of the species. Marker-based genetic distance estimates may be useful to avoid crosses between closely related lines (Lu *et al.*, 2009). This is however useful in cases where heterotic groups are not well established and pedigree information are not available. Molecular markers, such as amplified fragment length polymorphism (AFLP), randomly amplified polymorphic DNA (RAPD), restriction fragment length polymorphism (RFLP), simple sequence repeats (SSR) and single nucleotide polymorphisms (SNP) have been used to assess genetic diversity in maize germplasm.

The advantages of SSR markers over the other markers include its reproducibility, its very high allelic variations even among very closely related individuals, and its abundance and distribution in genome (Park *et al.*, 2009). Although SSR play a predominant role in evaluating genetic diversity and relatedness in plants (Thomson *et al.*, 2007) its detection is often conducted using time consuming methods such as agarose gel, polyacrylamide gel and sequencers (Yang *et al.*, 2011). Advances in high-density genotyping technologies have resulted in a shift from SSR markers “the marker of choice” to SNP (Prasanna, 2012). Although, SNPs are less informative than SSRs, SNPs can be used for similar studies as SSRs. SNPs can be used for linkage map construction, genetic diversity analysis, marker-trait association and marker-assisted selection (Yang *et al*., 2011). SNPs have lower genotyping error rate and lower levels of missing data (Jones *et al*., 2007). SNP markers are biallelic in nature and thus have lower information content when compared to SSRs. However, they 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 increased marker data quality and quantity when compared with SSRs (Jones *et al*., 2007; Hamblin *et al*., 2007). The advantages of SNPs over SSRs have made it the marker of choice.

Hamblin *et al*. (2007) compared the ability of SSRs and SNPs in assessment of population structure using 89 SSRs and 847 SNPs and found that population structure assessed by both marker types was consistent, although SSRs performed better in clustering individuals into populations. Similar findings were reported by Yang *et al*. (2011) who studied the genetic relatedness in 155 diverse maize inbred lines using 82 SSRs and 884 SNPs. Inghelandt *et al*. (2010) reported that between 7 - 11 times more SNPs than SSRs are needed to infer population structure. Wen *et al*. (2011) studied an association mapping panel consisting of 359 maize inbred lines from CIMMYT and IITA breeding programs with 1260 SNPs and found that lines derived from La Posta Sequía were consistently separated from other groups with both structure analysis and PCA methods. Liu *et al.* (2003) used 94 SSR markers to characterize the genetic structure and diversity of 260 maize inbreds. Legesse *et al*. (2007) also studied genetic diversity and relatedness among 56 inbred lines using 27 SSR markers. Liu *et al.* (2003) and Legesse *et al*. (2007) reported that the pattern of groupings of the inbred lines was consistent with available pedigree information. Assessment of the genetic diversity among CIMMYT and IITA inbred lines using molecular markers would be useful in selecting potential parents with diverse genetic backgrounds that could be utilized in a breeding program.

The objectives of this study were to:

i. Assess the genetic diversity present in some selected IITA and CIMMYT early maturing maize inbred lines using SSRs and SNPs.

ii. Investigate the population structure of the inbred lines using SNPs

3.2 Materials and Methods

3.2.1 Germplasm

Eighty-seven early maturing maize inbred lines developed at IITA and nine developed at CIMMYT were used in this study. The CIMMYT inbred lines were selected from a panel of early maturing CIMMYT inbred lines in the drought tolerant maize for Africa (DTMA) project at IITA. The lines from IITA are designated TZE while those from CIMMYT are designated ENT. Summarized pedigree information on the inbred lines is presented in Table 3.1.

3.2.2 DNA extraction and SSR and SNP genotyping

3.2.2.1 DNA extraction

Young leaves were harvested from fourteen day old seedlings from five plants per inbred line. Leaf discs were taken from each inbred line and placed in a 96 well plate (each well had two steel balls). The 96 well plates containing the leaf samples were kept at -80^{0}C prior to freeze drying. The samples were lyophilized in console dry system from Labconco (Labconco Inc., Missouri, USA) that dries at -50^{0}C and between 1-22 pascals pressure. After 24 hours the freeze-dried samples were ground using the Genogrinder 2000® instrument (BT and C Inc., New

Table 3. 1 List of 94 inbred lines used for diversity study

Inbreds	Source	Pedigree Information
ENT 3	CIMMYT	[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-1-6 x [KILIMA ST94A]-30/MSV-03-2-10-B-1-B-B-xP84c1 F27-4-1-6-B-5-B]3-1-2-B/CML442]-1-1
TZEI 65	IITA	TZE-W Pop STR Co S6 Inbred 141-1-2
TZEI 22	IITA	WEC STR S7 Inbred 9
ENT7	CIMMYT	[MBR C6 Bc F395-1-B-#-2-2-B-B-B-B-B/CML312SR]-1-1
TZEI 106	IITA	WEC STR S8 Inbred 19A
ENT16	CIMMYT	CML311/MBR C3 Bc F3-1-1-1-B-B-B-B-B
TZEI 53	IITA	TZE-W Pop STR Co S6 Inbred 60-1-4
TZEI 60	IITA	TZE-W Pop STR Co S6 Inbred 90-1-3
TZEI 56	IITA	TZE-W Pop STR Co S6 Inbred 75-1-3
TZEI 168	IITA	TZE-W Pop STR Co S6 Inbred 12-1-2
TZEI 4	IITA	TZE-W Pop x 1368 STR S7 Inb. 6
TZEI 33	IITA	TZE-W Pop x LD S6 Inbred 12
TZEI 1	IITA	TZE-W Pop STR Co S6 Inbred 1-2-4
TZEI 36	IITA	TZE-W Pop STR Co S6 Inbred 14-2-2
TZEI 7	IITA	WEC STR S7 Inbred 12
TZEI 189	IITA	TZE-W Pop STR $\mathrm{C_O}$S6 inb.149-2-3
TZEI 26	IITA	WEC STR S8 Inbred 4
TZEI 54	IITA	TZE-W Pop STR Co S6 Inbred 74
ENT10	CIMMYT	Cuba/Guad C3 F85-3-3-1-B-B-B-B
TZEI 83	IITA	TZE-W Pop x 1368 STR S7 Inb. 8
TZEI 82	IITA	TZE-W Pop x 1368 STR S7 Inb. 7
TZEI 112	IITA	WEC STR S7 Inbred 16-1-2
TZEI 114	IITA	WEC STR S7 Inbred 18
TZEI 87	IITA	TZE-W Pop x 1368 STR S7 Inb. 11
TZEI 79	IITA	TZE-W Pop x 1368 STR S7 Inb. 1B
TZEI 76	IITA	TZE-W Pop STR Co S6 Inbred 157-3-4 A
TZEI 108	IITA	WEC STR S7 Inbred 7
TZEI 188	IITA	TZE-W Pop STR Co S6 Inbred 1-1-4
TZEI 98	IITA	TZE-W Pop x LD S6 Inbred 12-1-2
TZEI 5	IITA	TZE-W Pop x 1368 STR S7 Inb. 9
TZEI 3	IITA	TZE-W Pop x 1368 STR S7 Inb. 4
TZEI 63	IITA	TZE-W Pop STR Co S6 Inbred 136-2-3
ENT12	CIMMYT	[Cuba/Guad C3 F34-2-1-1-B-B-B x CML264Q]-1-1
TZEI 91	IITA	TZE-W Pop x 1368 STR S7 Inb. 18
TZEI 202	IITA	TZE-W Pop x LD S6 inbred 2-1-2
TZEI 75	IITA	TZE-W Pop STR Co S6 Inbred 157-3-4
TZEI 103	IITA	TZE-W Pop x LD S6 Inbred 36
TZEI 111	IITA	WEC STR S7 Inbred 16
TZEI 32	IITA	TZE-W Pop x LD S6 Inbred 4
TZEI 104	IITA	WEC STR S8 Inbred 3
TZEI 2	IITA	TZE-W Pop x 1368 STR S7 Inb. 2
TZEI 80	IITA	TZE-W Pop x 1368 STR S7 Inb. 3
TZEI 89	IITA	TZE-W Pop x 1368 STR S7 Inb. 14
TZEI 19	IITA	TZE-W Pop STR Co S6 Inbred 143-3-3
TZEI 86	IITA	TZE-W Pop x 1368 STR S7 Inb. 10
TZEI 39	IITA	TZE-W Pop STR Co S6 Inbred 34-2-3
ENT11	CIMMYT	[[KILIMA ST94A]-30/MSV-03-1-10-B-1-B-B-1xP84c1 F27-4-1-6-B-5-B] F8-3-2-2-1 x G16SeqC1F47-2-1-2-1-BBBB-B-xP84c1 F26-2-2-6B-3-B]-3-1-B/CML395]-1-1
TZEI 68	IITA	TZE-W Pop STR Co S6 Inbred 149-1-3
TZEI 18	IITA	TZE-W Pop STR Co S6 Inbred 136-3-3

Table 3.1. List of 94 inbred lines used for diversity study

Inbreds	Source	Pedigree Information
TZEI 163	IITA	TZE-Y Pop STR Co S6 Inbred 142
TZEI 148	IITA	TZE-Y Pop STR Co S6 Inbred 62-1-3
TZEI 142	IITA	TZE-Y Pop STR Co S7 Inbred 35-3-3
TZEI 167	IITA	TZE Comp5-Y C6 S6 Inbred 13
TZEI 143	IITA	TZE-Y Pop STR Co S7 Inbred 35-3-5
ENT8	CIMMYT	[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-1-4 x (87036/87923)-X-800-3-1-X-1-B-B-1-1-1-B-B-XP84c1 F26-2-2-4-B-2-B]-1-1-B x CML486]-1-1
TZEI 12	IITA	TZE Comp5-Y C6 S6 Inbred 10
TZEI 130	IITA	TZE-Y Pop STR Co S6 Inbred 16-2-3
TZEI 135	IITA	TZE-Y Pop STR Co S6 Inbred 17-2-3
TZEI 13	IITA	TZE Comp5-Y C6 S6 Inbred 12
TZEI 115	IITA	TZE-Y Pop STR Co S6 Inbred 1
TZEI 140	IITA	TZE-Y Pop STR Co S6 Inbred 30-1-2
TZEI 120	IITA	TZE-Y Pop STR Co S6 Inbred 1-5-5
ENT15	CIMMYT	CLA149
TZEI 173	IITA	TZE Comp5-Y C6 S6 Inbred 21A
TZEI 126	IITA	TZE-Y Pop STR Co S6 Inbred 10-2-4
TZEI 146	IITA	TZE-Y Pop STR Co S7 Inbred 49-3-3
TZEI 11	IITA	TZE Comp5-Y C6 S6 Inbred 8
TZEI 175	IITA	TZE Comp5-Y C6 S6 Inbred 25B
TZEI 149	IITA	TZE-Y Pop STR Co S6 Inbred 102-2-2
TZEI 15A	IITA	TZE Comp5-Y C6 S6 Inbred 25
ENT4	CIMMYT	[[KILIMA ST94A]-30/MSV-03-2-10-B-1-B-B-xP84c1 F26-2-2-6-B-3-B]F17-1-2-1-1 x p43C9-1-1-1-1-1-BBBB-1-xP84c1 F26-2-2-6-B-3-B]-2-2-B x CML486]-1-1
TZEI 150	IITA	TZE-Y Pop STR Co S6 Inbred 66-3-3
TZEI 132	IITA	TZE-Y Pop STR Co S6 Inbred 16-5-5
TZEI 129	IITA	TZE-Y Pop STR Co S6 Inbred 16-1-3
TZEI 184	IITA	TZE-Y Pop STR Co S6 Inbred 171-2-2
TZEI 10	IITA	TZE-Y Pop STR Co S6 Inbred 152
TZEI 160	IITA	TZE-Y Pop STR Co S6 Inbred 102-2-3
TZEI 178	IITA	TZE Comp5-Y C6 S6 Inbred 62-3-3
TZEI 16	IITA	TZE Comp5-Y C6 S6 Inbred 31
TZEI 25	IITA	TZE-Y Pop STR Co S6 Inbred 171-1-2
TZEI 136	IITA	TZE-Y Pop STR Co S6 Inbred 21-1-3
TZEI 24	IITA	TZE-Y Pop STR Co S6 Inbred 142-2-2
TZEI 161	IITA	TZE-Y Pop STR Co S6 Inbred 103-2-3
TZEI 177	IITA	TZE Comp5-Y C6 S6 Inbred 62-1-2
TZEI 174	IITA	TZE Comp5-Y C6 S6 Inbred 25A
TZEI 9	IITA	TZE-Y Pop STR Co S6 Inbred 66
TZEI 23A	IITA	TZE-Y Pop STR Co S6 Inbred 62-2-3
TZEI 17	IITA	TZE Comp5-Y C6 S6 Inbred 35
TZEI 14	IITA	TZE Comp5-Y C6 S6 Inbred 21
TZEI 157	IITA	TZE-Y Pop STR Co S6 Inbred 102-1-2
TZEI 27	IITA	TZE-Y Pop STR Co S6 Inbred 1-4-5
TZEI 128	IITA	TZE-Y Pop STR Co S6 Inbred 10-4-4
TZEI 131	IITA	TZE-Y Pop STR Co S6 Inbred 16-3-3
TZEI 159	IITA	TZE-Y Pop STR Co S6 Inbred 102-1-3

Jersey) at 1000 strokes per minute for 2 minutes. Genomic DNA was extracted from the freeze dried samples using the modified CTAB (cetyltrimethylammonium bromide) procedure (Saghai-Maroof *et al.*, 1984).

3.2.2.2 SSR Primers and PCR amplification

Forty-five SSR markers were chosen from the 52 core SSR primers described by Warburton *et al* (2002). Out of the 45 primers screened only 31 were polymorphic when tested randomly on 12 samples. The 31 SSR primers were used in this study (Table 3.2). The polymerase chain reaction (PCR) was performed in a 25 µl reaction volume. The PCR reaction contained 2.5 ng of template DNA, 2.5 µl of 10x NH_4 reaction buffer, 1.0 µl of 50mM $MgCl_2$, 2.0 µl of 2.5 mM of dNTPs, 1.0 µl of DMSO, 1.0 µl of each of the forward and reverse primers, 0.1 µl of *Taq* DNA polymerase (Fermentas), and 13.9 µl of sterile water. The SSR fragments were amplified in a 96-well DNA engine (PTC-200 Peltier Thermal Cycler, MJ Research Inc., Watertown, Mass) using a touchdown program. The PCR amplification cycle consisted of initial denaturation at 94 °C for 2 minutes followed by 9 cycles of denaturation at 93°C for 15 seconds, primer annealing temperatures at 65-55 °C decreasing by 1 °C per cycle for 40 sec and primer extension at 72 °C for 30 seconds. The final extension step was performed at 72 °C for 5 minutes.

The amplified products were resolved on 7.5 ml of 40% bis-acrylamide (19:1), 39.44 ml sterile water, 2.5 ml of 10x TBE buffer, 50 µl of Temed and 500 µl of Aps agarose gel along with 50 bp ladder (Fermentas). The gel was run in 1x TBE buffer at a constant voltage of 100 V for about 1 hour or until the tracking dye migrated to the end of the gel. The gel was stained with ethidium bromide solution and photographed under UV light attached to a gel documentation system (GDS-8000 system UVP BioImaging Systems). Polymorphic SSR fragments (bands) were scored in a binary form where 1 = presence and 0 = absence of the band. Bands that could not easily be scored were considered as missing data.

3.2.2.3 SNPs genotyping

Freeze-dried leaf samples of the 94 inbred lines were sent to LG genomics (formerly KBioscience) for SNP genotyping. A total of 287 SNPs were used. Details on the principle and procedure of the DNA assay are available at http://www.kbioscience.co.uk/reagents/KASP.

3.3 Data analysis

3.3.1 Cluster analysis

Polymorphic information content (PIC), minor allele frequency, number of alleles, gene diversity and heterozygosity were estimated using PowerMarker version 3.25 (Liu and Muse, 2005). PIC values which are a measure of allelic diversity at a locus values were calculated using the formula:

$$\mathrm{PIC} = 1 - \sum_{i=1}^{n} p_i^2$$

where;

i = the *ith* allele of the *jth* marker

n = the number of alleles at the *jth* marker

p = allele frequency

Jaccard's coefficient (J) was used to estimate genetic similarities among pair wise comparison of inbred lines for SSRs using the Darwin software (Perrier and Jacquemoud-Collet, 2006). Genetic distance was estimated for the SNP data using Nei (1972). The cluster analysis for SSR and data were performed using Mega 5.2 (Tamura *et al*., 2011). The UPGMA method was used for the

SSR data while neighbor-joining was used for the SNP data. Sufficient data were not available for two inbred lines (ENT 3 and TZEI 65) and therefore they were not used in the data analysis.

3.3.2 Population structure analysis

For the SNP analysis, an admixture model-based clustering method was used to determine the genetic relationship among 92 early maturing maize inbred lines using the software package STRUCTURE version 2.3.4 (Pritchard *et al.*, 2000). The model assumed the number of clusters to be K. The number of K was varied from 1 to 11 and each K was run 7 times with a burn-in period of 100,000 and 100,000 Markov Chain Monte Carlo (MCMC) replications after burn-in. The LnP(D) in STRUCTURE output and the derived Δk (Evanno *et al.*, 2005) were used to determine the most probable K value. The derived Δk considers the rate of change of LnP(D) as k increases and also the variance of LnP(D) among repeated runs and tends to be maximum at the true value of *k*. The formula $\Delta k = M[|L(k - 1) - 2L(k) + L(k + 1)|]/S[L(k)]$ was used where: L(*k*) is the *k*th LnP(D), M is the mean of 7 runs, and S their standard deviation. The K with the highest maximum likelihood was used to assign individual genotypes to clusters. Individuals with membership probability greater than or equal to 0.70 were assigned to the same group while lines with membership probability less than 0.70 were assigned to a mixed group (Lu *et al.*, 2009; Yang *et al.*, 2011).

3.4 Results

Out of 45 SSR primers used for genotyping, 31 were polymorphic for the set of 92 inbred lines used in this study. The 31 SSR markers produced 114 alleles ranging from two (PHI 070 and PHI 072) to eight (PHI 034 and UMC 1136) alleles per locus with a mean of 3.68 alleles per locus (Table 3.2).

Table 3. 2 SSR locus, genomic location, polymorphic information content (PIC), number of alleles and gene diversity of 31 SSR primers used in studying genetic diversity of the 92 inbred lines.

Primer	Bin no.	Repeat	Bp size	PIC	No. of alleles	Gene diversity
NC 130	5	AGC	139-148	0.58	3	0.58
NC 133	2.05	GTGTC	110-120	0.32	4	0.68
PHI 008	5.03/7.02	GGC	85-106	0.64	3	0.65
PHI 015	8.08	AAAC	82-102	0.79	4	0.82
PHI 034	7.02	CCT	113-146	0.87	8	0.88
PHI 046	3.08	ACGC	62-66	0.86	4	0.87
PHI 053	3.05	ATAC	159-195	0.42	4	0.42
PHI 059	10.02	ACC	147-165	0.61	2	0.61
PHI 070	6.07	AGCTG	78-88	0.45	2	0.54
PHI 072	4.01	AAAC	142-163	0.62	4	0.62
PHI 084	10.04	GAA	153-162	0.50	4	0.50
PHI 087	5.06	ACC	150-174	0.72	3	0.78
PHI 108411	9.05	AGCT	117-125	0.64	3	0.67
PHI 109188	5.03	AAAG	160-172	0.69	3	0.72
PHI 109275	1.03	AGCT	123-143	0.69	3	0.75
PHI 109642	2.04	ACGG	136-148	0.65	4	0.69
PHI 112	7.01	AG	136-159	0.15	3	0.26
PHI 233376	8.09	CCG	139-160	0.69	4	0.72
PHI 328175	7.04	AGG	100-130	0.83	4	0.84
PHI 331888	5.04	AAG	127-151	0.33	3	0.45
PHI 374118	3.02	ACC	217-238	0.56	3	0.57
PHI420701	8	CCG	285-297	0.53	3	0.67
PHI 423796	6.01	AGATG	126-136	0.10	3	0.27
PHI 448880	9.07	AAG	173-198	0.35	3	0.46
PHI 452693	6.04	AGCC	125-145	0.67	5	0.67
PHI453121	3.01	ACC	206-227	0.62	3	0.72
UMC 1061	10.06	(TCG)6	101-113	0.55	3	0.66
UMC 1136	3.09	(GCA)5	132-171	0.80	8	0.80
UMC 1143	6	AAAAT	74-89	0.74	3	0.79
UMC 1196	10.07	CACACG	137-161	0.40	3	0.56
UMC 1279	9	(CCT)6	89-101	0.71	5	0.73
Mean				0.58	3.68	0.64

The PIC values obtained ranged from 0.10 (PHI 423796) to 0.87 (PHI 034) with an average of 0.58. Approximately 71% of the markers had above 0.5 PIC value. Eighteen SSR loci exhibited PIC values higher than 0.6, indicating their moderately high potential to detect differences among the inbred lines studied. Gene diversity ranged from 0.26 (PHI 112) to 0.88 (PHI 034) with a mean of 0.64. The genetic dissimilarity values between pairs of inbred lines using Jaccard's distance ranged from 0.17 for TZEI 11 and TZEI 15 to 0.88 for ENT 8 and TZEI 130 with a mean of 0.64.

SNP markers that were monomorphic or had more than 20% missing data points were removed from the analysis. Out of 287 SNP markers examined, only 261 SNPs (90.9%) were used in the analysis of the data. Base changes involved A/C (47), A/G (156), A/T (27), C/G (30), and G/T (1). A/G transition accounted for 59.8% of the informative SNPs while G/T transition was a rare allele in the set of inbred lines. Figure 3.1 summarizes the mean gene diversity per chromosome, minor allele frequency (MAF) per chromosome, heterozygosity per chromosome, PIC per chromosome and the number of SNPs per chromosome. The proportion of heterozygous individuals identified per marker ranged from 0 to 0.61 with an average of 0.08. The level of missing data ranged from 0 to 19.57% with an average of 7.37%. The PIC values ranged from 0.011 (PZA02514_1) to 0.375 (PZB00765_1) with an average of 0.254. The gene diversity ranged from 0.01 to 0.50 with an average of 0.31. The minor allele frequency ranged from 0.006 to 0.50. Of the 261 SNP markers, 34 (13.0%) showed MAF less than 0.05, 88 (33.7%) showed a MAF between 0.051 and 0.200, 137 (52.5%) SNP markers had MAF more than 0.20 (markers with normal allele frequencies), while two SNPs had MAF of approximately 0.5 for the two alternative alleles. The genetic distance between pairwise comparisons of the 92 inbred lines varied from 0 to 0.59 with an average of 0.44.

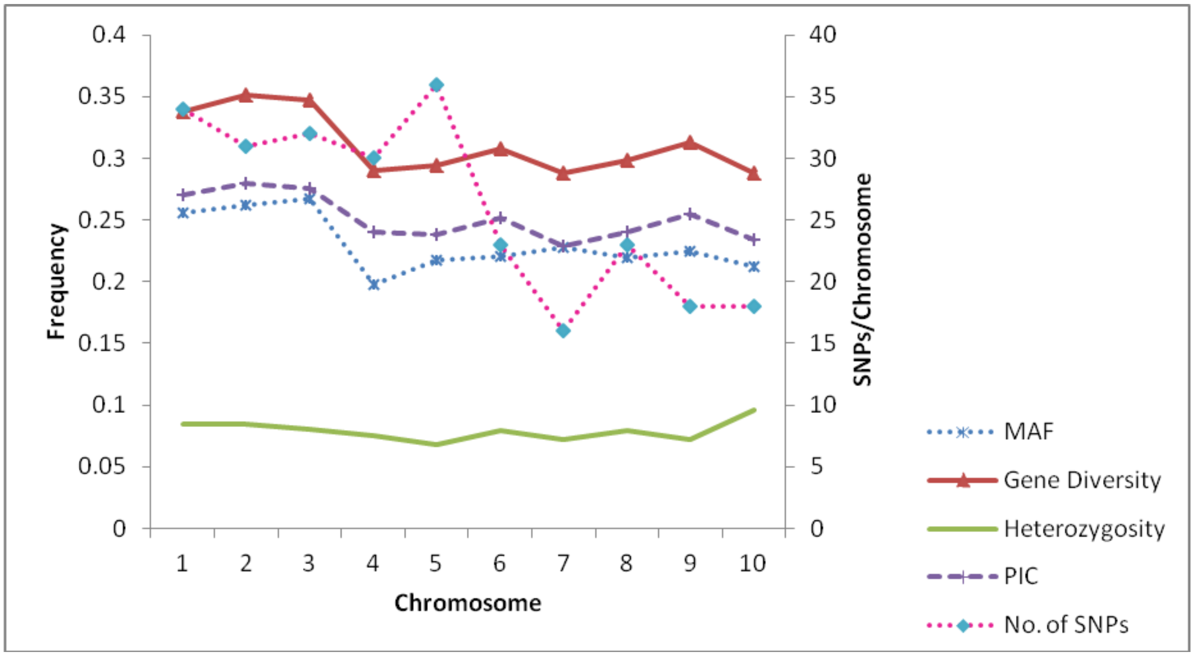

Figure 3. 1. Summary of the 261 SNP markers used in studying genetic divesity in 92 early maturing maize inbred lines.

The SSR markers using Jaccard's dissimilarity coefficient clustered the inbred lines into five groups (Figure 3.2). Thirty-one inbred lines were clustered in group I, 15 in group II, 34 in group III, nine in group IV and three in group V. All groups comprised of inbred lines from two or more germplasm sources. Group III was the largest group, consisting of 97.1% (33/34) of the inbred lines with white endosperm except ENT 15 (yellow). The next largest group (group 1) had 20 lines derived from TZE-Y Pop STR (yellow), five from TZE-W Pop STR, three from TZE Comp5-Y, one from WEC and two CIMMYT lines. Inbred lines from the TZE-Y Pop STR population clustered in groups I, II, IV and V but majority of it were in group I. The lines from CIMMYT had at least one present in each of the five groups. Ten out of the 15 inbred lines clustered in group II were developed from TZE Comp5-Y C_6 S_6 (yellow) germplasm source.

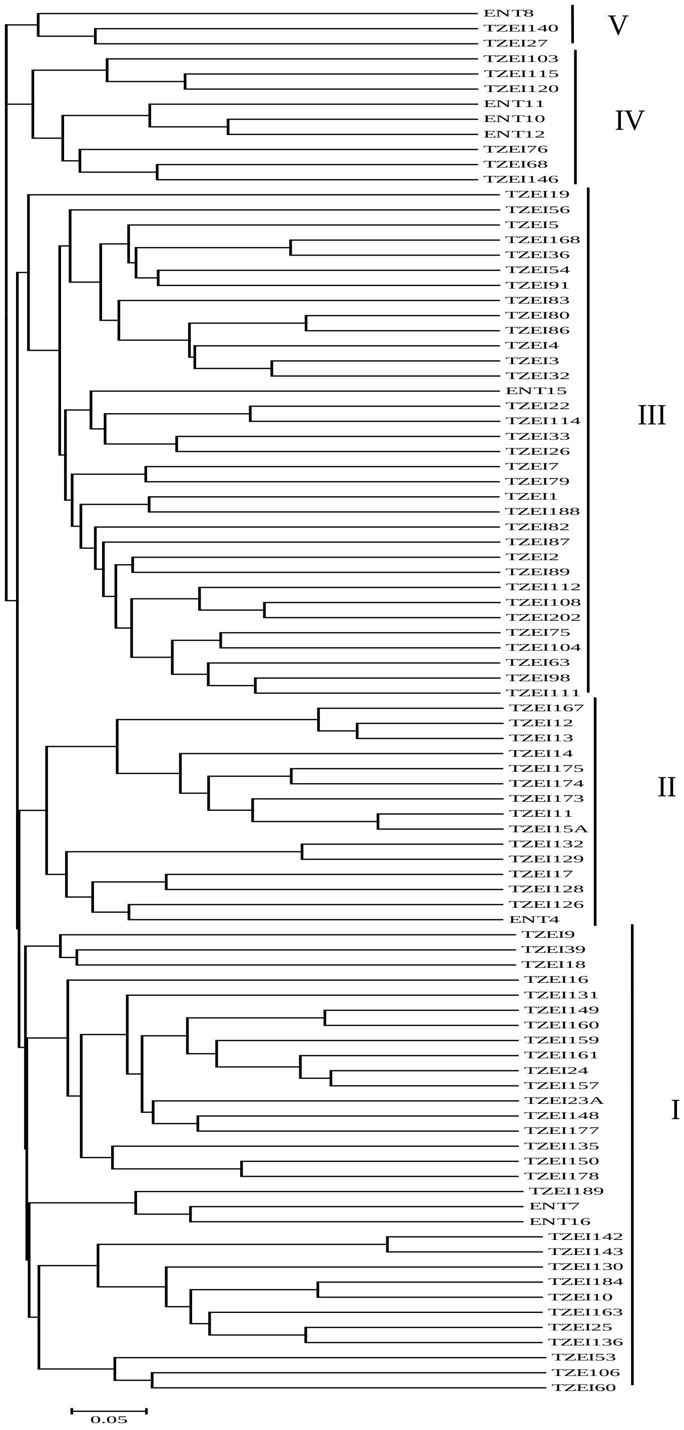

Figure 3. 2. Dendrogram of 92 early maturing maize inbred lines based on UPMGA method applied to dissimilarity matric generated from Jaccard dissimilarity coefficients using 31 SSR markers.

For the SNP analysis, the neighbor-joining tree generated from Nei's genetic distance matrix divided the inbred lines into three main groups (Figure 3.3). Group I consisted of 18 white endosperm lines all having pool 16 DT in their background. Group II consisted of 22 with diverse pedigree records including both lines from IITA and CIMMYT. Group III consisted of 52 lines and was sub-divided into five sub-groups (**a-e**). The sub-group **a** contained six white endosperm lines (five TZE-W Pop STR and one TZE-W Pop x LD S_6), sub-group **b** contained five lines (four TZE-Y Pop STR and one CIMMYT line), sub-group **c** contained 30 lines (13 TZE Comp 5 Y and 17 TZE-Y Pop STR), sub-group **d** contained 9 lines (8 TZE-Y Pop STR and one CIMMYT) and sub-group **e** contained two CIMMYT lines. The sub-group **c** could be further divided into two, one comprised solely of TZE Comp5-Y lines and the other with majority of TZE-Y Pop STR lines. Although SSRs clustered the inbred lines into five groups and SNPs into three major groups, both marker types grouped certain lines similarly. For example, 18 lines in group I from the dendrogram drawn using SSR data clustered in sub-group c when SNP data were used. Both marker systems grouped the majority of the TZE Comp 5 Y lines together.

The ad hoc statistic Δk increased sharply from k = 2 to k =3, with a sharp decrease when k increased from 3 to 4 (Figure 3.4a). Therefore, K = 3 was used to assign the 92 lines into populations. At k = 3, about 94.6% of the inbred lines (87 lines) were grouped into three clusters while 5.4% of the inbred lines (5 lines) had membership probabilities of less than 70% and were therefore classified into a mixed group. Figure 3.4b illustrates the three different clusters inferred from the structure analysis with red (group 1), green (group 2), and blue (group 3) colours. The number of inbred lines assigned into each cluster varied from 62 in group 1, 16 in group 2 and 9 in group 3 (Table 3.3).

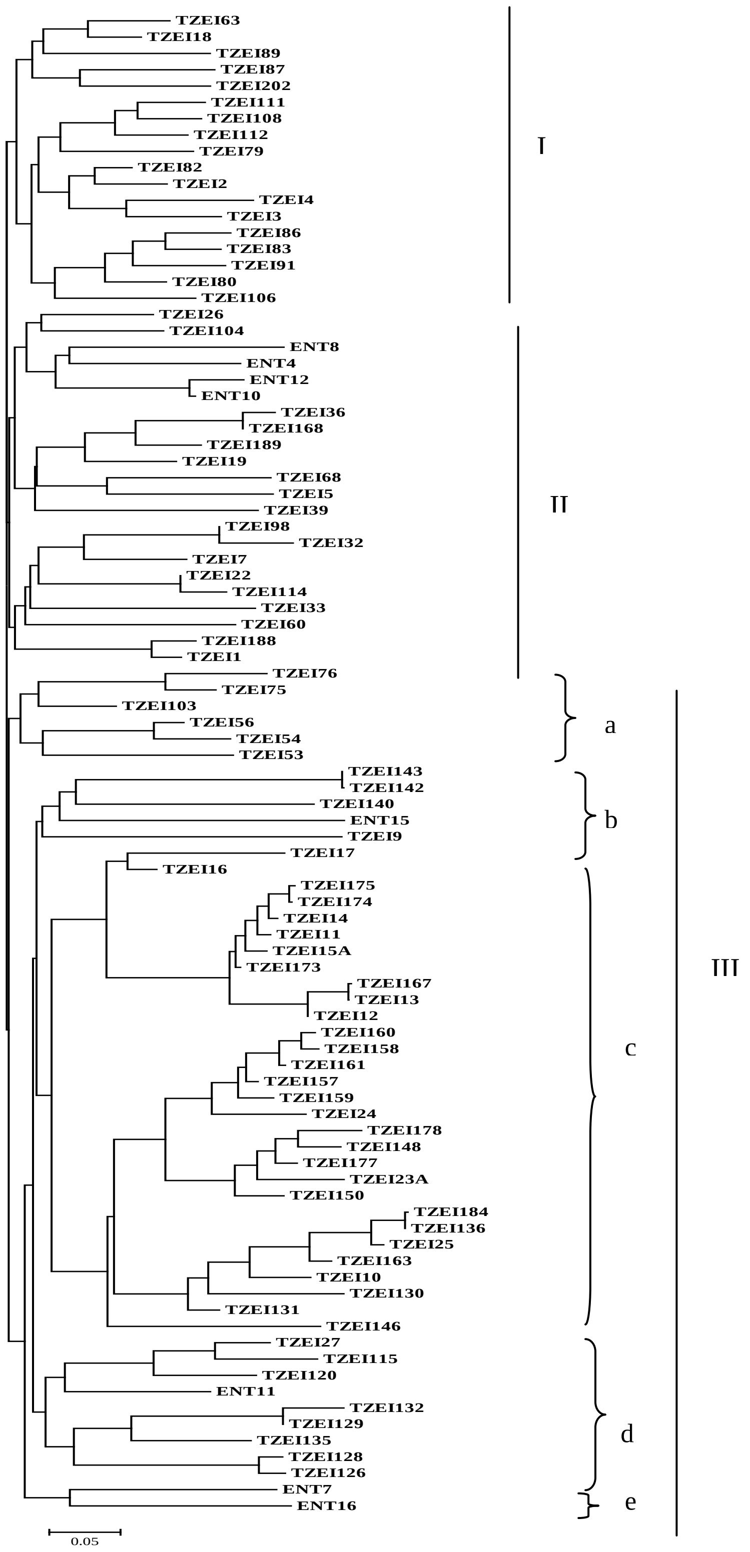

Figure 3. 3. Dendrogram of 92 inbred lines based on Nei's genetic distance estimated from 261 SNP markers.

The lines in group 1 included all inbred lines from WEC STR, TZE-W Pop STR, all lines that had TZE-W Pop as a common parent, all CIMMYT lines used in this study and 10 inbred lines from TZE-Y Pop STR. Group 2 consisted of 14 inbred lines from TZE-Y Pop STR and 2 from TZE Comp-5 Y. Group 3 consisted of 9 inbred lines all from TZE Comp-5 Y.

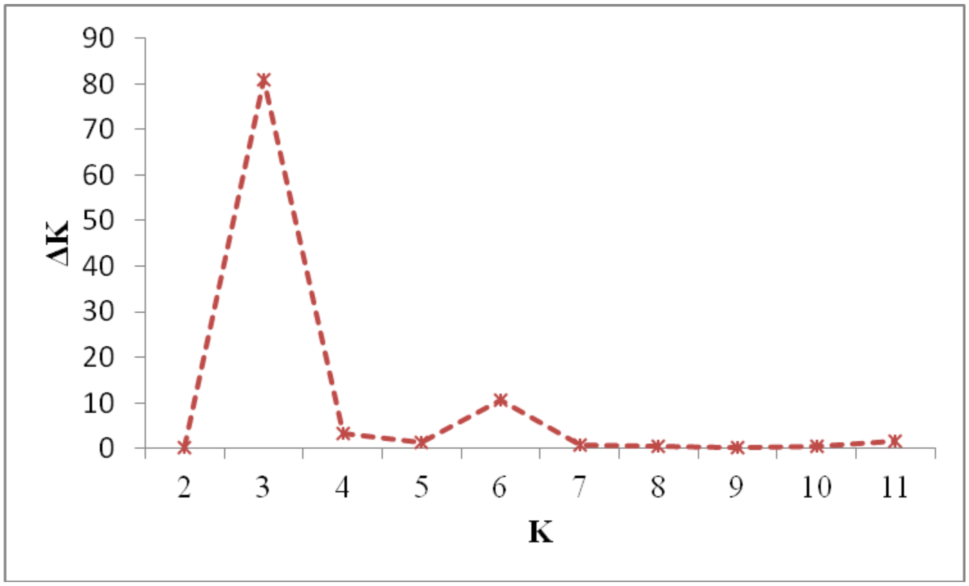

Figure 3. 4a. Plot of ad hoc statistic ΔK calculated for K ranging from 1 to 11

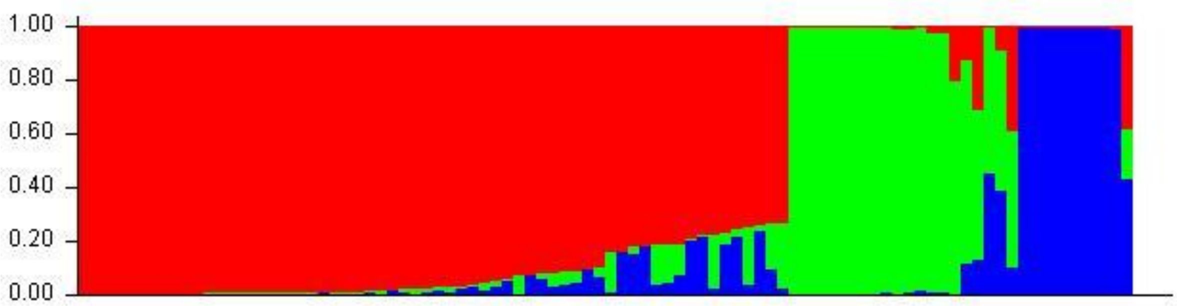

Figure 3. 4b. Population structure of 92 early maturing maize inbred lines based on 261 SNP markers for k=3. Each individual is represented by a single vertical line that is partitioned k=3 segments in the x-axis, with lengths proportional to the estimated probability membership (y-axis)

Table 3. 3 Population structure values of 92 early maturing maize inbred lines based on 261 SNP markers for k=3 for assigning lines in clusters.

No	INBRED	Populations			clusters	No	INBRED	Populations			clusters
		1	2	3				1	2	3	
1	TZEI 106	0.996	0.003	0.001	1	47	TZEI 60	0.839	0.15	0.012	1
2	TZEI 111	0.996	0.001	0.002	1	48	TZEI 129	0.837	0.005	0.159	1
3	TZEI 83	0.996	0.003	0.001	1	49	TZEI 76	0.816	0.028	0.155	1
4	TZEI 86	0.996	0.002	0.002	1	50	ENT 16	0.815	0.003	0.182	1
5	TZEI 104	0.995	0.003	0.002	1	51	TZEI 140	0.814	0.149	0.037	1
6	TZEI 80	0.995	0.003	0.002	1	52	TZEI 135	0.812	0.143	0.045	1
7	TZEI 108	0.994	0.003	0.003	1	53	ENT 15	0.808	0.118	0.074	1
8	TZEI 26	0.994	0.002	0.004	1	54	TZEI 128	0.79	0.007	0.203	1
9	TZEI 4	0.994	0.005	0.002	1	55	TZEI 75	0.777	0.003	0.22	1
10	TZEI 202	0.993	0.002	0.005	1	56	TZEI 143	0.776	0.197	0.027	1
11	TZEI 91	0.993	0.002	0.005	1	57	TZEI 115	0.766	0.043	0.19	1
12	TZEI 1	0.992	0.006	0.002	1	58	TZEI 132	0.755	0.024	0.221	1
13	TZEI 5	0.992	0.004	0.004	1	59	TZEI 142	0.748	0.215	0.037	1
14	TZEI 87	0.992	0.006	0.003	1	60	TZEI 27	0.74	0.023	0.237	1
15	TZEI 22	0.991	0.003	0.006	1	61	TZEI 39	0.733	0.173	0.093	1
16	TZEI 3	0.991	0.008	0.001	1	62	TZEI 9	0.733	0.244	0.023	1
17	TZEI 103	0.99	0.005	0.005	1	63	TZEI 148	0.001	0.998	0.001	2
18	TZEI 98	0.99	0.007	0.004	1	64	TZEI 158	0.001	0.998	0.001	2
19	TZEI 112	0.989	0.005	0.006	1	65	TZEI 160	0.001	0.998	0.001	2
20	TZEI 54	0.989	0.007	0.003	1	66	TZEI 24	0.001	0.998	0.001	2
21	TZEI 168	0.988	0.006	0.006	1	67	TZEI 177	0.003	0.996	0.001	2
22	TZEI 2	0.988	0.003	0.009	1	68	TZEI 23A	0.003	0.995	0.002	2
23	TZEI 33	0.988	0.008	0.004	1	69	TZEI 184	0.002	0.992	0.006	2
24	TZEI 36	0.988	0.008	0.004	1	70	TZEI 161	0.004	0.991	0.005	2
25	TZEI 56	0.988	0.011	0.002	1	71	TZEI 136	0.002	0.99	0.008	2
26	TZEI 114	0.985	0.005	0.01	1	72	TZEI 178	0.011	0.987	0.002	2
27	TZEI 189	0.984	0.013	0.003	1	73	TZEI 131	0.011	0.975	0.014	2
28	TZEI 82	0.98	0.003	0.017	1	74	TZEI 25	0.006	0.975	0.019	2
29	ENT 4	0.978	0.01	0.012	1	75	TZEI 159	0.023	0.968	0.009	2
30	TZEI 188	0.977	0.021	0.003	1	76	TZEI 157	0.027	0.961	0.012	2
31	TZEI 68	0.973	0.017	0.01	1	77	TZEI 150	0.205	0.793	0.002	2
32	TZEI 53	0.968	0.016	0.017	1	78	TZEI 163	0.122	0.757	0.121	2
33	TZEI 7	0.967	0.023	0.009	1	79	TZEI 11	0.001	0.001	0.998	3
34	TZEI 18	0.965	0.007	0.029	1	80	TZEI 12	0.001	0.001	0.998	3
35	TZEI 120	0.959	0.009	0.033	1	81	TZEI 13	0.001	0.001	0.998	3
36	TZEI 89	0.951	0.032	0.017	1	82	TZEI 14	0.001	0.001	0.998	3
37	ENT 10	0.943	0.025	0.033	1	83	TZEI 15A	0.001	0.001	0.998	3
38	ENT 12	0.938	0.008	0.054	1	84	TZEI 167	0.001	0.001	0.998	3
39	TZEI 32	0.926	0.072	0.003	1	85	TZEI 175	0.001	0.001	0.998	3
40	TZEI 79	0.925	0.002	0.074	1	86	TZEI 174	0.002	0.001	0.997	3
41	TZEI 126	0.92	0.016	0.064	1	87	TZEI 173	0.009	0.003	0.988	3
42	ENT 11	0.915	0.056	0.028	1	88	TZEI 10	0.003	0.544	0.453	mixed
43	ENT 8	0.914	0.047	0.039	1	89	TZEI 130	0.386	0.511	0.104	mixed
44	ENT 7	0.909	0.043	0.048	1	90	TZEI 146	0.309	0.561	0.13	mixed
45	TZEI 63	0.9	0.005	0.096	1	91	TZEI 16	0.088	0.521	0.391	mixed
46	TZEI 19	0.897	0.036	0.067	1	92	TZEI 17	0.382	0.187	0.431	mixed

3.5 Discussions

Among the 92 inbred lines, 3.68 SSR alleles per locus were detected with SSRs. This is relatively smaller than the number reported in studies by Senior *et al*. (1998) who detected 5 alleles per locus and Pejic *et al*. (1998) who detected 6.8 alleles per locus among temperate maize inbreds. Lu and Bernardo (2001) detected a mean of 4.9 alleles for 40 US maize inbred lines and Warbuton *et al*. (2002) reported an average of 4.9 alleles among 57 CML lines. The mean number of alleles per SSR marker in the present study was similar to the number reported by Leggesse *et al*. (2007) who detected 3.85 alleles per locus for 56 highland and midaltitude adapted maize inbreds, Adeyemo *et al*. (2011) detected 3.96 alleles per locus for 38 tropical adapted yellow maize inbreds and Makumbi *et al*. (2011) detected an average of 3.6 alleles per locus among 15 tropical maize inbred lines. The average number of SSR alleles is however higher than that reported by Badu-Apraku *et al*. (2013a) who detected 2.57 alleles per locus among 17 tropical-adapted extra-early maize inbred lines. According to Xia *et al*. (2004), the total number of alleles in diversity studies is usually proportional to sample size. The larger the population size the greater the frequency of the alleles in the population. This could be the reason for differences in average alleles reported by several authors. Differences observed in the number of alleles detected in this present study may have resulted from differences in germplasm used,the number of lines and number of SSR markers examined. However, this study showed that SSR markers were able to detect considerable level of genetic diversity among the 92 early maturing maize inbred lines.

Background information on the population from which the inbred lines were developed will provide a better understanding of the clusters based on SSR loci. The TZE-W Pop STR (white-grained population) is a broad-based *Striga hermonthica* resistant and drought tolerant early white population developed from recombining Pool 16 DT, Pool 16 sequoia C_2, DR-W Pool BC_1F_1 and an inbred line 5012. *Striga* resistance levels in the TZE-W Pop STR population were improved by incorporating resistance from inbred TZi 3 (1368 STR) thus giving rise to TZE-W Pop x 1368 STR. TZE-W Pop STR and TZE-W Pop x 1368 STR inbred lines were developed by inbreeding to S_6-S_8 generations. WEC STR inbred lines were derived from a cross between Pool 16 DT and STR sources (1368 STR and 9030 STR) while TZE-W Pop x LD S6 inbreds were developed from a cross between TZE-W Pop and *Striga* resistant inbred lines extracted from Pop 22 (Agbaje *et al*., 2008). Inbred lines from TZE-W Pop STR, TZE-W Pop x LD S6, TZE-W Pop x 1368 STR and WEC STR clustered predominantly in group III. This is not unexpected because these inbred lines all have Pool 16 DT in their background and this may explain the reason for their relatedness using the SSR markers. The TZE-Y Pop STR inbred lines were derived from a broad-based *Striga hermonthica* resistant and drought tolerant early yellow population. The population was formed by recombining DR-Y Pool BC_2F_2, KU1414 and an inbred line 9499 (Kim *et al*., 1987). TZE-Comp 5 Y C_6S_6 inbred lines were developed from the early maturing composite, TZE-Comp 5, which was derived by crossing TZESR-WC_3 with 10 *Striga* resistant inbred lines (Kling *et al*., 2000). Similarly, TZE-Y Pop STR inbred lines did cluster predominantly in the same group (cluster I). The TZE-Comp 5 Y inbred lines were predominantly clustered in group II. The eight CIMMYT inbred lines clustered in five different groups alongside some IITA inbred lines, suggesting that genetic diversity existed among the CIMMYT lines used in this study. Generally, the clustering of the inbred lines was predominantly consistent with pedigree record.

The low to relatively high genetic distance among the inbred lines indicates that this set of germplasm is diverse. The average genetic distance of 0.64 suggests the existence of large variability among the 92 inbred lines. This is similar to the findings of Vaz patto *et al*. (2004), who detected an average genetic distance of 0.63 among 104 inbred lines using 15 SSRs. The minimum genetic distance revealed between TZEI 11 and TZEI 15, both from the same pedigree, is an indication that the SSR markers could distinguish between closely related inbred lines. Similar findings were reported by Smith *et al*. (1997) and Legesse *et al*. (2007). The average genetic diversity among the IITA and CIMMYT inbred lines were relatively high (64%), suggesting that high levels of polymorphism existed among the inbred lines. Similar findings were reported by Vaz patto *et al*. (2004) and Legesse *et al*. (2007). Legesse *et al*. (2007) reported an average genetic diversity of 59% among 56 maize inbred lines using 27 SSR markers.

The effectiveness of SSR markers in clustering a number of inbred lines into distinct groups is an indication that SSR markers were efficient in classifying closely related lines. The grouping of lines of the same pedigree record into two or more clusters such as TZE-Y Pop STR and TZE Comp5-Y is an indication of the diversity that exists within the population or pool from which the inbred lines were developed. The clustering of CIMMYT and IITA inbred lines that were not related by pedigree could be as a result of response to adaptive selection and the use of markers identical in state but not by descent (Mumm and Dudley, 1994; Warburton *et al*., 2005). Similar results were reported by Warburton *et al*. (2005) and Makumbi *et al*. (2011).

The dendrogram based on SSR data clustered the inbred lines into 5 groups while the neighbor-joining tree and model based population partitioning from SNP data both assigned the inbred lines into 3 groups or populations. There was low correspondence between the neighbor-joining clustering and structure analysis in assigning the inbred lines into groups /populations when SSR and SNP markers were used. The dendrogram and structure analysis consistently grouped 9 out of the 13 lines from TZE Comp-5 Y into a distinct group. This corroborates the findings of Wen *et al*. (2011) who reported that in an association mapping panel consisting of 359 maize inbred lines from CIMMYT and IITA breeding programs, both structure analysis and PCA methods consistently separated lines derived from La Posta Sequía from other groups. The structure analysis grouped all lines from Pool 16 DT into one population although with lines from other pedigree sources.

3.6 Conclusions

There was correspondence between cluster analysis and pedigree information of the inbred lines with both marker types used in the study. Structure analysis was more effective in classifying the inbred lines into populations. SSR marker analysis revealed a relatively high level of genetic diversity among the IITA and CIMMYT early maturing maize inbred lines that could be exploited for population improvement, hybrid production and development of new lines.

CHAPTER FOUR

4.0 Performance of early maturing maize inbred lines under low N and *Striga*-infested environments.

4.1 Introduction

Maize production and productivity is faced with a complex of biotic and abiotc constraints in West Africa. Prominent among the constraints are *Striga hermonthica*, low soil nitrogen (Low N) and recurrent drought. Declining soil fertility is a major constraint to agricultural production in Sub-saharan Africa (Sanchez, 2010) and nitrogen is the most limiting nutrient (Carsky and Iwuafor, 1999). Low soil nitrogen (Low N) aggravates the *Striga* problem in the subregion. Due to the occurrence of multiple stresses on farmers' field it is increasingly becoming important to use an approach that involves identifying genotypes with tolerance to stresses present in the target environment (Badu-Apraku and Akinwale 2011a). Maize genotypes with resistance to *Striga* and tolerance to low N is important for increased maize production in *Striga* endemic areas of sub-Saharan Africa.

Heritability of yield under stress is low and as a result, secondary traits that have high heritability and strong correlations with grain yield under stress have been used to select for resistance/tolerance genotypes (Menkir *et al.*, 2007; Badu-Apraku and Akinwale 2011b; Akaogu *et al.* 2012; Ziyomo & Bernardo, 2013). The evaluation of inbred lines developed from *Striga* resistant and/or drought tolerant populations under low N and *Striga*-infested environments are necessary to provide information on the level of resistance/tolerance to *Striga* and low N. This will aid the selection of lines for developing hybrids with resistance to *Striga*, and tolerance to drought and low N. The objective of this study was to assess the performance of early maturing maize inbred lines under low N and *Striga*-infested environments.

4.2 Materials and methods

4.2.1 Genetic materials

One hundred entries comprising 11 CIMMYT and 89 IITA early maturing maize inbred lines were used in this study (Table 4.1). The 11 CIMMYT inbred lines were not developed for *Striga* resistance but are drought tolerant while the IITA inbred lines were developed from *Striga* resistant and drought tolerant populations. All CIMMYT inbred lines used in this study are designated ENT and the IITA inbred lines TZEI.

4.2.2 Experimental sites and field layout

The experiment was conducted under low N conditions at Ile-Ife (7^o29'N and 4^o35'E, 275 m asl, 1,350 mm) and Mokwa (9^o18'N and 5^o04'E, 457 m asl, 1,100 mm annual rainfall), and *Striga*-infested conditions in Abuja (9^o15'N and 7^o 20'E, 300 m asl, 1,700 mm annual rainfall). The low N experiment was conducted in 2010 and 2011 while *Striga* experiment was conducted at Abuja in 2010 and 2011, and Mokwa in 2011 and 2012. The experimental design was a 10 x 10 lattice design with two replications. Single row plots each 4 m long, spaced 0.75 m apart with 0.4 m spacing between plants in each row were used across low N and *Striga*-infested environments. Three seeds of the inbred lines were planted in each hole and thinned to two plants per hill at two weeks after emergence to give a population density of 66,000 plants per hectare.

4.2.3 *Striga hermonthica* field infestation procedure

The artificial *Striga* infestation was carried out as recommended by IITA Maize Program (Kim and Winslow, 1991). Matured *Striga* plants were collected from sorghum fields and air dried for 7 - 9 days (Figure 4.1a). After drying, the *Striga* plants were threshed and the seeds

Table 4. 1 List of 100 inbred lines evaluated for *Striga* resistance and low N tolerance in the study.

SN	Inbred designation	Pedigree
1	TZEI 1	TZE-W Pop STR Co S6 Inbred 1-2-4
2	TZEI 2	TZE-W Pop x 1368 STR S7 Inb. 2
3	TZEI 3	TZE-W Pop x 1368 STR S7 Inb. 4
4	TZEI 5	TZE-W Pop x 1368 STR S7 Inb. 9
5	TZEI 10	TZE-Y Pop STR Co S6 Inbred 152
6	TZEI 11	TZE Comp5-Y C6 S6 Inbred 8
7	TZEI 12	TZE Comp5-Y C6 S6 Inbred 10
8	TZEI 13	TZE Comp5-Y C6 S6 Inbred 12
9	TZEI 14	TZE Comp5-Y C6 S6 Inbred 21
10	TZEI 15	TZE Comp5-Y C6 S6 Inbred 25
11	TZEI 18	TZE-W Pop STR Co S6 Inbred 136-3-3
12	TZEI 19	TZE-W Pop STR Co S6 Inbred 143-3-3
13	TZEI 23	TZE-Y Pop STR Co S6 Inbred 62-2-3
14	TZEI 25	TZE-Y Pop STR Co S6 Inbred 171-1-2
15	TZEI 27	TZE-Y Pop STR Co S6 Inbred 1-4-5
16	TZEI 32	TZE-W Pop x LD S6 Inbred 4
17	TZEI 33	TZE-W Pop x LD S6 Inbred 12
18	TZEI 37	TZE-W Pop STR Co S6 Inbred 14-2-2
19	TZEI 53	TZE-W Pop STR Co S6 Inbred 60-1-4
20	TZEI 54	TZE-W Pop STR Co S6 Inbred 74
21	TZEI 60	TZE-W Pop STR Co S6 Inbred 90-1-3
22	TZEI 65	TZE-W Pop STR Co S6 Inbred 141-1-2
23	TZEI 68	TZE-W Pop STR Co S6 Inbred 149-1-3
24	TZEI 75	TZE-W Pop STR Co S6 Inbred 157-3-4
25	TZEI 76	TZE-W Pop STR Co S6 Inbred 157-3-4 A
26	TZEI 26	WEC STR S8 Inbred 4
27	TZEI 79	TZE-W Pop x 1368 STR S7 Inb. 1B
28	TZEI 80	TZE-W Pop x 1368 STR S7 Inb. 3
29	TZEI 82	TZE-W Pop x 1368 STR S7 Inb. 7
30	TZEI 83	TZE-W Pop x 1368 STR S7 Inb. 8
31	TZEI 86	TZE-W Pop x 1368 STR S7 Inb. 10
32	TZEI 87	TZE-W Pop x 1368 STR S7 Inb. 11
33	TZEI 89	TZE-W Pop x 1368 STR S7 Inb. 14
34	TZEI 91	TZE-W Pop x 1368 STR S7 Inb. 18
35	TZEI 24	TZE-Y Pop STR Co S6 Inbred 142-2-2
36	TZEI 98	TZE-W Pop x LD S6 Inbred 12-1-2
37	TZEI 22	WEC STR S7 Inbred 9
38	TZEI 103	TZE-W Pop x LD S6 Inbred 36
39	TZEI 104	WEC STR S8 Inbred 3
40	TZEI 106	WEC STR S8 Inbred 19A
41	TZEI 108	WEC STR S7 Inbred 7
42	TZEI 111	WEC STR S7 Inbred 16
43	TZEI 112	WEC STR S7 Inbred 16-1-2

Table 4. 1 List of 100 inbred lines evaluated for *Striga* resistance and low N tolerance in the study.

SN	Inbred designation	Pedigree
44	TZEI 115	TZE-Y Pop STR Co S6 Inbred 1
45	TZEI 114	WEC STR S7 Inbred 18
46	TZEI 120	TZE-Y Pop STR Co S6 Inbred 1-5-5
47	TZEI 126	TZE-Y Pop STR Co S6 Inbred 10-2-4
48	TZEI 128	TZE-Y Pop STR Co S6 Inbred 10-4-4
49	TZEI 130	TZE-Y Pop STR Co S6 Inbred 16-2-3
50	TZEI 131	TZE-Y Pop STR Co S6 Inbred 16-3-3
51	TZEI 132	TZE-Y Pop STR Co S6 Inbred 16-5-5
52	TZEI 135	TZE-Y Pop STR Co S6 Inbred 17-2-3
53	TZEI 136	TZE-Y Pop STR Co S6 Inbred 21-1-3
54	TZEI 140	TZE-Y Pop STR Co S6 Inbred 30-1-2
55	TZEI 142	TZE-Y Pop STR Co S7 Inbred 35-3-3
56	TZEI 143	TZE-Y Pop STR Co S7 Inbred 35-3-5
57	TZEI 7	WEC STR S7 Inbred 12
58	TZEI 146	TZE-Y Pop STR Co S7 Inbred 49-3-3
59	TZEI 148	TZE-Y Pop STR Co S6 Inbred 62-1-3
60	TZEI 149	TZE-Y Pop STR Co S6 Inbred 66-2-2
61	TZEI 150	TZE-Y Pop STR Co S6 Inbred 66-3-3
62	TZEI 156	TZE-Y Pop STR Co S6 Inbred 69-3-4
63	TZEI 158	TZE-Y Pop STR Co S6 Inbred 102-2-2
64	TZEI 159	TZE-Y Pop STR Co S6 Inbred 102-1-3
65	TZEI 160	TZE-Y Pop STR Co S6 Inbred 102-2-3
66	TZEI 163	TZE-Y Pop STR Co S6 Inbred 142
67	TZEI 167	TZE Comp5-Y C6 S6 Inbred 13
68	TZEI 168	TZE-W Pop STR Co S6 Inbred 12-1-2
69	TZEI 173	TZE Comp5-Y C6 S6 Inbred 21A
70	TZEI 174	TZE Comp5-Y C6 S6 Inbred 25A
71	TZEI 175	TZE Comp5-Y C6 S6 Inbred 25B
72	TZEI 177	TZE Comp5-Y C6 S6 Inbred 62-1-2
73	TZEI 184	TZE-Y Pop STR Co S6 Inbred 171-2-2
74	TZEI 188	TZE-W Pop STR Co S6 Inbred 1-1-4
75	TZEI 189	TZE-W Pop STR COS6 inb.149-2-3
76	TZEI 190	TZE Comp5-Y C6 S6 Inbred 35A
77	TZEI 4	TZE-W Pop x 1368 STR S7 Inb. 6
78	TZEI 9	TZE-Y Pop STR Co S6 Inbred 66
79	TZEI 200	TZE-W SR BC5 X 1368 STR S6 Inbred 55b
80	TZEI 202	TZE-W Popx LD S6 inbred 2-1-2
81	ENT 8	[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-1-4 x (87036/87923)-X-800-3-1-X-1-B-B-1-1-1-B-B-XP84c1 F26-2-2-4-B-2-B]-1-1-B x CML486]-1-1
82	ENT 7	[MBR C6 Bc F395-1-B-#-2-2-B-B-B-B-B/CML312SR]-1-1
83	ENT 4	[[KILIMA ST94A]-30/MSV-03-2-10-B-1-B-B-xP84c1 F26-2-2-6-B-3-B]F17-1-2-1-1 x p43C9-1-1-1-1-1-BBBB-1-xP84c1 F26-2-2-6-B-3-B]-2-2-B x CML486]-1-1

Table 4. 1 List of 100 inbred lines evaluated for *Striga* resistance and low N tolerance in the study.

SN	Inbred designation	Pedigree Information
84	ENT 3	[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-1-6 x [KILIMA ST94A]-30/MSV-03-2-10-B-1-B-B-xP84c1 F27-4-1-6-B-5-B]3-1-2-B/CML442]-1-1
85	ENT 17	[(87036/87923)-X-800-3-1-X-1-B-B-1-1-1-B-B-xP84c1 F26-2-2-4-B-2-B]F47-3-1-1-3 x M37W/Z607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B]-3-2-B x P33c3 F64-1-1-4-BB]-1-1
86	ENT 16	CML311/MBR C3 Bc F3-1-1-1-B-B-B-B-B
87	ENT 15	CLA149
88	ENT 13	M37W/Z607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B]F2-1-2-1-1-1-B x CML486]-1-1
89	ENT 12	[Cuba/Guad C3 F34-2-1-1-B-B-B x CML264Q]-1-1
90	ENT 11	[[KILIMA ST94A]-30/MSV-03-1-10-B-1-B-B-1xP84c1 F27-4-1-6-B-5-B] F8-3-2-2-1 x G16SeqC1F47-2-1-2-1-BBBB-B-xP84c1 F26-2-2-6B-3-B]-3-1-B/CML395]-1-1
91	ENT 10	Cuba/Guad C3 F85-3-3-1-B-B-B-B
92	TZEI 17	TZE Comp5-Y C6 S6 Inbred 35
93	TZEI 16	TZE Comp5-Y C6 S6 Inbred 31
94	TZEI 129	TZE-Y Pop STR Co S6 Inbred 16-1-3
95	TZEI 157	TZE-Y Pop STR Co S6 Inbred 102-1-2
96	TZEI 178	TZE Comp5-Y C6 S6 Inbred 62-3-3
97	TZEI 161	TZE-Y Pop STR Co S6 Inbred 103-2-3
98	TZEI 56	TZE-W Pop STR Co S6 Inbred 75-1-3
99	TZEI 63	TZE-W Pop STR Co S6 Inbred 136-2-3
100	TZEI 39	TZE-W Pop STR Co S6 Inbred 34-2-3

Figure 4. 1a. The drying of *Striga* plants after collection

Figure 4. 1b. Mixing of the *Striga* seed and fine sand

Figure 4.1c. The ethylene gas injector

Figure 4. 1d. Ethylene gas cylinder

were stored for a minimum of six months to allow conditioning and breakage of dormancy. Six months later, germination test was conducted as described by Menkir (2006).The seeds were thoroughly mixed with finely sieved sand at the ratio 1:99 by weight (Figure 4.1b). The sand served as the carrier and provided adequate volume for rapid and uniform infestation. After land preparation, ethylene gas was injected into the soil to induce suicidal germination of *Striga* seeds present in the soil to ensure uniform infestation. The ethylene gas injector was plunged into the soil at a depth of 12 cm before the gas was injected into the soil (Figures 4.1c & 4.1d). 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. About 30 kg ha^{-1} each of N, P, and K was applied as 15-15-15 NPK 30 days after planting. Weeds other than *Striga* were controlled manually.

4.2.4 Low Soil Nitrogen treatment

The low nitrogen experiment was conducted in soils depleted of nitrogen by continuously growing maize without applying fertilizer and removing the biomass after each cropping. The low N blocks were depleted to zero level of nitrogen. Nitrogen was applied in the form of urea at 30 kg N ha^{-1}. The low N plots received 60 kg P ha^{-1} as single superphosphate (P_20_5) and 60 kg K ha^{-1} as muriate of potash (K_2O). Weeds were controlled through the use of Atrazine and Gramozone as pre- and post- emergence herbicides at 5 litres/ha each of Primextra and praraquat and subsequently by hand weeding.

4.3 Data collection

Data for all measured traits were recorded on per plot basis. Data collected were as follows:

Days to anthesis = number of days from planting to the day that 50% of the plants in a plot started to shed pollen.

Days to silking = number of days from planting to the day that 50% of the plants in a plot showed silk.

Anthesis-silking interval (ASI) = the difference between days to 50% silking and 50% anthesis.

Plant height (cm) = the distance from the base of the plant to the height of the first tassel branch (the mean of five random plants).

Ear height (cm) = the distance from the base of the plant and the node bearing the upper ear (the mean of five random plants).

Ear aspect which is the assessment of the general appeal of the ears without the husks was rated on a scale of 1 - 9. The factors considered included ear size; uniformity of size, colour and texture; extent of grain filling, insect and disease damage. Where,

1 = excellent with no disease/insect damage, large cobs, uniform ears and fully filled grains

2 = very good with no disease/insect damage and fully filled grains, one or two irregularity in cob size

3 =good with no disease/insect damage and fully filled grains, one or two irregularity in cob size,

4= mild insect damage, no disease, fully filled grains, one or two irregularity in cob size poor,

5 = mild disease/insect damage and fully filled grains, one or two irregularity in cob size,

6= severe disease/insect damage and fully filled grains, smaller cobs, non-uniform cob size,

7= severe disease/insect damage, scanty grain filling, few ears, non-uniformity of cobs

8= severe disease/insect damage, scanty grain filling, very few ears

9= only one or no ears

Husk cover was rated on a scale of 1 – 5 where, 1= Very tight husk extending beyond the tip and 5 = exposed ear tip.

Root lodging = the proportion or percentage of plants that fell from the root,

Stalk lodging = proportion or percentage of plants with broken stalk below the ear or the stalk bending more than 45^0 from the upright position.

Number of ears per plant (EPP) = the total number of ears with at least one fully developed grain and divided by the number of harvested plants.

In addition, the following data were taken under *Striga*-infested environments

Data on the number of emerged *Striga* plants and host plant damage (*Striga* damage rating) were collected at 8 and 10 weeks after planting.

Striga emergence count = the number of emerged *Striga* plants per plot at 8 and 10 WAP

Striga damage symptoms rating was on a scale of 1 - 9 as described by (Kim, 1994), where,

1= Normal plant growth, no visible symptoms,

2=Small and vague purplish-brown leaf blotches visible,

3= Mild leaf blotching with some purplish-brown necrotic spots,

4= Extensive blotching and mild wilting. Slight but noticeable stunting and reduction in ear and tassel size,

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

6=Extensive leaf scorching with mostly grey necrotic spots, some stunting and reduction in stem diameter, ear size and tassel size,

7=Extensive leaf scorching, with grey necrotic spots, and leaf wilting and rolling, severe stunting and reduction in stem diameter, ear size and tassel size, often causing stalk lodging, brittleness and husk opening at the late growing stage,

8=Extensive leaf scorching with extensive grey necrotic spots, conspicuous stunting, leaf wilting, rolling, severe stalk lodging and brittleness, reduction in stem diameter, ear size and tassel size, and

9= Complete scorching of all leaves, causing premature death or collapse of host plant and no ear formation.

Husk was removed and field weight of the ears per plot was measured using a measuring balance. Moisture tester was used to determine the amount of moisture in the grain. Grain yield was calculated in kilogram per hectare and was estimated based on 80% shelling percentage and adjusted to 15% moisture. Grain yield under *Striga*-infested environment was calculated as follows:

$$GY = fwt \times \frac{(100-m)}{85} \times \frac{10000}{(8 \times \phi)} \times 0.8$$

where,

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

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

m = grain moisture content at harvest

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

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

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

Additional data measured under low N included the following:

Plant aspect rated based on the assessment of the general architecture of plants in a plot as they appeal to sight. Plant aspect was rated on a scale of 1-5. Where,

1 = excellent overall phenotypic appeal,

2 = very good overall phenotypic appeal,

3 =good overall phenotypic appeal,

4= poor overall phenotypic appeal and

5 = very poor overall phenotypic appeal

Stay-green characteristic was scored at 10 weeks after planting on a scale of 1-9 on the basis of the percentage of dead leaf area below the ear, where:

1 = 0-10% dead leaf area

2 = 10-20% dead leaf area

3 = 20-30% dead leaf area

4 = 30-40% dead leaf

5 = 50-60% dead leaf area

6 = 60-70% dead leaf area

7 = 70-80% dead leaf area

8 = 80-90% dead leaf area

9 = 90-100% dead leaf area

All ears harvested per plot were shelled and grain weight measured. Grain yield was adjusted to 15% moisture and estimated from the shelled grain weight.

Grain yield (GY) under low N was calculated as follow:

$$\ldots\ldots\ldots\ldots GY = Gwt \times \frac{(100-m)}{85} \times \frac{10000}{(8 \times \phi)}$$

where, Gwt = shelled grain weight per plot (Kg)

m = moisture content grain at harvest

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

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

ϕ = number of hills/plot (11).

4.4 Data analyses

The analysis of variance was performed for the inbreds using the PROC GLM in SAS. The entry means were adjusted for block effects, according to the lattice design (Cochran and Cox, 1960). Each year-location combination was considered as a test environment. The environments, replications and blocks were treated as random factors. Data on number of emerged *Striga* plants was transformed as [log(counts+1)] to reduce the heterogeneity of variance for *Striga* counts. Restricted maximum likelihood (REML) estimates of the inbreds genetic and phenotypic variances were obtained with SAS PROC Varcomp and were used to compute broad-sense heritability for each trait.

Broad-sense heritability (H^2) was estimated as:

$$H^2 = \frac{\sigma_g^2}{\sigma_g^2 + \left(\frac{\sigma_{ge}^2}{e}\right) + \left(\frac{\sigma_e^2}{re}\right)}$$

σ_g^2 is variance for genotype, σ_e^2 is error variance, σ_{ge}^2 variance for genotype x environment interaction, *r* is number of replications, and *e* is number of environments (Fehr, 1991).

4.4.1 Base index for selection

Selection of inbred parents for *Striga* resistance/tolerance was based on an index similar to that used by MIP (1996) and Menkir and Kling (2007).

The *Striga* base index combines the standardized means of grain yield, number of emerged *Striga* plants, *Striga* damage syndrome rating, and number of ears per plant.

The *Striga* index score (I_S) was computed as

$I_S = 2.0GY + 1.0EPP - (SDR8 + SDR10) - 0.5(ESP8 + ESP10)$

where, GY is grain yield under *Striga* infestation, EPP is number of ears per plant, SDR8 and SDR10 are *Striga* damage ratings at 8 and 10 WAP, ESP8 and ESP10 are number of emerge *Striga* plants at 8 and 10 WAP.

The base index used for identifying low N tolerant genotypes integrated grain yield, EPP, stay-green characteristics, plant aspect, ear aspect and ASI. Low N index (I_N) score was computed as:

$I_N = 2.0GY + EPP – SG – ASI – PASP – EASP$

where, GY is grain yield under low N, EPP is ears per plant, SG is stay-green characteristics and ASI is anthesis-silking interval, PASP is plant aspect, and EASP ear aspect. Each parameter of the base index score was standardized with a mean of zero and a standard deviation of 1 to minimize the effects of different scales. For both low N and *Striga*-infested environments positive index value was an indicator of resistance/tolerance to *Striga* or low N while negative value was an indicator of susceptibility of the inbred lines to *Striga* or low N.

4.5 Results

The combined analysis of variance across low N environments and years indicated that there were significant ($P < 0.05$) differences among inbred lines for all traits (Table 4.2). Genotype x environment interaction effects were also significant ($P < 0.05$) for most traits except plant height, root lodging, ears per plant and ear aspect. Broad sense heritability estimates on plot-mean basis ranged from 24% for days to silking to 60% for anthesis-silking interval. H^2 estimates for grain yield was 57% (Table 4.2). The result revealed low to moderately high broad sense heritability for most traits except for days to anthesis and husk cover under low N. Heritability estimates for husk cover and days to anthesis could not be estimated due to the negative genotype variance for the traits.

Grain yield of the inbred lines ranged from 485 kg ha^{-1} for TZEI 26 to 1859 kg ha^{-1} for TZEI 32 with a mean of 1149 kg ha^{-1} across low N environments (Table 4.3). Stay-green characteristic ranged from 2.6 to 5.7 with a mean of 4.9. Higher days to silking, increased anthesis-silking interval, reduced plant aspect, fewer ears per plants and reduced ear aspects were observed among the lowest yielding inbred lines. Out of the 100 inbred lines evaluated under low N, 52 had positive base indices (an indication of tolerance to low N) with 43 producing grain yield above the mean. Six lines (ENT 11, ENT 13, ENT 15, ENT 16, ENT 3 and ENT 17) out of the eleven drought tolerant CIMMYT inbred lines had positive base indices under low N. Similarly, 46 out the 89 IITA inbred lines had positive base indices under low N out of which 28 are drought tolerant. The best inbred lines under low N were TZEI 32, ENT 3, TZEI 173, ENT

Table 4. 2 Mean squares of 100 early maturing maize inbred lines across low N environments in Ile-Ife and Mokwa in 2010 and 2011

Sources	**df**	**Yield (Kg ha^{-1})**	**Days to 50% silking**	**Days to 50% Anthesis**	**Anthesi-silking interval**	**Plant height (cm)**	**Ear height (cm)**	**Stay-green (1 – 9)**	**Plant aspect (1 – 5)**	**Husk cover (1 – 5)**	**Ears per plant**	**Ear aspect (1 - 9)**
Env	3	7456227.7**	1369.11**	1165.25**	34.57**	34435.72**	5019.04**	53.21**	5.89**	112.92**	0.59**	23.80**
Blk(Env x Rep)	72	505562.2**	11.72**	10.46**	1.43**	411.88**	144.64**	1.02**	0.52**	1.24**	0.03ns	1.26**
Rep(E)	4	2164501.5**	87.52**	47.37*	9.06**	2669.87**	1638.21**	2.64**	1.88**	2.19**	0.17**	2.99**
Entry	99	765898.9**	24.03**	14.58**	4.56**	982.79**	280.80**	2.38**	0.72**	0.89**	0.06**	2.09**
Entry x Env	297	245556.2**	5.54**	3.56**	1.88**	139.62ns	72.16**	0.65**	0.28**	0.83**	0.02ns	0.75ns
error	324	136909.9	2.83	2.23	0.83	141.51	52.47	0.36	0.16	0.38	0.02	0.65
H^2		57	24	-	60	50	56	54	53	-	52	53

*, **, Significant at 0.05 and 0.01 probability levels, respectively, ns not significant, and H^2, broad sense heritability

Table 4. 3 Performance of the best 20 and worst 10 inbred lines evaluated across low N environments in Ile-Ife and Mokwa, 2010 and 2011

Inbreds	Grain yield (Kg ha^{-1})	Days to silking	Anthesis-silking interval	Husk cover (1 – 5)	Plant aspect (1 – 5)	Stay-green (1 – 9)	Ears per plant	Ear aspect (1 – 9)	Low N base index
TZEI 56	1580.64	57.05	0.34	2.74	2.36	3.35	0.89	3.70	9.73
TZEI 7	1581.02	59.45	0.19	3.05	2.53	3.03	0.91	3.98	9.60
TZEI 32	1858.71	60.70	0.88	3.11	2.53	3.48	0.93	4.25	9.38
TZEI 75	1598.34	60.24	1.18	2.83	2.33	3.78	0.93	4.01	8.10
ENT 13	1701.26	58.48	1.85	2.66	2.24	3.20	0.89	4.51	7.76
ENT 11	1377.47	61.00	0.74	2.18	2.19	3.89	0.85	3.43	7.63
TZEI 18	1448.70	60.35	1.58	3.28	2.31	2.96	0.90	4.20	7.50
TZEI 157	1524.90	59.01	0.19	2.76	2.57	3.34	0.89	4.49	7.42
ENT 3	1856.29	62.93	2.55	2.99	2.32	3.44	0.80	3.94	7.35
TZEI 106	1548.91	54.96	0.20	3.13	2.36	4.03	0.94	4.76	7.08
TZEI 178	1595.52	55.61	0	3.34	2.90	3.30	0.90	4.95	6.96
TZEI 177	1368.56	57.61	0.78	2.78	2.51	2.88	0.92	4.90	6.35
TZEI 146	1586.55	58.88	1.75	2.96	2.66	3.66	0.91	4.33	5.64
TZEI 1	1663.95	60.05	0.94	2.80	2.46	4.23	0.77	4.23	5.30
TZEI 86	1370.74	59.06	0	3.19	2.89	4.11	0.89	4.08	5.19
TZEI 173	1710.14	61.86	2.46	2.43	2.62	3.59	0.90	4.59	5.17
TZEI 2	1517.75	59.53	1.31	3.09	2.64	4.36	0.94	4.18	5.11
TZEI 22	1351.53	59.85	1.09	3.60	2.41	3.90	0.92	4.51	5.09
TZEI 174	1517.30	63.15	2.73	2.61	2.33	3.78	0.93	4.36	5.02
TZEI 19	1386.56	62.73	2.34	2.70	2.56	3.25	0.87	4.01	4.95
TZEI 24	748.79	61.65	2.99	2.80	3.10	3.66	0.72	5.45	-6.61
TZEI 82	700.88	60.66	1.09	4.01	3.37	4.84	0.70	4.88	-6.78
TZEI 37	781.38	58.30	1.66	3.31	3.29	4.91	0.76	5.24	-6.81
TZEI 27	532.61	64.20	2.26	2.73	3.16	4.20	0.75	5.61	-8.20
TZEI 132	641.90	61.83	2.79	3.66	3.32	4.38	0.74	5.29	-8.47
ENT 4	907.20	63.66	3.81	2.86	3.41	4.43	0.71	5.24	-8.72
TZEI 53	513.46	60.16	2.80	2.89	3.04	4.03	0.65	5.84	-9.84
TZEI 142	646.02	62.63	1.63	2.73	3.48	5.68	0.62	5.35	-11.35
TZEI 26	484.55	60.79	2.21	3.36	3.52	5.21	0.62	5.54	-12.64
TZEI 143	505.66	63.53	1.89	3.13	3.54	5.29	0.36	6.36	-16.82
Mean	1148.8	60.82	1.55	2.98	2.87	3.87	0.82	4.91	
Min	484.55	54.96	0	2.18	2.19	2.64	0.36	3.43	
Max	1858.71	64.38	3.81	4.01	3.54	5.68	0.96	6.36	
Lsd	364.94	1.65	0.86	0.6	0.4	0.59	0.14	0.79	

13, TZEI 83, TZEI 1, TZEI 188, TZEI 75, TZEI 178, TZEI 146, TZEI 7, TZEI 56, TZEI 106, TZEI 157, TZEI 2, TZEI 135, TZEI 174 and TZEI 98.

The combined analysis of variance showed significant ($P < 0.01$) differences among inbred lines for all traits across years under *Striga*-infestation (Table 4.4). The genotype x environment interactions was significant ($P < 0.05$) for all traits except ear height while significant differences were detected in the environments for all the traits. Broad sense heritability estimates based on plot-mean basis ranged from 10% for *Striga* damage at 10 WAP to 74% for EPP. H^2 estimate for grain yield was 62% (Table 4.4). The result revealed low to moderately high heritability for the traits under *Striga* infestation. H^2 estimate for husk cover could not be determined due to the negative value obtained for genotype variance. Grain yield of the inbred lines across *Striga*-infested environments ranged from 356 kg ha^{-1} for TZEI 27 to 1574 kg ha^{-1} for TZEI 2 with a mean of 993 kg ha^{-1} (Table 4.5). *Striga* damage ratings at 8 WAP ranged from 1.7 to 5.8 with a mean of 3.6, while at 10 WAP, it ranged from 3.1 to 7.0 with a mean of 4.9. The number of emerged *Striga* plants ranged from 3.7 to 39.5 at 8 WAP and from 6.1 to 43.4 at 10 WAP. Three CIMMYT (ENT 11, ENT 10 and ENT 12) and 47 IITA inbred lines had positive base indices under *Striga* infestation, but eight (8) of the lines had grain yield below the mean. Out of the fifty inbred lines, twenty-seven (One CIMMYT and 26 IITA lines) had positive base index values under low N and 18 of them are also drought tolerant (Table 4.6). The outstanding inbred lines in terms of grain yield, fewer number of emerged *Striga* plants and reduced *Striga* damage under *Striga* infestation were TZEI 2, ENT 11, TZEI 13, TZEI 39, TZEI 167, TZEI 175, TZEI 16, TZEI 174, TZEI 75, TZEI 161, TZEI 7, TZEI 23, TZEI 177, TZEI 173, TZEI 56, TZEI 136, TZEI 33, TZEI 111 and TZEI 178.

Table 4. 4 Mean squares of 100 inbred lines evaluated for two years under *Striga* infestations at Abuja and Mokwa in Nigeria

Sources	df	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Plant height (cm)	Ear height (cm)	*Striga* damage rating		*Striga* emergence count		Husk cover **(1 – 5)**	Ear aspect **(1 – 9)**	Ears per plant
								8 WAP	10WAP	8 WAP	10WAP			
Env	3	17327657**	844.2**	556.4**	170.8**	51972**	11611**	184.4**	75.3**	34.9**	33.15**	111.4**	54.9*	0.80**
Blk(Rep x Env)	72	524877**	7.8**	3.8**	2.5ns	379.6**	142.9**	1.3**	1.6**	0.2**	0.16**	0.30**	1.1**	0.04**
Rep (Env)	4	3859691**	18.1**	15.4**	1.1ns	800.4**	383.2**	7.4**	5.7**	2.31**	1.77**	1.39**	8.2**	0.25**
Entry	99	1913609**	52.2**	27.1**	9.2**	948.2**	239.8**	7.1**	6.3**	0.27**	0.22**	0.64**	3.6**	0.16**
Entry x Env	297	390824**	6.9**	3.8**	3.5**	188.9*	63.0ns	1.5**	1.4**	0.1**	0.09**	0.29**	1.1**	0.04**
Error	324	205636	3.7	1.7	2.2	148.6	52.3	0.6	0.7	0.07	0.06	0.18	0.7	0.02
H^2		65	69	65	48	37	32	55	66	11	10	-	58	74

*, **, Significant at 0.05 and 0.01 probability levels, respectively, ns not significantand H^2, broad sense heritability

ns not significant

Table 4. 5 Performance of the best 20 and worst 10 inbred lines across *Striga*-infested environments in Abuja and Mokwa, 2010 and 2011.

Inbreds	Grain yield kg/ha	Days to silking	*Striga* damage rating		*Striga* emergence count		Ears per plant	Ear aspect	*Striga* index
			8 WAP	10 WAP	8 WAP	10 WAP			
TZEI 23	1297.9	54.19	1.7	3.38	6.41	8.64	0.98	4.14	8.95
ENT 11	1552.71	60.75	2.01	3.13	17.7	24.65	0.89	3.33	8.53
TZEI 175	1451.04	60.68	2.44	3.73	5.38	7.76	0.86	3.43	8.26
TZEI 2	1573.61	56.21	2.94	4.08	13.53	19.45	0.85	4.13	7.01
TZEI 173	1292.86	61.21	2.76	3.66	5.88	8.01	0.86	4.35	6.8
TZEI 174	1361.12	60.85	2.69	3.93	6.39	13.24	0.84	4.19	6.65
TZEI 167	1505.56	62.3	2.41	4.53	10.9	19.59	0.79	4.49	6.3
TZEI 136	1275.85	56.74	2.23	3.64	8.15	12.06	0.76	4.48	6.21
TZEI 16	1390.47	61.2	2.74	4.18	12.93	18.46	0.89	4.19	6.15
TZEI 148	1203.81	55.69	2.23	3.96	6.76	11.99	0.87	5.03	6.14
TZEI 177	1297.74	54.56	2.59	3.71	13.5	16.69	0.86	4.05	5.94
TZEI 103	1225.16	58.09	2.89	4.03	5.85	14.04	0.92	4.86	5.91
TZEI 178	1251.59	53.73	2.86	3.68	14.49	20.1	0.97	4.39	5.87
TZEI 13	1532.23	62.68	3.01	4.33	11.73	20.65	0.76	4.63	5.84
TZEI 159	1207.75	59.66	2.5	3.55	9.01	19.71	0.84	4.25	5.54
TZEI 75	1333.39	57.5	2.59	3.94	14.68	17.31	0.81	3.94	5.52
TZEI 14	1109.42	61.93	2.23	3.98	3.71	9.74	0.8	3.96	5.31
TZEI 150	966.82	54.43	2	3.69	5.69	8.71	0.88	4.73	5.31
TZEI 24	1073.15	57.25	2.46	3.38	7.6	11.41	0.81	3.75	5.19
TZEI 15	1100.63	61.93	2.76	3.63	9.78	15.19	0.86	3.61	4.76
ENT 15	571.98	62.74	4.91	6.35	12.59	15.51	0.43	6.03	-7.21
ENT 7	566.99	56.16	5.15	6.33	10.19	17.46	0.44	6.33	-7.34
TZEI 26	718.5	61.01	5.13	6.23	23.3	24.51	0.45	6.11	-7.36
TZEI 202	609.14	63.09	5.63	6.75	8.49	14.68	0.46	6.13	-7.55
ENT 4	742.03	62.01	4.69	6.51	27.2	31.34	0.45	6.16	-7.66
TZEI 142	526.28	63.84	5.44	6.45	4.14	6.05	0.34	5.85	-7.7
ENT 3	778.3	63.05	5.04	6.16	34.65	43.4	0.45	5.54	-8.58
TZEI 129	591.83	58.8	5.81	6.99	14.09	18.63	0.38	5.71	-9.29
TZEI 27	355.72	64.46	4.46	6.5	12.65	23.98	0.37	6.45	-9.37
TZEI 112	587.43	57.65	4.66	5.95	39.5	42.96	0.48	6.01	-9.45
Mean	993.42	58.87	3.61	4.91	14.27	20.26	0.68	5.02	
Min	355.72	53.73	1.7	3.13	3.71	6.05	0.34	3.33	
Max	1573.61	64.46	5.81	6.99	39.5	43.4	0.98	6.45	
Lsd	327.63	1.90	0.76	0.83	9.40	11.08	0.18	0.81	

Table 4. 6 List of early maturing maize inbred lines resistant/tolerant to single or multiple stresses

Low N	*Striga*	*Striga* and low N
ENT 13	ENT 10	ENT 11*
ENT 15	ENT 12	TZEI 10
ENT 16	TZEI 103	TZEI 106
ENT 17	TZEI 111	TZEI 11*
ENT 3	TZEI 13	TZEI 12
TZEI 1	TZEI 131	TZEI 130*
TZEI 108	TZEI 136	TZEI 14*
TZEI 120	TZEI 148	TZEI 146*
TZEI 126	TZEI 15	TZEI 150*
TZEI 128	TZEI 160	TZEI 157*
TZEI 129	TZEI 167	TZEI 158*
TZEI 135	TZEI 184	TZEI 159
TZEI 140	TZEI 189	TZEI 16*
TZEI 149	TZEI 190	TZEI 161*
TZEI 156	TZEI 24	TZEI 173
TZEI 18	TZEI 25	TZEI 174
TZEI 19	TZEI 3	TZEI 175
TZEI 200	TZEI 33	TZEI 177*
TZEI 22	TZEI 39	TZEI 178*
TZEI 32	TZEI 54	TZEI 188
TZEI 4	TZEI 65	TZEI 2*
TZEI 5	TZEI 68	TZEI 23*
TZEI 60	TZEI 91	TZEI 56*
TZEI 63		TZEI 7*
TZEI 86		TZEI 75*
		TZEI 83*
		TZEI 98

*Drought tolerant

The best inbred lines across *Striga*-infested environments were TZEI 173, TZEI 174, TZEI 178, TZEI 2, TZEI 56, TZEI 7 and TZEI 75.

Analysis of combined data across research environments showed that the genotypic differences were significant (P < 0.01) for all traits except stalk lodging and husk cover (Table 4.7). Genotype x environment interactions were significant (P < 0.01) for only ear aspect while environment was significantly (P < 0.01) different for all traits. Under low N environments, genotype accounted for (32.3%) of the total sum of squares for grain yield, while genotype x environment interactions accounted for 31.1%, and environment 9.5%. Similarly, under *Striga*-infested environments, genotype accounted for 38.1% of the total sum of squares for grain yield, genotype x environment interactions accounted for 31.6% and environment 10.7%. Genotype explained the largest proportion (44.9%) of the total sum of squares for grain yield across all research environments, while environment and genotype x environment interactions accounted for 10.5 and 31.7%.

4.6 Discussion and Conclusions

The objective of this study was to identify inbred lines that are *Striga* resistant/tolerant and/or low N tolerant that could serve as sources of favorable alleles for population improvement and as parent for development of superior hybrids that combine resistance to *Striga* and tolerance to low N. The significant genotypic variation observed across low N and *Striga* environments among the inbred lines for grain yield and the other traits indicated that significant progress can be made in selecting for low N tolerance and *Striga* resistance. The large environmental effects detected for grain yield and most traits in the early maturing inbred lines under both stresses at two locations for two years suggested that the inbred lines are variable across the environments. Similarly, the significant genotype x environment interactions detected for grain yield and most

Table 4. 7 Mean squares of grain yield and other traits of 100 inbred across low N and *Striga*-infested environments, 2010 and 2011.

Sources of variation	df	Grain yield Kg ha^{-1}	Days to 50% silking	Days to 50% anthesis	Anthesis -silking interval	Plant height cm	Ear height cm	Root lodging	Stalk lodging	Husk cover	Ear per plant	Ear aspect
Blk(Rep x E)	144	356208.1**	13.0**	8.8ns	3.1ns	438.4**	139.7**	114.0**	102.9ns	1.9ns	0.05ns	1.9**
Rep(E)	8	540413.9*	37.1**	20.8*	5.2ns	1544.6**	1077.7**	1930.4**	476.1**	4.9ns	0.1*	5.5**
Env	7	7552396.4**	2026.2**	1185.4**	125.5**	75765.5**	14764.9**	8781.4**	14456.6**	485.3**	0.7**	57.5**
Entry	99	976252.9**	70.4**	38.7**	10.4**	1983.3**	498.5**	96.5**	118.9ns	2.5ns	0.2**	4.4**
Entry x Env	693	229159.9ns	8.0ns	4.5ns	3.1ns	235.6ns	93.6ns	53.3ns	71.7ns	1.2ns	0.04ns	1.2**
Error	1124	226272.8	7.3	7.6	2.7	227.7	82.6	65.4	120.4	5.8	0.04	0.9

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

traits is an indication that the inbred lines should be tested in several environments to identify stable, low N tolerant inbred lines for hybrid production. Similar findings were reported by Meseka *et al.* (2006) and Makumbi *et al.* (2011) under low N, while under *Striga* infestation, similar results were reported by Menkir *et al.* (2003), Badu-Apraku *et al.* (2012a), Menkir *et al.* (2012) and Badu-Apraku *et al*. (2013a). However, there were no significant differences among hybrids across low N, drought stress and well-watered environments (Makumbi *et al.*, 2011). Significant environmental effects across research environments suggested that the test environments were variable, an indication that it is necessary to evaluate the inbred lines under both low N and *Striga* environments. The moderate heritability estimates for grain yield, anthesis-silking interval, plant height, ear height, stay-green characteristic, plant aspect, ear aspect, and number of ears per plant suggested that early generation selection for these traits to improve low N tolerance would be effective. Under *Striga* the moderate to high heritability estimates for grain yield, days to anthesis and silking, *Striga* damage ratings at 8 and 10 WAP, ear aspect and number of ears per plant is an indication that early generation selection for these traits to improve *Striga* resistance/tolerance would be effective.

The 100 inbred lines were characterized as *Striga* resistant/tolerant using the base index which combined high grain yield, low *Striga* damage ratings, low number of emerged *Striga* plants and high number of ears per plant. Fifty percent (50%) of the inbred lines evaluated under *Striga* infestation had positive base index and, therefore, had some level of tolerance/resistance to *Striga*. The high percentage of inbred lines with positive base indices under *Striga* is not surprising because most of the lines except the CIMMYT inbred lines were developed from *Striga* resistant and drought tolerant populations. Menkir (2006) defined *Striga* resistance as the ability of a genotype to sustain low *Striga* damage and support significantly fewer emerged

Striga plants. The use of S*triga* resistant genotypes reduces parasite seed reproduction and contributes to depletion of the *Striga* seed bank (Haussmann *et al.*, 2004; Badu-Apraku *et al*., 2007a). On the other hand, *Striga* tolerance is the ability of the host plant to withstand the effects of the parasites that are already attached and to produce significantly higher yield than the susceptible genotype when *Striga* infested (Badu-Apraku *et al*., 2008). Based on these criteria, nineteen inbred lines were identified as resistant to *Striga*. The outstanding inbred lines under *Striga* infestation are TZEI 2, ENT 11, TZEI 13, TZEI 39, TZEI 167, TZEI 175, TZEI 16, TZEI 174, TZEI 75, TZEI 161, TZEI 7, TZEI 23, TZEI 177, TZEI 173, TZEI 56, TZEI 136, TZEI 33, TZEI 111 and TZEI 178. Although CIMMYT inbreds were not intentionally selected for *Striga* resistance, three out of the eleven CIMMYT lines (ENT 11, ENT 10 and ENT 12) had positive base indices under *Striga* infestation suggesting the presence of *Striga* resistant alleles in the CIMMYT inbred lines. Similar findings were reported by Karaya *et al*. (2012a) who found *Striga* resistance in CIMMYT inbred lines that were not intentionally selected for resistance to *Striga*.

Several inbred lines were also characterized as tolerant to low N using the base index that combined high grain yield, number of ears per plant, short ASI, better plant aspect, better ear aspect and good stay-green characteristic. About fifty-two percent (52%) of the inbred lines were identified to have some level of tolerance to low N. Among these were six CIMMYT and 28 IITA drought tolerant inbred lines with positive base index values under low N, an indication that they were tolerant to low N. This corroborates the reports of Lafitte and Edmeades (1995), Meseka *et al.* (2006), Makumbi *et al.* (2011), Kamara *et al.* (2012) and Badu-Apraku and Akinwale (2011a) who reported good performance of drought tolerant lines under low N conditions. Overall, the inbred lines with outstanding performance under low N were TZEI 32,

ENT 3, TZEI 173, ENT 13, TZEI 83, TZEI 1, TZEI 188, TZEI 75, TZEI 178, TZEI 146, TZEI 7, TZEI 56, TZEI 106, TZEI 157, TZEI 2, TZEI 135, TZEI 174 and TZEI 98. Under low N and *Striga* environments, 27% of the inbred lines had positive index values. This is an indication that the inbred lines combine resistance to *Striga* and tolerance to low N. The inbred lines are ENT 11, TZEI 10, TZEI 106, TZEI 11, TZEI 12, TZEI 130, TZEI 14, TZEI 146, TZEI 150, TZEI 157, TZEI 158, TZEI 159, TZEI 16, TZEI 161, TZEI 173, TZEI 174, TZEI 175, TZEI 177, TZEI 178, TZEI 188, TZEI 2, TZEI 23, TZEI 56, TZEI 7, TZEI 75, TZEI 83 and TZEI 98. Among the top 20 inbred lines across low N and *Striga*-infested environments, seven were identified as resistant/tolerant to *Striga* and low N. The inbred lines include ENT 11, TZEI 173, TZEI 174, TZEI 177, TZEI 178, TZEI 2 and TZEI 75. On the other hand, ENT 4, TZEI 142, TZEI 26 and TZEI 27 were identified to be susceptible to both *Striga* and low N. The results of this experiment provided information that aided the selection of inbred lines for further study.

CHAPTER FIVE

5.0 Genetic analysis of *Striga* resistance and low N tolerance in early maturing inbred lines and performance of their hybrids

5.1 Introduction

Low soil N aggravates the *Striga* problems in West Africa (WA). The resource poor farmers are the most affected as they apply fertilizer at suboptimal levels because it is too expensive. In order to combat the problem of *Striga* and low N, the use of varieties with combined resistance/tolerance to both stresses is the most economical, feasible and sustainable approach for the resource poor farmer. Farmers presently are growing open pollinated varieties with average yields of 1.6 tonnes ha^{-1} (FAO, 2012). With the emergence of several seed companies in WA, there is need to make available high yielding and promising hybrids with combined resistance/tolerance to the stresses present on the farmer's field. The use of *Striga* resistant and low N tolerant hybrids will increase maize production and productivity and lead to improved incomes and livelihoods of farmers as well as enhance the sustainability of the seed companies.

Recurrent selection for drought tolerance has resulted in improvements in maize populations for tolerance to drought stress (Edmeades *et al.*, 1999) as well as good performance under low N conditions (Bänziger *et al.*, 2002; Monneveux *et al.*, 2006; Meseka *et al.*, 2006; Kamara *et al.*, 2005; 2012; Badu-Apraku *et al.*, 2010). Similarly, recurrent selection for *Striga* resistance under artificial infestation in two early and two extra-early maize populations resulted in selection gains in grain yield under low and high N environments and a reduction in *Striga* damage and/or emergence (Badu-Apraku *et al.*, 2009).

However, there has been little research on the performance of *Striga* resistant varieties or inbred lines under low N. In WA, selection for improved grain yield of maize under *Striga* infestation is done under low N fertilizer; 30 kg N ha^{-1}, instead of the 120 kg N ha^{-1} recommended for production. This low rate of nitrogen is used in selection for low N tolerance in WA. Therefore, some genotypes selected for *Striga* resistance may also show tolerance to low N. On the other hand, direct selection under low N and indirect selection under high N for low N target environments have been employed by CIMMYT in selection for low N tolerance. In the direct selection for low N tolerance, N fertilizer is not applied. Interestingly, Karaya *et al.* (2012a) found *Striga* resistance in the CIMMYT inbreds that were not intentionally selected for *Striga* resistance suggesting that some lines tolerant to drought and low N possess also alleles that enabled them to express an appreciable degree of tolerance/resistance to *Striga*. Therefore, it was necessary to identify genotypes that combine resistance to *Striga* and tolerance to low N. The use of hybrids with resistance/tolerance to *Striga* and low N would be appropriate and more sustainable for small scale farmers in areas where low agricultural inputs are utilized and *Striga* problems are endemic.

The objectives of the study were to:

(i) Determine the gene action conditioning *Striga* resistance and tolerance to low N in early maturing maize inbreds under low N and *Striga*-infested environments, and

(ii) Assess the performance and stability of the hybrids across low N, *Striga*-infested and optimum environments.

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 100 lines screened for *Striga* resistance and low N tolerance in Chapter three. The lines were selected based on their performance (response to *Striga* and/or low N) under *Striga* infestation in Abuja (2010) and low N in Ile-Ife and Mokwa (2010). The 30 inbred lines were crossed in a NC II mating design (Comstock and Robison, 1948) with six sets each of five inbred lines. The five inbred lines in one set were used as females and crossed with five inbred lines in another set used as males. Each inbred line was used as a female parent in one set and a male parent in another set. A total of 150 crosses (6 sets x 25 hybrids) were made.

5.2.2 Field Evaluation

The 150 single cross hybrids plus six hybrid checks were evaluated under low N, *Striga*-infested and optimum environments in 2011 and 2012. Evaluation under *Striga*-infestation was conducted in Mokwa (9^{o}18’N and 5^{o}04’E, 457 m asl, 1,100 mm annual rainfall) and Abuja (9^{o}15’N and 7^{o} 20’E, 300 m asl, 1,700 mm annual rainfall) while the low N and optimum experiments were conducted at Ile-Ife (7^{o}29’N and 4^{o}35’E, 275 m asl, 1,350 mm) and Mokwa. The experimental design was a 12 x 13 lattice with two replications. The low N plots received 30 kg N per hectare while optimum plots received 90 kg N per hectare applied in two splits at 2 and 5 weeks after planting. Both low N and optimum fields received 60 kg P ha^{-1} as single superphosphate (P_20_5) and 60 kg K ha^{-1} as muriate of potash (K_2O). Under low N and optimum environments, weeds were controlled through the use of Atrazine and Gramozone as pre- and post- emergence herbicides at 5 litres/ha each of Primextra and paraquat and subsequently by hand weeding. *Striga* plots were artificially infested with about 5000 germinable *Striga* seeds per

Table 5. 1 Characteristics of selected 30 early maturing maize inbred lines used in the study

Inbred lines	**source**	**Grain colour**	**Reaction to stress**	
			Striga	**Low N**
ENT 11	CIMMYT	white	Resistant/Tolerant	Tolerant
ENT 12	CIMMYT	white	Resistant/Tolerant	Susceptible
ENT 16	CIMMYT	white	Susceptible	Tolerant
ENT 3	CIMMYT	white	Susceptible	Tolerant
TZEI 108	IITA	white	Susceptible	Tolerant
TZEI 168	IITA	white	Susceptible	Susceptible
TZEI 22	IITA	white	Susceptible	Tolerant
TZEI 32	IITA	white	Susceptible	Tolerant
TZEI 33	IITA	white	Resistant/Tolerant	Susceptible
TZEI 39	IITA	white	Resistant/Tolerant	Susceptible
TZEI 4	IITA	white	Susceptible	Tolerant
TZEI 54	IITA	white	Resistant/Tolerant	Susceptible
TZEI 56	IITA	white	Resistant/Tolerant	Tolerant
TZEI 65	IITA	white	Resistant/Tolerant	Susceptible
TZEI 89	IITA	white	Susceptible	Susceptible
ENT 13	CIMMYT	yellow	Susceptible	Tolerant
TZEI 10	IITA	yellow	Resistant/Tolerant	Tolerant
TZEI 135	IITA	yellow	Susceptible	Tolerant
TZEI 142	IITA	yellow	Susceptible	Susceptible
TZEI 146	IITA	yellow	Resistant/Tolerant	Tolerant
TZEI 149	IITA	yellow	Susceptible	Tolerant
TZEI 157	IITA	yellow	Resistant/Tolerant	Tolerant
TZEI 17	IITA	yellow	Susceptible	Susceptible
TZEI 173	IITA	yellow	Resistant/Tolerant	Tolerant
TZEI 175	IITA	yellow	Resistant/Tolerant	Tolerant
TZEI 177	IITA	yellow	Resistant/Tolerant	Tolerant
TZEI 184	IITA	yellow	Resistant/Tolerant	Susceptible
TZEI 23	IITA	yellow	Resistant/Tolerant	Tolerant
TZEI 24	IITA	yellow	Resistant/Tolerant	Susceptible
TZEI 9	IITA	yellow	Susceptible	Susceptible

hole. Under *Striga*-infested environments weeds were manually controlled. Details of both low N and *Striga* experiments are described in Chapter four.

5.2.3 Data collection

The data collected for the optimum experiment included days to silking, days to anthesis, plant aspect, ear aspect, root lodging, stalk lodging and number of ears per plant. Grain yield was calculated in kg/ha and estimated based on 80% shelling percentage and adjusted to 15% moisture. Grain yield under optimum environment was calculated as follows:

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

Where:

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

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

m = moisture content grain at harvest

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

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

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

Data collected for *Striga*-infested and low N environments are as described in Chapter four.

5.2.4 Data analyses

Data on *Striga* emergence count was transformed as [log(counts+1)] to reduce the heterogeneity of variance for *Striga* counts while data, taken for ear rot, stalk and root lodging in percentages were transformed using arcsine. Each year-location combination was considered as a test environment. The analysis of variance (ANOVA) was performed separately for low N, *Striga* and optimum environments. The ANOVA for the 156 entries was performed using the PROC GLM in SAS. The entry means were adjusted for block effects, according to the lattice design (Cochran and Cox, 1960). The environment, replication and block were treated as random factors and entry as fixed.

The yield data were further subjected to genotype main effect plus genotype × environment interaction (GGE) biplot analysis to evaluate the G × E interactions of each experiment using the GGE biplot windows application (Yan *et al.*, 2000; Yan, 2001). The GGE biplot model equation is:

$Y_{ij} - Y_j = \lambda_1\xi_{i1}\eta_{j1} + \lambda_2\xi_{j2}\eta_{j2} + \Sigma_{ij}$

Where, Y_{ij} is the average yield of genotype i in environment j,

Y_j is the average yield across all genotypes in environment j,

λ_1 and λ_2 are the singular values for principal component (PC)1 and PC2,

ξ_{i1} and ξ_{j2} are the PC1 and PC2 scores for genotype i,

$\eta_{j1}$and η_{j2} are the PC1 and PC2 scores for environment j and

Σ_{ij} is the residual of the model associated with the genotype i in environment j.

The data were not transformed (Transform=0), not standardized (Scale=0) and were environment-centered (Centering=2).

The ANOVA of NC II for each environment was performed on the entries without the checks using PROC GLM in SAS using a RANDOM statement with the TEST option (SAS, 2008). The hybrids (sets) component of variation was divided into variation due to male (sets), female (sets), and female x male (sets) interaction. The main effects of male (sets) and female (sets) represent the general combining ability (GCA) while the female x male (sets) interaction represents specific combining ability (SCA) effect (Hallauer and Miranda, 1988).The F tests for male (sets), female (sets), and female x male (sets) mean squares were computed using the mean squares for their respective interaction with environment. The mean square attributable to environment x female x male (sets) was tested using the pooled error mean squares.

The general linear model for the NC II mating design with sets 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:

X_{ijklm}= 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_l= average effect of the lth set;

$g_i(S_l)$= GCA effect common to all hybrids of the ith female nested within lth set

$g_j(S_l)$= GCA effect common to all hybrids of the jth male nested within lth set;

$h_{ij}(S_l)$= SCA effect of hybrid from the ith female and jth 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;

$(E_g)_{im}(S_l)$ 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 mid-parent (MPH) and better parent heterosis (BPH) value for a cross were computed for each trait as: $MPH = \left(\frac{F_1 - MP}{MP}\right) x 100$

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

F_1 = Mean of the hybrid,

MP = the mean of the parents that constituted the hybrids and

BP = the mean of the better parent.

MPH and BPH were averaged across low N, *Striga*-infested and optimum environments.

The relationship between per se performance of parental lines and their hybrids was determined using simple linear correlation analysis of the mid-parent values on the hybrid performance at the same environment. The interrelationship among the traits used as indices for tolerance to low N and *Striga* resistance was determined using correlation analysis.

General combining ability (GCA) was estimated as:

$GCA_f = X_f - \mu$,

$GCA_m = X_m - \mu$ where,

GCA_m and GCA_f= General combining ability of male and female parents respectively,

X_f and X_m = Mean of male and female parents respectively and

μ = Overall mean of crosses in the trial

Specific combining ability (SCA) was estimated as:

$SCA_X = X_X - E(X_X) = X_X - [GCA_f + GCA_m + \mu]$ where,

SCA_x = specific combining ability of the cross x

X_X = Observed mean value of the cross

$E(X_X)$ = Expected mean value of the cross based on the GCA of both parent μ = Overall mean of crosses

The base indices as described in section 4.4.1 for *Striga* resistance and low N tolerance was used in identifying hybrids that are *Striga* resistant and low N tolerant.

5.3 Results

5.3.1 Genetic analysis of performance of early maturing maize inbred lines under contrasting environments

Significant ($P < 0.01$) differences were observed among hybrids and environments for all traits (Table 5.2) under *Striga*-infested environments. Similarly, the GCA_m, GCA_f and SCA were significant ($P < 0.01$) for all traits. In contrast, the hybrid x environment interactions was significant for all traits except ear aspect. Furthermore, GCA_m x environment interaction were significant for all traits under *Striga* infestations except ears per plant while GCA_f x environment interactions were significant for all traits except *Striga* damage at 8WAP. Also, the SCA x environment interactions were significant ($P < 0.05$) for days to silking, days to anthesis, anthesis-silking interval and ears per plant but not for grain yield, *Striga* damage at 8 and 10 WAP, number of emerged *Striga* plants at 8 and 10 WAP and ear aspect. The GCA_f and GCA_m variances were larger than those of SCA for all traits under *Striga* infestation.

Under low N environments, significant ($P < 0.01$) differences were observed among hybrids, environments, GCA_m, and GCA_f for all traits (Table 5.3). On the other hand, the hybrid x environment interaction was significant ($P < 0.05$) for all traits except grain yield and ear aspect while the SCA effects were significant for all traits except the stay-green characteristic. GCA_m x environment interaction effects were significant for days to silking, anthesis-silking interval, stay-green characteristics and ears per plant but not for grain yield, days to anthesis,

Table 5. 2 Mean squares of grain yield and other traits of early maturing hybrids evaluated under *Striga*-infested environments at Abuja and Mokwa in 2011 and 2012.

Source	df	Grain yield kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	*Striga* damage score		*Striga* emergence count		Ears per plant	Ear aspect (1-9)
						8 WAP	10 WAP	8 WAP	10 WAP		
ENV	3	135757397**	1685.21**	1391.14**	279.53**	67.56**	133.07**	21.04**	20.0**	0.79**	47.80**
SETS	5	9014643**	153.73**	34.74**	43.08**	35.63**	29.50**	0.76**	0.69**	0.64**	7.54**
ENV x SETS	15	2729207*	5.80ns	2.42*	8.99ns	1.09ns	5.11**	0.21ns	0.18ns	0.09*	1.54ns
Hybrids	155	4771120**	28.55**	9.28**	11.28**	8.48**	7.79**	0.30**	0.24**	0.12**	3.23**
GCA$_m$/sets	24	9585605**	37.14**	16.71**	14.12**	15.62**	15.53**	0.55**	0.44**	0.23**	6.56**
GCA$_f$/sets	24	7974460**	50.47**	17.96**	15.68**	16.46**	14.67**	0.50**	0.35**	0.15**	5.21**
SCA/sets	96	2069684**	10.60**	3.08**	6.58**	2.08**	2.28**	0.14*	0.13**	0.04**	1.39**
Hybrid x Env	465	1274675**	7.62**	1.27**	5.73**	1.33**	1.70**	0.14**	0.11**	0.04**	0.97ns
Env x GCA$_m$/sets	72	1370415*	10.08**	1.79**	6.22**	1.77**	1.88**	0.16*	0.13*	0.04ns	1.23**
Env x GCA$_f$/sets	72	1413792*	7.84**	1.34**	5.84**	1.24ns	2.00**	0.17**	0.13**	0.04*	1.13**
Env x SCA/sets	288	1058878ns	6.10**	1.03*	4.67**	1.14ns	1.32ns	0.12ns	0.10ns	0.04**	0.81ns
Pooled error	480	1022775	4.65	0.85	3.63	1.0	1.13	0.11	0.09	0.03	0.75

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

Table 5. 3 Mean squares of grain yield and other traits of early maturing hybrids evaluated under low N environments at Ile-Ife and Mokwa in 2011 and 2012.

Source	df	Grain yield Kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-5)	Stay-green (1-9)	Ears per plant	Ear aspect (1-9)
ENV	3	58816958**	912.41**	1382.41**	113.92**	244.05**	17.51**	0.35**	13.71**
SETS	5	8588628**	33.92**	31.21**	1.94*	4.53**	5.66**	0.02ns	0.37**
ENV*SETS	15	798381ns	4.93**	3.50*	2.90**	0.71ns	3.86**	0.01ns	0.14**
Hybrids	155	3007670**	16.56**	10.85**	2.25**	2.3**	1.29**	0.02**	1.66**
GCA$_m$/sets	24	3713129**	38.05**	25.17**	4.37**	2.54**	2.52**	0.03**	0.56**
GCA$_f$/sets	24	4211172**	37.09**	23.73**	3.43**	2.26**	2.48**	0.03**	0.65**
SCA/sets	96	1797100**	5.60**	3.34**	1.31*	1.92**	0.42ns	0.02**	0.28**
Hybrids x Env	465	846139ns	3.43**	2.16**	1.12*	0.75**	0.68**	0.01**	0.49ns
Env x GCA$_m$/sets	72	695868ns	3.83**	1.76ns	1.55**	0.75ns	0.84**	0.01**	0.11ns
Env x GCA$_f$/sets	72	1283844**	3.97**	2.18ns	1.62**	0.91*	0.77**	0.02**	0.15ns
Env x SCA/sets	288	725808ns	3.12**	2.15*	0.83ns	0.61ns	0.47ns	0.01**	0.11ns
Pooled error	480	691308	2.31	1.71	0.94	0.66	0.46	0.01	0.1

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

plant and ear aspects. Also, the GCA_f x environment interaction effects were significant for all traits except days to anthesis and ear aspect while the SCA x environment interaction effects were significant for all traits except grain yield, anthesis-silking interval, plant aspect, stay-green characteristic and ear aspect. The GCA_m and GCA_f mean squares were substantially larger than SCA effects for all traits under low N.

Under optimum environments, significant differences were observed among hybrids, environment and hybrid x environment interaction effects, GCA_f and SCA effects for all traits (Table 5.4). However, the GCA_m x environment interaction mean squares were significant for all traits except days to anthesis, anthesis-silking interval and ears per plant while GCA_f x environment interaction effects were significant for all traits except days to anthesis and ears per plant. Furthermore, SCA x environment interaction effects were significant for all traits except for anthesis-silking interval, plant aspect and ears per plant. The GCA_m and GCA_f effects were substantially larger than SCA effects for most traits except ears per plant.

The combined analysis of variance showed that variation due to environment and genotype x environment interactions were significantly ($P < 0.05$) different for grain yield and other traits that were common across research environments (Table 5.5). The GCA_m and GCA_f variances were significant for all traits while SCA mean squares were significant for all traits except root lodging, stalk lodging and ears per plant. The GCA_m, GCA_f and SCA interactions with environment were significantly different for grain yield, days to silking, anthesis-silking interval, stalk lodging, ears per plant and ear aspect. The GCA_m and GCA_f effects were substantially larger than SCA effects for most traits.

Table 5. 4 Mean squares of grain yield and other traits of early maturing hybrids evaluated under optimum environments at Ile-Ife and Mokwa in 2011 and 2012.

Source	df	Grain yield Kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-5)	Ears per plant	Ear aspect (1-9)
ENV	3	126832959**	559.78**	484.69**	5.63*	147.01**	0.57**	321.71**
SETS	5	35981810**	33.92**	33.40**	3.22**	11.64**	0.01ns	4.98**
ENV x SETS	15	1037089ns	4.42ns	2.14ns	1.25*	1.15*	0.02ns	1.46*
Hybrids	155	5287586.9**	13.34**	9.02**	1.68**	3.29**	0.006**	2.11**
GCA$_m$/sets	24	6618429**	28.74**	17.11**	3.43**	5.31**	0.01ns	3.42**
GCA$_f$/sets	24	6505185**	27.0**	18.80**	2.37**	4.48**	0.01ns	4.46**
SCA/sets	96	2681130**	5.19**	3.17**	0.91*	1.94**	0.02**	1.02**
Hybrid x Env	465	960461.9**	2.39**	1.7*	0.82*	0.72**	0.005**	0.81**
Env x GCA$_m$/sets	72	1170508**	2.99**	1.82ns	0.88ns	0.90**	0.01ns	1.05**
Env x GCA$_f$/sets	72	1190820**	2.25*	1.60ns	0.90*	0.92**	0.01ns	1.01**
Env x SCA/sets	288	849799**	2.18**	1.65*	0.77ns	0.64ns	0.01ns	0.63*
Pooled error	480	524710	1.65	1.38	0.67	0.57	0.01	0.53

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

Table 5. 5 Mean squares of grain yield and other traits of early maturing hybrids evaluated across research environments in 2011 and 2012.

Source	df	Grain yield Kg ha^{-1}	Days to silking	Days to anthesis	Anthesis -silking interval	Root lodging (%)	Stalk lodging (%)	Ears per plant	Ear aspect (1-9)
ENV	11	312929277**	1113.7**	1043.3**	173.3**	9018.3**	28592**	2.57**	152.17**
SETS	5	18562149**	186.2**	96.41**	18.51*	227.62**	544.3ns	0.17ns	2.71ns
ENV x SETS	55	4495268**	7.27ns	2.46ns	6.26*	55.54ns	353.21*	0.07**	2.01ns
Hybrids	465	960461.9**	2.39**	1.70*	0.82*	24.41**	124.26*	0.005**	0.81**
GCA_m/S	24	9448552**	93.81**	56.52**	15.16**	113.85**	533.56**	0.08**	5.69**
GCA_f/S	24	10691822**	98.06**	56.56**	12.60**	190.98**	538.11**	0.06**	6.96**
SCA/S	96	4163948**	12.69**	6.86**	3.35**	60.06ns	85.16ns	0.02ns	2.00**
Hybrid x Env	465	960461.9**	2.39**	1.70*	0.82*	24.41**	124.26*	0.005**	0.81**
ENV x GCA_m/S	264	1855969**	5.49**	1.67ns	2.94**	58.86*	154.44**	0.03**	1.34**
ENV x GCA_f/S	264	1771622**	5.37**	1.72ns	3.08**	56.02ns	126.13**	0.03**	1.23**
ENV x SCA/S	1056	926914**	3.84**	1.54**	2.19**	48.07ns	69.07*	0.02**	0.65**
Error	1440	746264	2.87	1.32	1.75	49.33	61.86	0.01	0.56

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

5.3.2 Relative contributions of combining ability effects

The relative importance of GCA and SCA effects was determined as the ratio of GCA effects to the total the genetic effects using the sum of squares. The closer the ratio is to unity, the greater the predictability based on GCA (Baker, 1978). Under *Striga*-infested environments, the overall contributions of GCA (GCA_m plus GCA_f) sum of squares to the total variation among hybrids varied from 53% for anthesis-silking interval to 79% for *Striga* damage at 8WAP while SCA varied from 20.6% for *Striga* damage ratings at 8 WAP to 46.9% for anthesis-silking interval (Fig. 5.1). GCA accounted for about 68% of the sum of squares for grain yield, 77% for *Striga* damage at 10WAP, 64% and 60% for number of emerged *Striga* plants at 8 and 10 WAP, respectively. The contribution of GCA_m (37.1%) was slightly higher than GCA_f (30.9%) and SCA (32%) for grain yield. The GCA_f (38.8%) was larger than GCA_m (28.6%) and SCA (32.6%) sum of squares for days to silking while GCA_m (41.3%) contribution was larger than GCA_f (27.2%) and SCA (31.5%) sum of squares for ears per plant.

Under low N, the contribution of GCA to genotypic sum of squares ranged from 38% for plant aspect to 78% for days to anthesis while SCA ranged from 22% for days to anthesis to 62% for plant aspect (Fig. 5.2). The contribution of GCA_m, GCA_f and SCA to genotypic sum of squares for grain yield were 24%, 28% and 48%. The contribution of GCA_m, GCA_f and SCA to genotypic sum of squares for stay-green characteristic were 38%, 37% and 25%. The SCA (62%) was larger than GCA_m (20%) and GCA_f (18%) for plant aspect.

GCA contributions to genotypic sum of squares varied from 20% for ears per plant to 74% for days to anthesis under optimum environments while SCA varied from 26% for days to anthesis to 80% for ears per plant (Fig. 5.3). The contribution of GCA_m (28%) and GCA_f (27%) to genotypic sum of squares for grain yield was about the same magnitude under optimum environments while SCA was 45%. SCA accounted for 80% of the variation observed for ears per plant while GCA accounted for most of the variation observed in grain yield, days to silking, days to anthesis, anthesis-silking interval and ear aspect.

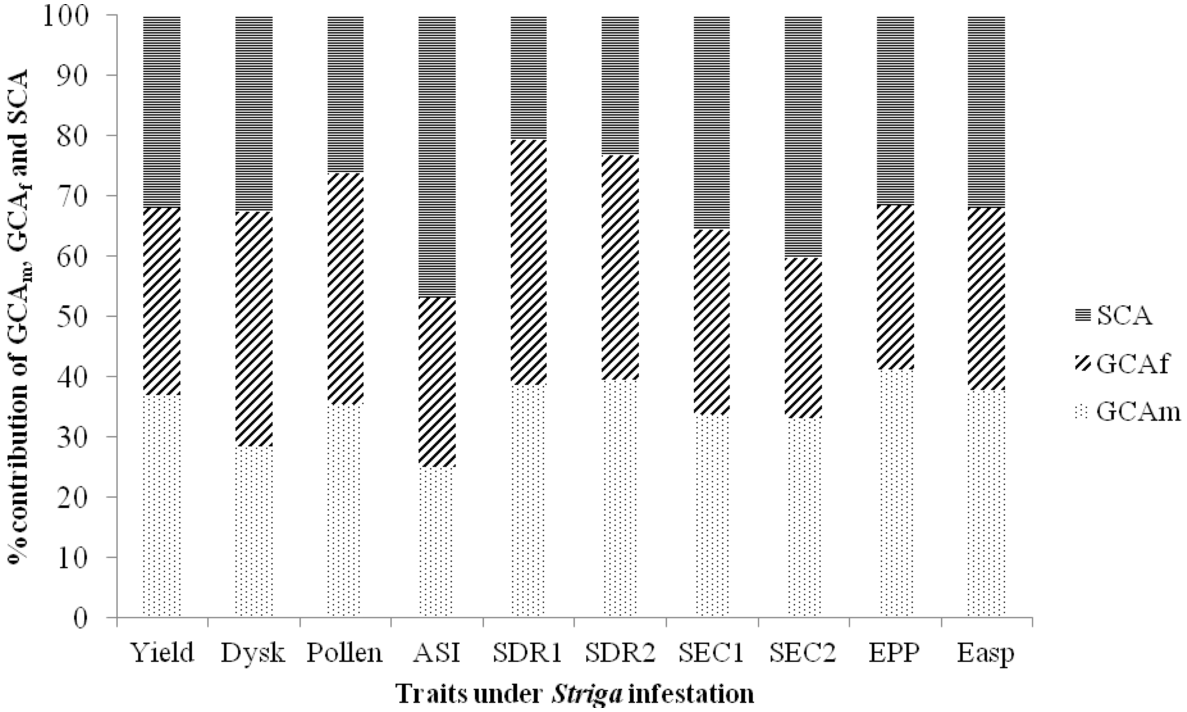

Figure 5. 1. Proportion of total genotypic sum of squares of grain yield and other agronomic traits of early maturing inbred lines attributable to GCA$_m$, GCA$_f$ and SCA across *Striga* infested environments.

Dysk = days to 50% silking, Pollen = days to 50% anthesis, ASI= anthesis-silking interval, SDR1 and SDR2 = *Striga* damage ratings at 8 and 10 WAP respectively, SEC1 and SEC2 = number of emerged *Striga* plants at 8 and 10 WAP respectively, EPP = ears per plant and EASP = ear aspect.

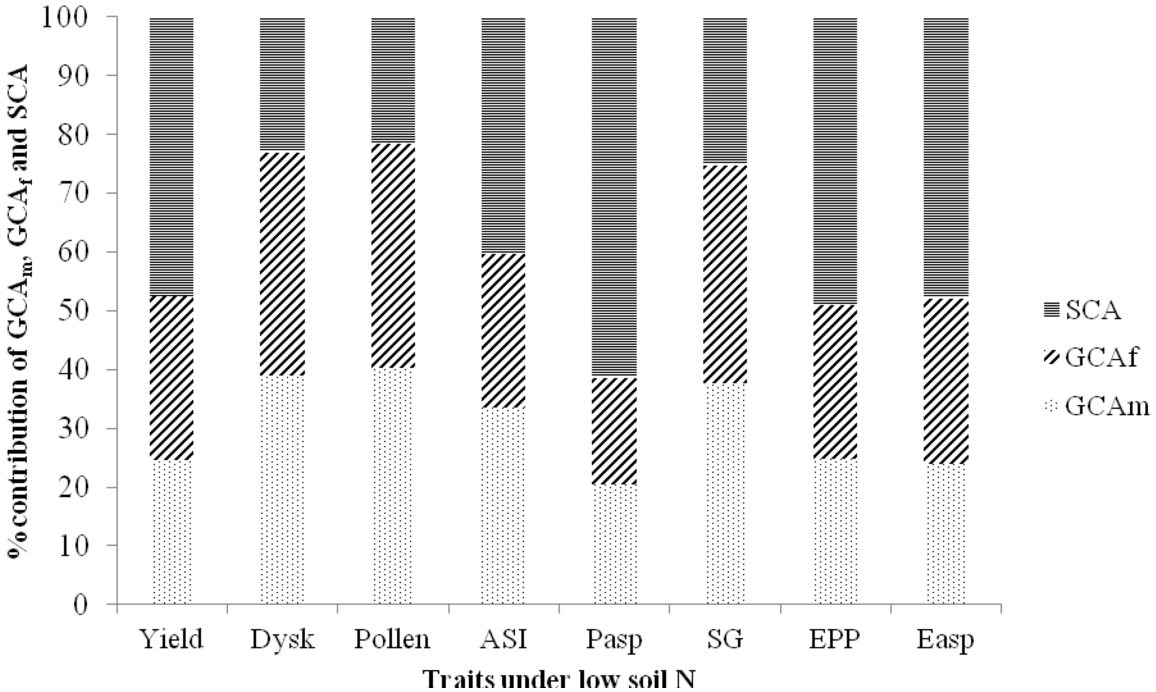

Figure 5. 2. Proportion of total genotypic sum of squares for grain yield and other agronomic traits of early maturing inbreds attributable to GCA_m, GCA_f and SCA across low soil nitrogen environments.

Dysk = days to 50% silking, Pollen = Days to 50% anthesis, ASI = anthesis-silking interval,
PASP = plant aspect, SG = stay-green characteristic, EPP = ears per plant and EASP = ear aspect

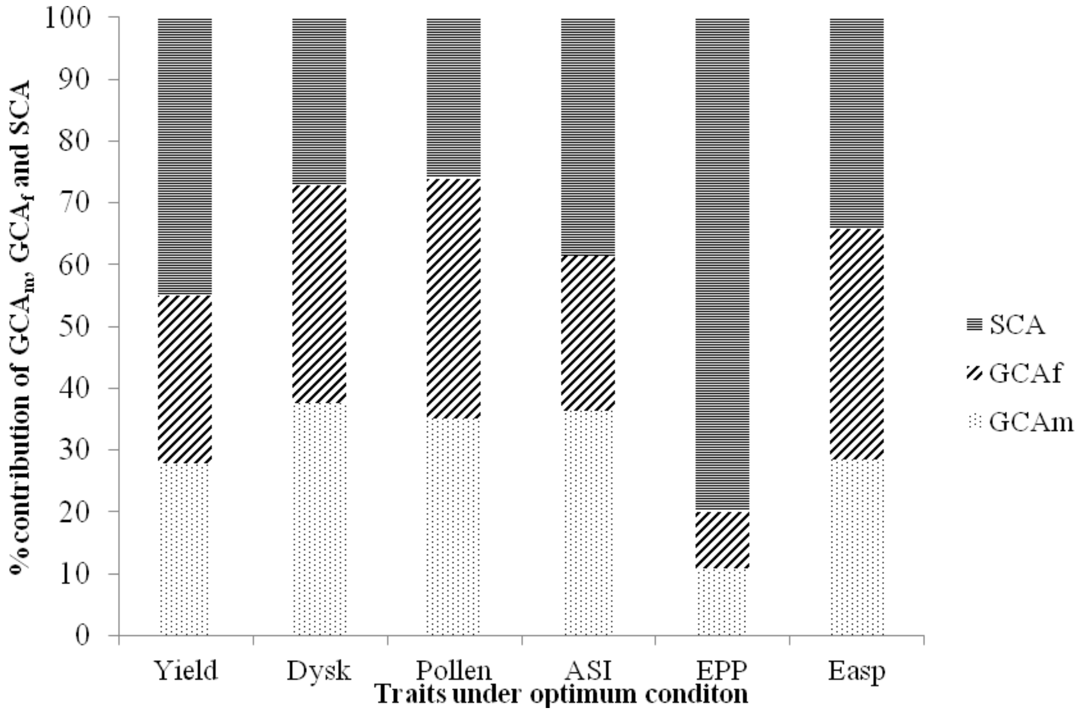

Figure 5. 3. Proportion of GCA_m, GCA_f and SCA to total genotypic sum of squares for grain yield and other agronomic traits of 30 early maize inbreds across optimum environments.

Dysk = days to 50% silking, Pollen = Days to 50% anthesis, ASI = anthesis-silking interval, EPP = ears per plant and Easp = ear aspect

5.3.3 General combining ability effects

The GCA_m effects for grain yield under *Striga* infestations ranged from -885 for TZEI 135 to 1362 for ENT 11 while GCA_f effects ranged from -686 for TZEI 168 to 1308 for ENT 11 (Table 5.6). Of the 24 inbred lines identified as *Striga* resistant/tolerant only seven had significant GCA_m and/or GCA_f effects. Inbred lines TZEI 173, TZEI 175, ENT 11 and TZEI 39 had superior positive GCA effects (significant positive GCA_m and GCA_f effects), TZEI 23 and ENT 12 had significant positive GCA_m effects while TZEI 22 had significant positive GCA_f effect for grain yield (Table 5.6). The inbred lines with superior negative GCA effect (significant negative GCA_m and GCA_f effects) were TZEI 135, TZEI 108, TZEI 168, TZEI 33 and TZEI 54. Inbreds TZEI 135, TZEI 108, TZEI 168, TZEI 54 and TZEI 89 had both significant positive GCA_m and GCA_f effects for *Striga* damage at 8 and 10 WAP while TZEI 173, TZEI 24, ENT 11, ENT 12 and TZEI 39 had both significant negative GCA_m and GCA_f effects for *Striga* damage at 8 and 10 WAP. GCA_m and GCA_f effects for ear aspect were significant and positive for TZEI 135, TZEI 108, TZEI 168 and TZEI 54 but significant and negative for TZEI 175, ENT 11 and TZEI 39. Inbred lines which had both positive significant GCA_m and GCA_f effects for grain yield had negative significant effects for *Striga* damage scores and ear aspects (TZEI 173, TZEI 175 ENT 11 and TZEI 39) while inbreds with both significant negative GCA_m and GCA_f effect had significant positive *Striga* damage and ear aspect (TZEI 135, TZEI 108, TZEI 168 and TZEI 54). Inbred TZEI 39 in addition to having significant positive GCA_m and GCA_f effects for grain yield had significant negative GCA effects for *Striga* damage score and ear aspect and also showed significant positive GCA_m and GCA_f effects for *Striga* emergence count at 8 and 10

Table 5. 6 General combining ability effects of early maturing inbred lines evaluated under *Striga*-infested environments.

Inbred lines lines	Grain yield		Days to silking		*Striga* damage score 8WAP		*Striga* damage score 10WAP		*Striga* emergence count 8WAP		*Striga* emergence count 10WAP	
	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$
ENT 13	-456.04*	-18.91	0.70	1.03**	0.31	0.14	0.31	0.09	11.03**	13.83**	12.68**	15.25**
TZEI 10	99.32	31.78	-0.42	-0.42	-0.25	-0.29	-0.10	-0.19	-0.47	-2.77	-5.44	-1.36
TZEI 135	-885.2**	-577.99*	0.57	-0.34	1.22**	0.88**	1.08**	1.08**	0.42	4.84	-0.50	3.77
TZEI 142	-296.83	-82.69	1.35**	2.68**	0.81**	0.60**	0.67**	0.33	2.59	3.22	6.65	-0.41
TZEI 146	322.49	148.88	-1.41**	-0.92*	-0.54**	-0.13	-0.24	-0.09	1.17	4.39	5.38	5.27
TZEI 149	-168.25	-401.36*	-1.53**	-1.13**	0.31	0.37*	0.38*	0.32	4.64	-3.26	5.46	-4.30
TZEI 157	-220.63	105.11	0.57	-0.67	0.11	-0.13	0.04	-0.24	1.48	-1.36	-0.85	2.33
TZEI 17	16.60	-113.56	0.47	0.44	0.11	-0.05	-0.02	-0.26	-2.14	-3.31	-2.87	-2.53
TZEI 173	446.80*	510.89*	0.80	1.24**	-0.54**	-0.40*	-0.71**	-0.54**	1.02	-3.15	3.44	-5.16
TZEI 175	622.44*	735.34*	1.65**	2.06**	-0.49**	-0.29	-0.65**	-0.47*	-15.69**	-6.11	-17.08**	-5.26
TZEI 177	148.73	-190.76	-1.22**	-1.37**	-0.16	-0.04	-0.21	0.07	-1.63	6.33	-3.53	7.14
TZEI 184	-33.02	-47.53	0.40	0.95*	0.02	-0.05	0.07	0.04	-2.43	-6.15	-2.20	-6.26
TZEI 23	401.76*	215.87	-1.09*	-1.59**	-0.79**	-0.39*	-0.58**	-0.20	-0.01	-2.04	-0.07	-2.79
TZEI 24	293.09	15.80	-0.42	-1.11**	-0.48*	-0.59**	-0.57**	-0.51*	-8.59**	-5.34	-8.51*	-5.28
TZEI 9	-291.25	-330.86*	-0.40	-0.84*	0.36	0.37*	0.54**	0.57**	8.62**	0.88	7.45*	-0.41
ENT 11	1362.1**	1307.88**	0.01	-0.79*	-1.17**	-1.3**	-1.36**	-1.46**	8.18*	5.82	11.51**	11.51**
ENT 12	573.75*	257.19	0.15	-0.1	-0.75**	-0.78**	-0.81**	-0.55**	4.18	2.03	5.54	0.55
ENT 16	-119.24	244.1	1.32**	0.90	0.06	-0.28	-0.13	-0.3	-3.61	0.1	-6.64	-3.32
ENT 3	-575.36*	-276.57	1.51**	1.33**	0.55**	-0.16	0.67**	0.22	-2.7	7.15*	1.37	8.0*
TZEI 108	-347.78*	-541.24*	-1.17**	-1.09**	0.56**	0.81**	0.41*	0.7**	-4.07	-8.24*	-6.77	-12.49**
TZEI 168	-542.87*	-686.23*	-0.88*	0.3	1.04**	1.27**	0.96**	1.04**	3.16	-2.62	-0.2	-5.15
TZEI 22	157.03	403.77*	-0.19	0.55	-0.46*	-0.52**	-0.19	-0.29	2.63	-0.18	9.96**	1.05
TZEI 32	-88.52	-129.84	-0.33	0.81*	-0.08	-0.04	0.02	0.18	-0.02	2.26	-2.23	-0.55
TZEI 33	-350.44*	-360.23*	-0.03	-0.27	0.13	0.69**	0.26	0.35	-1.39	-7.0*	-3.88	-6.47
TZEI 39	958.7**	414.7*	-1.57**	-1.23**	-1.41**	-1.18**	-1.36**	-1.03**	18.99**	15.12**	27.27**	23.6**
TZEI 4	-129.52	-278.38	0.29	-1.02**	0.47*	0.02	0.18	0.15	-8.31**	7.05*	-12.39**	9.86*
TZEI 54	-582.43*	-437.62*	-0.02	-0.52	0.71**	0.85**	0.96**	0.58**	-6.01	-7.7*	-6.83	-12.06**
TZEI 56	-58.39	303.65	0.63	0.27	-0.29	0.01	-0.14	-0.35	-1.66	-6.28	-2.91	-6.32
TZEI 65	-145.72	133.62	-0.69	-0.84*	-0.29	-0.26	0.08	-0.18	-3.19	-4.06	-3.34	-3.99
TZEI 89	-111.33	-354.78*	0.95*	1.70**	0.47*	0.88**	0.45*	0.93**	-6.18	-3.46	-10.45**	-4.24
SE±	165.55	168.15	0.45	0.40	0.19	0.16	0.19	0.2	3.19	3.51	3.79	3.94

GCA$_m$ =GCA effects of the inbred used as a male parent, GCA$_f$ = GCA effects of the inbred used as a female parent, *, **, Significant at probability level of 0.05 and 0.01probability levels, respectively, ns not significant

WAP. Thus, it is a tolerant inbred since it was associated with large number of emerged *Striga* plants. ENT 11 had significant positive GCA_m effects for number of emerged *Striga* plants.

The GCA_m for grain yield varied from -637 for TZEI 175 to 603 for TZEI 142 while GCA_f varied from -580 for TZEI 108 to 686 for TZEI 32 under low N (Table 5.7). Low N tolerant inbred lines with superior positive GCA effects (significant GCA_m and GCA_f) for grain yield were ENT 13, ENT 11, ENT 12, ENT 16 and TZEI 32. Also, TZEI 108 a low N tolerant line had significant negative GCA effects for grain yield. TZEI 142 an inbred line susceptible to Low N had superior GCA effects for grain yield under low N. Inbred lines TZEI 157, TZEI 175, TZEI 22, TZEI 33, and TZEI 54 had significant negative GCA_m while TZEI 17, TZEI 9, and TZEI 168 had significant positive GCA_m effects. TZEI 65 had significant negative GCA_f effects for grain yield. In addition, TZEI 142 had significant positive GCA effects for days to silking, stay-green characteristics and a negative significant GCA effect for plant aspect and number of ears per plant. Under low N, inbred lines with significant positive GCA effects for grain yield also had significant negative GCA effects for ear aspect. Positive values for the GCA effects for stay-green characteristic observed in TZEI 142, TZEI 9, ENT 11, TZEI 108 and TZEI 89 indicate early senescence while negative values as observed in TZEI 24 and TZEI 33 indicate delayed senescence. The lines with the poor values for plant and ear aspect were those with positive GCA_f and/or GCA_m effects (Table 5.7).

The GCA effects due to males within sets (GCA_m) for grain yield under optimum condition varied from -665 for TZEI 23 to 1169 for TZEI 142 while the GCA effects due to females within sets (GCA_f) ranged from -614 in TZEI 108 to 997 for TZEI 142 (Table 5.8). Significant positive GCA effects for grain yield was observed in ENT 13, TZEI 142 and ENT 12 while significant negative GCA effects was observed in TZEI 177, TZEI 23, TZEI 24, TZEI 33

Table 5. 7 General combining ability effects of early maturing inbred lines evaluated across low soil nitrogen environments.

Inbred lines	Grain yield		Days to silking		Anthesis-silking interval		Plant aspect		Stay green		Ear aspect	
	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$
ENT 13	300.98*	499.61**	-0.03	-0.34	0.01	-0.07	-0.43**	-0.18	-0.1	0.16	-0.28**	-0.27*
TZEI 10	-182	-100.23	-0.14	-0.60*	-0.16	-0.21	0.005	-0.09	-0.06	-0.12	0.23**	0.15**
TZEI 135	-168.3	-15.91	-0.61*	-1.54**	0.004	-0.38*	0.1	0.13	0.02	0.003	0.21**	0.06
TZEI 142	602.86**	488.03**	1.62**	1.48**	0.31	0.16	-0.57**	-0.60**	0.49**	0.48**	-0.49**	-0.54**
TZEI 146	75.4	282.89	-0.54*	-0.74**	-0.40*	-0.52**	-0.03	-0.05	0.01	0.16	-0.17**	-0.21**
TZEI 149	146.17	-289.95	-1.55**	-0.96**	-0.32	-0.27	0.08	0.51**	-0.17	-0.18	0.01	0.36**
TZEI 157	-346.06**	-57.34	0.36	-0.06	0.04	-0.11	0.19	0.005	-0.11	-0.14	0.23**	0.06
TZEI 17	320.41**	76.79	-0.37	0.82**	-0.18	0.27	0.002	0.05	-0.06	-0.17	-0.28**	-0.20**
TZEI 173	-45.52	-243.54	1.66**	2.06**	0.74**	0.84**	-0.07	-0.04	0.09	0.13	0.004	0.21**
TZEI 175	-636.85**	193.59	2.51**	1.94**	0.81**	0.49**	0.69**	-0.21	-0.01	-0.01	0.48**	-0.24**
TZEI 177	-219.56	-155.69	-0.94**	-1.03**	-0.2	-0.32	0.24*	0.23	0.1	-0.12	0.19**	-0.03
TZEI 184	194.02	-120.74	0.4	0.85**	0.15	0.17	-0.25*	0.11	-0.29	-0.12	-0.21**	0.20**
TZEI 23	-231.25	-154.27	-1.43**	-1.24**	-0.3	0.09	0.40**	0.25	-0.19	-0.1	0.28**	0.31**
TZEI 24	-223.84	-182.06	-0.22	-0.51	-0.05	-0.08	0.003	0.08	-0.26*	-0.43**	0.18**	0.13*
TZEI 9	413.54**	-221.2	-0.71*	-0.13	-0.45*	-0.08	-0.35**	-0.2	0.54**	0.46**	-0.39**	0.02
ENT 11	419.0**	418.21**	0.4	0.42	-0.45*	-0.49**	-0.09	-0.26	0.38**	0.27*	-0.30**	-0.39**
ENT 12	234.07*	396.02*	0.70*	0.33	-0.2	-0.14	-0.2	-0.39**	0.001	-0.03	-0.21**	-0.41**
ENT 16	377.24**	568.80**	0.53	0.88**	0.26	0.17	-0.40**	-0.27*	-0.22	-0.06**	-0.31**	-0.40**
ENT 3	-36.75	-222.12	0.95**	1.09**	0.49**	0.36*	0.01	0.1	-0.08	-0.005	-0.02	0.1
TZEI 108	-252.83*	-580.28**	-1.02**	-0.93**	-0.18	0.01	0.16	0.21	0.49**	0.34**	0.20**	0.38**
TZEI 168	265.08*	130.02	-1.58**	-1.06**	-0.05	0.02	0.01	0	-0.02	-0.08	-0.09	-0.15**
TZEI 22	-239.41*	-312	0.83**	1.14**	0.23	0.31	0.17	0.34*	0.17	0.21	0.15**	0.33**
TZEI 32	392.08**	685.86**	0.26	-0.26	0.08	0.06	-0.07	-0.13	-0.49**	-0.18	-0.20**	-0.18**
TZEI 33	-521.51**	-301.67	-0.60*	-0.32	0.05	0.06	-0.004	0.07	-0.29*	-0.43**	0.33**	0.08
TZEI 39	-79.96	-226.36	-0.44	-0.54	-0.26	-0.08	-0.1	0.42**	0.01	-0.05	0.02	0.14*
TZEI 4	-40.93	89.78	-0.24	-0.35	0.17	-0.21	-0.04	-0.06	-0.03	-0.22	0.03	0.004
TZEI 54	-319.67**	-204.16	0.22	-0.3	0.36*	0.11	0.31*	-0.06	-0.17	-0.34**	0.31**	0.12*
TZEI 56	-218.81	-303.82	0.29	-0.06	-0.14	0.02	0.05	0.1	-0.11	0.13	0.12*	0.22**
TZEI 65	97.6	-349.12*	-0.58*	-0.54	-0.16	-0.13	0.08	0.01	0.09	-0.07	-0.04	0.27**
TZEI 89	-75.2	210.83	0.27	0.49	-0.2	-0.08	0.11	-0.1	0.29*	0.51**	0.01	-0.13*
SE±	117.97	160.24	0.28	0.28	0.18	0.18	0.06	0.07	0.13	0.12	0.09	0.11

GCA$_m$ =GCA effects of the inbred used as a male parent, GCA$_f$ = GCA effects of the inbred used as a female parent, * and **significant at 5 and 1% probability levels

Table 5. 8 General combining ability effects of early maturing inbred lines evaluated across optimum environments.

Lines	Grain yield		Days to silking		Anthesis-silking interval		Plant aspect		Ears per plant		Ear aspect	
	GCA_m	GCA_f	GCA_m	GCA_f	GCA_m	GCA_f	GCA_m	GCA_f	GCA_m	GCA_f	GCA_m	GCA_f
ENT 13	414.71**	428.51**	0.06	0.02	-0.1	-0.06	-0.39**	-0.48**	0.03*	0.03	-0.41**	-0.63**
TZEI 10	-220.07	187.92	-0.11	0.05	0.01	0.002	0.33*	-0.23	-0.001	-0.01	0.01	0.01
TZEI 135	-65.54	-169.63	0.01	-0.90**	0.29*	-0.15	0.04	-0.07	-0.002	-0.02	0.17	0.06
TZEI 142	1169.26**	997.30**	1.14	0.92**	0.26*	-0.05	-1.02**	-1.02**	-0.01	-0.005	-0.77**	-1.06**
TZEI 146	-18.64	96.86	-0.97**	-1.07**	-0.61**	-0.48**	0.13	-0.05	-0.01	0.02	-0.08	0.001
TZEI 149	-128.48	-425.82**	-1.38**	-0.86**	-0.31*	-0.28*	0.17	0.58**	-0.01	-0.01	0.19	0.46**
TZEI 157	-403.05**	-219.02	-0.1	0.18	-0.2	-0.19	0.28	0.22	-0.01	-0.005	-0.05	0.23
TZEI 17	96.23	46.2	0.002	0.17	-0.05	-0.08	0.04	0.11	0.01	0.04	0.03	-0.18
TZEI 173	208.02	-161.35	1.07**	1.76**	0.35**	0.71**	-0.53**	0.25	0	-0.03	-0.13	0.11
TZEI 175	-292.31	753.90**	2.20**	1.62**	0.69**	0.30*	0.48**	-0.35**	-0.04**	0.0004	0.41**	-0.09
TZEI 177	-468.66**	-388.47*	-0.73**	-0.57**	-0.03	0.21	0.34*	0.31*	0.01	0.01	0.21	0.26
TZEI 184	367.44	94.48	0.55*	0.45*	0.21	0.17	-0.34*	-0.08	0.01	-0.005	0.13	0.23
TZEI 23	-664.99**	-484.29**	-0.86**	-0.97**	-0.24	-0.13	0.74**	0.56**	0.01	0.01	0.48**	0.33*
TZEI 24	-472.12**	-556.61**	-0.29	-0.17	-0.12	0.21	0.41**	0.48**	-0.005	-0.02	0.40**	0.40**
TZEI 9	478.19**	-199.98	-0.59*	-0.61**	-0.16	-0.17	-0.67**	-0.24	0.03*	0.001	-0.58**	-0.14
ENT 11	394.99*	234.16	0.58*	0.62**	-0.33*	-0.32	-0.33*	-0.30*	0.001	0.01	-0.04	-0.49**
ENT 12	474.79**	764.35**	0.60*	0.92**	-0.15	-0.01	-0.15	0.1	-0.02	0.01	-0.16	-0.26
ENT 16	161.17	232.87	0.62*	0.88**	0.32*	0.28*	-0.36**	-0.31*	0.01	0.01	-0.36*	-0.15
ENT 3	149.71	154.75	1.05**	0.90**	0.51**	0.29*	0.1	-0.24	0.01	0.01	-0.1	-0.04
TZEI 108	-204.9	-614.48**	-1.53**	-1.07**	-0.32*	-0.05	0.08	0.24	0.003	-0.001	-0.02	0.35*
TZEI 168	100.38	-535.44**	-1.17**	-1.03**	-0.07	-0.14	0.24	0.06	0.02	-0.02	-0.04	-0.07
TZEI 22	-116.59	-409.51**	0.49*	0.28	0.04	0.05	0.22	-0.08	-0.001	-0.01	0	0.05
TZEI 32	284.04	634.12**	0.39	-0.37	0.12	0.04	0.1	-0.19	0.01	0.0002	-0.11	-0.18
TZEI 33	-623.85**	-408.54**	-0.49*	-0.07	0.02	0.04	0.05	0.49**	-0.01	-0.02	0.27	0.35*
TZEI 39	20.44	-165.63	-0.86**	-0.69**	-0.49**	-0.37**	-0.09	0.29*	-0.01	-0.01	0.09	-0.16
TZEI 4	-192.77	113.52	-0.24	-0.18	0.18	0.02	-0.39**	-0.24	0.03*	-0.003	0.07	-0.07
TZEI 54	-438.42**	-437.85**	-0.06	-0.35	0.08	0.08	0.33*	-0.03	-0.01	0.02	0.34*	0.24
TZEI 56	-265.82	67.09	0.32	0.004	-0.01	0.08	0.08	0.16	-0.03	0.01	0.13	0.34*
TZEI 65	-129.76	442.05**	-0.24	-0.50**	0.03	-0.02	0.02	0.17	-0.003	-0.01	0.26	0.23
TZEI 89	386.57*	-71.44	0.54*	0.66**	0.07	0.02	0.09	-0.13	0.01	-0.003	-0.32*	-0.16
SE±	153	154.33	0.24	0.21	0.13	0.13	0.13	0.13	0.01	0.02	0.14	0.14

GCA_m =GCA effects of the inbred used as a male parent, GCA_f = GCA effects of the inbred used as a female parent, * and **significant at 5 and 1% probability levels and TZEI 54. TZEI 157 had significant negative GCA_m effects for grain yield; TZEI 9, ENT 11 and TZEI 89 had significant positive GCA_m effects; TZEI 149, TZEI 108, TZEI 168, TZEI 22, exhibited significant negative GCA_f effects and TZEI 175, TZEI 32 and TZEI 65 exhibited significant positive GCA_f effects for grain yield. ENT 13 and TZEI 142 had significant negative GCA effects for plant aspect and ear aspects.

Across research environments, the GCA_m for grain yield ranged from -499 for TZEI 33 to 725 for ENT 11. Three inbred lines TZEI 142, ENT 11 and ENT 12 had significant positive GCA_m effects while TZEI 33 and TZEI 54 showed significant negative GCA_m effects for grain yield (Table 5.9). The GCA_f effects for grain yield ranged from -579 for TZEI 108 to 653 for ENT 11. Significant positive GCA_f effects occurred in TZEI 142, TZEI 175, ENT 11, ENT 16 and TZEI 32 while a negative GCA_f effects occurred in TZEI 108. Two inbred lines with outstanding GCA effect for grain yield and ear aspect across research environments were ENT 11 and TZEI 142. In addition ENT 11 had a negative GCA_m effect for ear rot.

5.3.4 Performance of early maturing hybrids under *Striga*-infested, Low N and optimum environments

Grain yield of hybrids under *Striga* infested environments ranged from 775 kg ha^{-1} for TZEI 168 x TZEI 54 to 4735 kg ha^{-1} for ENT 11 x ENT 12 with a mean of 2612 kg ha^{-1} (Table 5.10). Days to silking ranged from 50 to 61 with a mean of 56 while days to anthesis ranged from 50 to 57 with a mean of 54 under *Striga*-infested environments (Table 5.10). Anthesis-silking interval ranged from 0 to 6 with a mean of 2. Short anthesis-silking interval was observed among the best 20 hybrids while it was delayed in the susceptible hybrids. For example, the *Striga* resistant check TZEI 23 x ZEI 13 had short anthesis-silking interval of 1 while the

Table 5. 9 General combining ability effects of early maturing inbred lines evaluated across research environments.

Inbreds	Grain yield		Days to silking		Anthesis-silking interval		Ears per plant		Ear aspect		Husk cover		Ear rot	
	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$	GCA$_m$	GCA$_f$
ENT 13	86.55	303.07	0.24	0.24	0.16	0.09	0	0.03	-0.12	-0.23	0.05	-0.05	0.97	1.86
TZEI 10	-100.92	39.82	-0.22	-0.33	-0.12	-0.24	0.01	0.02	0.09	0.07	0.06	0	1.35	-1.14
TZEI 135	-373.01	-254.51	-0.01	-0.92**	0.40	-0.07	-0.05*	-0.04*	0.40*	0.21	0.14	0.13	3.48*	2.42
TZEI 142	491.76*	467.55*	1.37**	1.69**	0.25	0.39	-0.05*	-0.04*	-0.39*	-0.49**	-0.23	-0.17	-2.88	-1.04
TZEI 146	126.42	176.21	-0.97**	-0.91**	-0.56*	-0.38	0.01	0.01	-0.14	-0.08	0.01	-0.06	-1.93	0.11
TZEI 149	-50.19	-372.38	-1.49**	-0.99**	-0.35	-0.28	0	-0.01	0.12	0.35*	0.02	0.17	0.70	0.81
TZEI 157	-323.25	-57.09	0.28	-0.18	-0.01	-0.29	-0.03	0.01	0.07	-0.03	0.08	0.05	0.28	-2.35
TZEI 17	144.41	3.14	0.03	0.48	-0.06	0.11	0.03	0.01	-0.16	-0.21	-0.06	-0.01	-0.52	-1.03
TZEI 173	203.10	35.33	1.18**	1.68**	0.34	0.57*	0	0.01	-0.20	0.01	-0.15	-0.06	-2.38	-0.36
TZEI 175	-102.24	560.94**	2.12**	1.88**	0.59*	0.42	0	-0.02	0.11	-0.31	-0.07	-0.17	-0.72	-1.95
TZEI 177	-179.83	-244.97	-0.97**	-0.99**	-0.22	-0.24	0.02	0.00	0.10	0.12	0.10	0.06	0.86	1.21
TZEI 184	176.15	-24.59	0.45	0.75*	0.18	0.31	0.02	0.00	0.04	0.19	-0.10	-0.12	0.42	0.99
TZEI 23	-164.83	-140.90	-1.12**	-1.27**	-0.20	-0.17	0.04*	0.03	0.19	0.22	0.15	0.18	1.32	1.19
TZEI 24	-134.29	-240.95	-0.31	-0.60	-0.11	-0.04	0.02	0.02	0.18	0.21	-0.08	-0.05	-1.83	-0.74
TZEI 9	200.16	-250.68	-0.56	-0.52	-0.29	-0.20	-0.01	-0.02	-0.29	-0.03	0.09	0.10	0.88	0.02
ENT 11	725.37**	653.41**	0.33	0.08	-0.67**	-0.72**	0.04*	0.05**	-0.53**	-0.63**	-0.12	-0.08	-4.53**	-4.11
ENT 12	427.54*	283.95	0.48	0.38	-0.34	-0.28	0.03	0.03	-0.26	-0.30	-0.07	-0.03	-0.76	0.08
ENT 16	139.72	396.60*	0.82*	0.88**	0.50*	0.32	0.00	0.01	-0.19	-0.27	-0.13	-0.15	-1.28	-1.09
ENT 3	-154.13	-114.65	1.17**	1.11**	0.67**	0.45	-0.03	-0.01	0.14	0.07	0.07	0	1.67	-0.58
TZEI 108	-268.50	-578.67**	-1.24**	-1.03**	-0.21	-0.04	-0.02	-0.02	0.18	0.37*	0.07	0.07	1.55	2.05
TZEI 168	-59.14	-211.39	-1.21**	-0.60	0.07	0.29	0.00	-0.04*	0.09	0.13	0.08	-0.02	1.12	0.40
TZEI 22	-66.32	82.37	0.38	0.66*	-0.07	0.18	-0.01	0	0.01	0.07	0.10	0.10	0.68	-0.40
TZEI 32	195.87	396.71*	0.11	0.06	-0.02	0.29	0.01	0	-0.05	-0.01	-0.02	0.05	1.61	2.62
TZEI 33	-498.60**	-356.81	-0.37	-0.22	0.24	0.03	0.00	-0.03	0.26	0.20	0.00	-0.04	-0.30	0.02
TZEI 39	299.73	-5.16	-0.95**	-0.82*	-0.70**	-0.48	0.05*	0.01	-0.18	-0.11	-0.16	0.09	-3.34*	-1.08
TZEI 4	-121.07	-27.88	-0.06	-0.52	0.27	-0.38	0.01	0	0.06	-0.01	0.03	-0.07	-0.55	3.03
TZEI 54	-446.84*	-215.99	0.05	-0.39	0.09	-0.03	-0.02	-0.01	0.34*	0.30	0.13	0.04	0.42*	3.30
TZEI 56	-181.01	-127.05	0.41	0.07	0.07	0.18	-0.03	0.01	0.09	0.11	-0.14	0.02	-0.48	-3.11
TZEI 65	-59.29	-239.35	-0.50	-0.63	-0.11	-0.11	0	0	0.11	0.11	0.08	0.02	3.41*	0.54
TZEI 89	66.68	63.90	0.59	0.95**	0.22	0.30	-0.02	-0.02	-0.09	-0.02	0.06	-0.01	0.80	-1.68
SE±	192.66	188.24	0.33	0.33	0.24	0.25	0.02	0.02	0.16	0.16	0.13	0.11	1.66	1.74

GCA$_m$ =GCA effects of the inbred used as a male parent, GCA$_f$ = GCA effects of the inbred used as a female parent, * and **significant at 5 and 1% probability levels

Table 5. 10 Grain yield and other agronomic traits of some selected hybrids (best 20 and worst 10) evaluated under *Striga*-infested environments at Abuja and Mokwa in 2011 and 2012

HYBRID	Grain yield kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	*Striga* damage score		*Striga* emergence		Ears per plant	Ear aspect	Base index
					8 WAP	10 WAP	8 WAP	10 WAP			
TZEI 175 x TZEI 177	3938	55.39	53.78	1.51	1.96	3.10	6.62	13.63	0.96	3.94	10.98
TZEI 173 x TZEI 24	4340	56.17	54.15	1.93	2.18	2.99	15.69	19.78	0.91	3.75	10.30
TZEI 146 x TZEI 175	4385	55.48	54.00	1.48	2.34	3.08	14.10	19.98	0.90	3.83	10.19
ENT 11 x ENT 12	4735	56.83	55.47	1.31	1.72	2.70	30.40	43.31	0.97	3.80	9.61
TZEI 10 x TZEI 175	3811	56.06	53.78	2.39	2.44	3.81	10.31	11.66	0.95	4.16	9.22
TZEI 10 x TZEI 24	2880	55.46	54.06	1.32	2.20	3.57	0.58	2.84	0.95	5.50	8.79
TZEI 184 x TZEI 173	3555	55.41	53.67	1.78	2.50	3.36	11.06	19.17	0.92	4.52	8.20
TZEI 17 x TZEI 24	3298	54.17	52.86	1.55	2.42	3.61	9.32	11.94	0.93	4.84	8.07
TZEI 23 x TZEI 13(Check)	3869	53.38	52.86	0.75	2.41	4.05	18.64	29.01	0.99	4.58	7.57
TZEI 175 x TZEI 23	3890	54.95	53.40	1.46	2.19	3.27	19.12	33.33	0.87	4.22	7.30
TZEI 23 x TZEI 173	3555	54.12	52.90	1.14	2.02	3.49	18.22	26.94	0.91	4.63	7.24
TZEI 9 x TZEI 23	3120	52.46	51.99	1.01	1.96	3.75	17.21	20.36	1.00	4.88	7.23
TZEI 173 x TZEI 149	3923	54.37	53.03	1.32	2.71	4.05	18.97	26.64	0.91	4.79	6.98
TZEI 135 x TZEI 175	3560	55.29	53.47	1.80	2.83	4.24	12.81	13.11	0.86	4.63	6.80
TZEI 65 x ENT 11	3960	55.83	54.91	0.81	2.33	3.61	23.23	36.14	0.90	3.78	6.73
TZEI 24 x TZEI 23	3253	51.72	51.24	1.27	1.89	3.21	24.07	25.67	0.94	4.55	6.73
TZEI 24 x TZEI 17(Check)	3741	55.53	53.70	1.84	3.13	3.97	13.58	23.84	0.88	4.08	6.62
TZEI 175 x TZEI 184	3932	55.58	53.20	2.29	2.85	4.03	19.76	25.14	0.84	4.52	6.34
TZEI 157 x TZEI 173	3413	55.02	53.64	1.38	2.19	3.60	17.08	36.74	0.92	4.09	6.19
ENT 11 x TZEI 4	4042	55.29	55.25	0.62	1.98	2.99	35.68	42.66	0.88	4.25	6.18
TZEI 135 x ENT 13	1643	55.54	52.85	2.72	4.67	6.02	42.65	47.81	0.72	5.84	-7.54
TZEI 168 x ENT 16	1110	58.60	53.17	5.45	5.87	6.51	13.03	13.46	0.43	6.47	-7.84
TZEI 168 x TZEI 65	1168	54.24	52.41	1.65	5.54	6.86	20.64	32.21	0.64	6.22	-8.04
TZEI 54 x TZEI 33	1382	57.85	53.06	5.07	5.08	6.23	30.50	40.56	0.57	6.43	-8.39
ENT 16 x TZEI 108	1566	57.19	53.54	3.99	5.50	6.62	27.25	35.67	0.50	6.05	-8.70
TZEI 33 x TZEI 168	1212	55.92	52.89	2.87	6.00	6.92	26.47	36.05	0.61	5.95	-9.37
TZEI 89 x ENT 3	1286	61.15	55.48	5.59	5.39	6.89	26.20	38.84	0.48	6.45	-9.82
TZEI 89 x TZEI 108	1437	57.34	52.99	4.40	5.64	6.84	29.95	39.79	0.50	6.30	-9.83
TZEI 26 x TZEI 5 (check)	988	58.74	53.64	5.19	5.95	7.05	32.04	42.87	0.45	6.69	-12.28
TZEI 168 x TZEI 54	775	57.39	53.05	4.24	6.61	7.47	26.42	38.12	0.38	6.74	-13.54
Mean	2613	55.53	53.52	2.1	3.46	4.76	26.03	35.7	0.78	5.19	
Min	775	50.20	50.33	0	1.72	2.70	0.58	2.84	0.38	3.74	
Max	4735	61.15	57.11	5.59	6.61	7.47	68.91	100.47	1.08	6.79	
Lsd	978	2.14	0.91	1.90	0.98	1.04	18.90	22.14	0.17	0.85	

susceptible check TZEI 26 x TZEI 5 had delayed anthesis-silking interval of 6. *Striga* damage ratings at 8 WAP ranged from 1.7 to 6.6 with a mean of 3.5 while at 10 WAP, it ranged from 2.7 to 7.5 with a mean of 4.8. ENT 11 x ENT 12 had the lowest *Striga* damage rating both at 8 and 10 WAP while TZEI 168 x TZEI 54 had the highest *Striga* damage rating. ENT 11 x ENT 12 out yielded the best check by 18.3%. Number of emerged *Striga* plants ranged from 0.6 to 36.5 at 8 WAP and 2.8 to 57.5 at 10 WAP with a mean of 28.1 and 31.5 respectively. Using the base indices for selection, the top three hybrids under *Striga* infestation were TZEI 175 x TZEI 177, TZEI 176 x TZEI 24 and TZEI 146 x TZEI 175. The hybrid, TZEI 10 x TZEI 24 (2880 kg ha^{-1}) was the lowest yielding among the best 20 hybrids, and was ranked higher than the *Striga* resistant check, TZEI 23 x TZEI 13 (3869 kg ha^{-1}), ENT 11 x TZEI 4 (4141 kg ha^{-1}) and some other hybrids that yielded higher than it. TZEI 10 x TZEI 24 was classified as resistant/tolerant to *Striga* due to the presence of few emerged *Striga* plants, reduced *Striga* damage ratings and high ears per plant although its yield was significantly lower than the best check. Three hydrids involving ENT 11, a CIMMYT line as a parent (ENT 11 x ENT 12, TZEI 65 x ENT 11 and ENT 11 x TZEI 4) are among the highest yielding hybrids under *Striga* infestation although with emerged *Striga* plants not different from that of the susceptible check. The number of ears per plants ranged from 0.84 to 1.0 for the best 20 hybrids and from 0.38 to 0.64 for the worst 10 hybrids under *Striga* infestation. Crosses involving both *Striga* resistant/tolerant inbreds (T x T) out yielded those involving *Striga* susceptible inbreds (S x S) by 34.3%, T x S by 18.1%, S x T by 17.1% and checks by 19.9% (Table 5.11). A higher grain yield, shorter anthesis-silking intervals, reduced *Striga* damage and better ear aspect were observed in the T x T hybrids compared to the checks and other inbred combinations.

Table 5. 11 Mean and SE (±) for grain yield and other agronomic traits of hybrid groups across *Striga*-infested environments for two years

Traits	Check	Inbred line combinations*			
		S x S	**S x T**	**T x S**	**T x T**
Grain yield	2506^{b} ± 226	2053^{c}± 245	2594^{b} ± 110	2561^{b}± 107	3128^{a}± 53
Days to silking	57.5^{a} ± 0.69	57.4^{a} ± 0.64	55.6^{b} ± 0.32	55.6^{b} ± 0.25	55.4^{b} ± 0.13
Days to anthesis	54.5^{a} ± 0.33	54.3^{a} ± 0.31	53.7^{b} ± 0.19	53.7^{b} ± 0.17	53.8^{b}± 0.09
Anthesis-silking interval	3.0^{a} ± 0.55	3.2^{a} ± 0.57	2.0^{b} ± 0.24	2.0^{b} ± 0.19	1.7^{b} ± 0.08
***Striga* damage 8 WAP**	4.3^{a} ± 0.25	4.3^{a} ± 0.23	3.6^{b} ± 0.13	3.6^{b} ± 0.12	2.8^{c} ± 0.06
***Striga* damage 10 WAP**	6.7^{bc} ± 0.27	8.7^{a} ± 0.26	8.1^{ab} ± 0.12	8.3^{ab} ± 0.12	6.0^{c} ± 0.06
SEC1	24.4^{bc} ± 2.87	30.0^{ab} ± 3.54	31.2^{a} ± 1.89	29.2^{ab} ± 1.96	22.8^{c} ± 1.03
SEC2	29.2^{a} ± 3.15	33.0^{a} ± 3.77	32.8^{a} ± 2.14	32.6^{a} ± 2.18	28.3^{a} ± 1.28
Ears per plants	1.0^{a} ± 0.04	0.8^{b} ± 0.04	1.0^{b} ± 0.02	1.0^{b} ± 0.02	0.9^{b} ± 0.01
Ear aspect (1-9)	6.2^{a} ± 0.2	5.5^{b} ± 0.23	5.2^{bc} ± 0.09	5.3^{b} ± 0.09	4.6^{c} ± 0.04

*T = Resistant/Tolerant and S = Susceptible, means with the same letter are not significantly different (Duncan multiple range test), SEC1 and SEC2 = number of emerged *Striga* plants at 8 and 10 WAP respectively.

Under low N, grain yield of hybrids ranged from 1254 kg ha^{-1} for TZEI 173 X TZEI 175 to 5541 kg ha^{-1} for ENT 16 x TZEI 32 with a mean grain yield of 3375 kg ha^{-1} (Table 5.12). Grain yield of ENT 16 x TZEI 32 (5541 kg ha^{-1}) and TZEI 33 x ENT 12 (5095 kg ha^{-1}) were not significantly different from that of the best check TZEI 5 x TZEI 98 (5094 kg ha^{-1}) under low N. However, ENT 16 x TZEI 32 out yielded the best check by 8%. Days to silking varied from 52.2 for TZEI 24 x TZEI 23 to 62.0 for TZEI 173 x TZEI 175 with a mean of 56.1 while days to anthesis varied from 51.9 for TZEI 24 x TZEI 23 to 58.1 for TEI 175 x TZEI 142 with a mean of 54.7. The hybrid TZEI 173 x TEI 175 had a prolonged anthesis-silking interval of 4.2. Among the best 20 hybrids, stay-green characteristic was lowest in ENT 16 x TZEI 32 and highest in

ENT 11 x TZEI 22 (Table 5.12). There were no clear differences among the hybrid groups for grain yield and most traits under low N. The checks yielded higher than the T x T inbred combinations as well as the other combinations (Table 5.13).

Mean grain yield of the early maturing maize hybrids under optimum condition ranged from 1915 kg ha^{-1} for TZEI 149 x TZEI 157 to 6426 kg ha^{-1} for ENT 12 x TZEI 89 with an overall mean of 4640 kg ha^{-1}(Table 5.14). The highest yielding hybrid ENT 12 x TZEI 89 was not superior to the check. Days to silking, days to anthesis and anthesis-silking interval observed in the early maturing maize hybrids under optimum environments were shorter than when evaluated under *Striga* and low N environments. Days to silking of the early maturing hybrids varied from 51.4 to 59.6 with a mean of 54 while days to anthesis varied from 51.1 to 56.5 with a mean of 53.1 (Table 5.14).

Across research environments, grain yield of the hybrids ranged from 1786 kg ha^{-1} for TZEI 149 X TZEI 157 to 4806 kg ha^{-1} for ENT 11 X TZEI 4 with an overall mean of 3543 kg ha^{-1}(Table 5.15). Days to silking varied from 51.8 to 60.8 with a mean 55.2. Anthesis-silking interval ranged from 0.48 to 3.96 with a mean of 1.5. Root lodging was lower (10.4%) than stalk lodging (39.3%). The summary of other traits are shown in Table 5.15.

Information on yield reduction as a result of the stress is necessary to ascertain whether the severity of the stress was high enough to identify resistant/tolerant genotypes for the target stress. Yield reduction was higher in susceptible hybrids than resistant/tolerant hybrids both under low N and *Striga*-infested environments when compared to their performance under optimum environments. Under *Striga*-infested environments, yield reduction ranged from -11% to 59.1% among resistant/tolerant hybrids and from 14.9% to 84.4% in the susceptible hybrids.

Table 5. 12 Mean grain yield and other agronomic traits of early maturing maize hybrids (best 20 and worst 10) evaluated under low N environments in Ile-Ife and Mokwa in 2011 and 2012

Hybrids	Grain yield Kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	SG* (1-9)	Ears per plant	Ear aspect (1-9)	Base index
ENT 16 x TZEI 32	5541	56.95	55.33	1.49	4.10	2.23	0.98	3.38	15.11
TZEI 5 x TZEI 98 (check)	5095	56.16	55.73	0.47	3.96	3.83	1.01	3.85	11.63
TZEI 33 x ENT 12	4304	55.91	55.18	0.72	4.08	2.89	0.93	3.95	8.98
ENT 11 x TZEI 22	4146	58.21	58.01	0.46	4.06	4.02	0.99	4.02	7.26
ENT 11 x TZEI 4	4287	57.00	56.12	0.82	4.43	3.39	0.95	4.03	7.12
ENT 12 x TZEI 39	4073	55.71	55.16	0.56	4.26	3.41	0.96	4.27	6.88
TZEI 33 x TZEI 168	3873	54.05	53.3	1.06	4.42	2.81	1.01	4.56	6.76
TZEI 32 x ENT 12	4855	57.1	55.92	1.2	4.70	3.38	0.90	4.20	6.59
TZEI 32 x TZEI 168	4519	54.5	53.13	1.44	4.75	3.21	0.99	4.48	6.36
TZEI 4 x ENT 16	4237	56.28	54.74	1.48	4.39	3.02	0.95	4.38	6.06
TZEI 32 x TZEI 56	4041	55.89	54.67	1.14	4.05	3.16	0.96	4.58	5.99
TZEI 24 x TZEI 142	4093	55.52	54.44	1.33	3.98	3.54	0.96	4.19	5.84
ENT 12 x ENT 16	3858	57.38	55.7	1.67	4.29	2.72	0.96	4.28	5.80
TZEI 32 x TZEI 4	4298	56.79	55.31	1.41	4.51	3.14	0.95	4.40	5.71
ENT 13 x TZEI 184	3787	55.12	54.2	0.83	4.26	3.74	1.00	4.19	5.69
ENT 16 x ENT 11	4168	57.06	56.43	0.63	4.66	3.79	0.94	4.07	5.56
TZEI 65 x ENT 11	4153	55.99	55.35	0.89	4.58	3.57	0.97	4.44	5.40
TZEI 168 x ENT 16	3897	55.73	54.32	1.44	4.24	3.30	0.99	4.33	5.40
TZEI 56 x ENT 16	3990	56.48	55.19	1.42	4.35	3.32	1.00	4.54	5.18
TZEI 168 x TZEI 54	4022	54.48	52.85	1.71	4.71	2.92	1.02	4.72	5.08
TZEI 23 x TZEI 173	2628	56.33	53.93	2.42	5.24	3.50	0.88	5.34	-6.74
TZEI 17 x TZEI 175	2477	59.3	57.13	2.24	5.91	3.62	0.94	5.35	-7.39
TZEI 39 x TZEI 33	2307	55.82	53.92	1.91	5.68	3.22	0.86	5.53	-7.71
TZEI 108 x TZEI 22	2724	56.28	54.59	1.78	5.44	3.89	0.80	5.46	-8.27
TZEI 175 x TZEI 157	2525	58.96	56.36	2.55	5.44	3.69	0.82	5.25	-9.09
TZEI 149 x TZEI 157	2212	54.99	54.33	0.92	6.41	3.54	0.85	5.84	-9.23
TZEI 56 x TZEI 54	1866	57.64	54.96	2.52	6.09	3.07	0.88	5.90	-11.12
TZEI 24 x TZEI 184	1657	58.57	56.31	2.28	6.46	2.89	0.90	6.18	-11.79
TZEI 184 x TZEI 10	1340	59.15	56.76	2.34	6.49	3.60	0.81	6.40	-16.75
TZEI 173 x TZEI 175	1254	62.00	57.73	4.21	6.98	4.01	0.76	6.47	-23.22
Mean	3375	56.1	54.73	1.43	4.93	3.52	0.93	4.78	
Min	1254	52.2	51.92	0.41	3.81	2.23	0.75	3.38	
Max	5541	62	58.11	4.21	6.98	5.02	1.05	6.47	
Lsd	803	1.48	1.28	0.95	0.80	0.67	0.09	0.60	
SE	578	1.06	0.92	0.68	0.57	0.48	0.07	0.43	

***Stay-green characteristic**

Table 5. 13 Mean grain yield and other agronomic traits of hybrid groups evaluated under low N environments at Ile-Ife and Mokwa in 2011 and 2012

Traits	Check	Line combinations			
		S x S	S x T	T x S	T x T
Grain yield	$4534^{a} \pm 226$	$3336^{bc} \pm 95$	$3255^{c} \pm 71$	$3627^{b} \pm 69$	$3395^{bc} \pm 59$
Days to silking	$56.1^{a} \pm 0.39$	$55.8^{a} \pm 0.21$	$56.5^{a} \pm 0.18$	$55.8^{a} \pm 0.16$	$55.9^{a} \pm 0.14$
Days to anthesis	$55.0^{ab} \pm 0.37$	$54.4^{b} \pm 0.2$	$55.1^{a} \pm 0.16$	$54.5^{ab} \pm 0.16$	$54.4^{b} \pm 0.14$
Anthesis-silking interval	$1.1^{b} \pm 0.16$	$1.4^{ab} \pm 0.08$	$1.5^{a} \pm 0.08$	$1.4^{ab} \pm 0.06$	$1.4^{ab} \pm 0.06$
Plant aspect	$4.3^{b} \pm 0.22$	$4.9^{a} \pm 0.1$	$4.8^{a} \pm 0.08$	$4.8^{a} \pm 0.08$	$5.0^{a} \pm 0.06$
Stay-green characteristics	$3.8^{a} \pm 0.15$	$3.6^{a} \pm 0.08$	$3.5^{a} \pm 0.06$	$3.7^{a} \pm 0.06$	$3.5^{a} \pm 0.04$
Ears per plant	$1.0^{a} \pm 0.02$	$0.94^{ab} \pm 0.01$	$0.92^{b} \pm 0.01$	$0.95^{ab} \pm 0.01$	$0.94^{ab} \pm 0.01$
Ear aspect	$4.3^{b} \pm 0.14$	$4.8^{a} \pm 0.07$	$4.8^{a} \pm 0.06$	$4.6^{a} \pm 0.05$	$4.8^{a} \pm 0.04$

Means with the same letter are not significantly different (Duncan multiple range test)

The negative sign indicated that the hybrids had higher yield under the particular stress than optimum condition thus, there was reduction in yield under optimum condition. The absence of the negative sign indicates that the hybrids had higher yield under optimum environments than when evaluated under the stress. This is important for the identification of *Striga* resistant genotypes without compromising yield performance under *Striga*-free environments. Among the best 20 hybrids under *Striga* infestation, yield reduction relative to their performance under optimum environments ranged from -11% to 36.7% and from 60.2% to 84.4% in the worst 10 susceptible hybrids. Under low N, grain yield reduction among the tolerant hybrids ranged from -5.4% to 47% while it ranged from -15.5% to 54.2% among susceptible hybrids. Yield reduction among the best 20 hybrids ranged from -5.4% to 29.5% and from -15.5% to 54.2% among the worst 10 hybrid. Overall, low N reduced grain yield by 27.3% while *Striga* infestation reduced grain yield by 43.7%. Out of the 156 hybrids evaluated, 74 hybrids had positive base indices

Table 5. 14 Mean grain yield and other agronomic traits of the best 20 and worst 10 hybrids evaluated under optimum environments at Ile-Ife and Mokwa in 2011 and 2012

HYBRID	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	Root lodging (%)	Stalk lodging (%)	Husk cover (1-5)	Ears per plant	Ear aspect (1-9)	Ear rot (%)
ENT 12 x TZEI 89	6426	56.43	56.07	0.57	4.11	0	11.77	2.08	1.00	2.88	4.27
TZEI 32 x ENT 12	6386	54.61	54.10	0.86	3.76	0.56	2.89	2.38	0.95	3.49	3.79
ENT 11 x TZEI 4	6082	55.08	54.91	0.11	3.39	0.76	7.33	1.80	0.98	3.60	1.33
TZEI 5 x TZEI 98 (Check)	6023	54.02	53.67	0.58	3.31	2.63	6.59	1.56	1.00	3.90	3.07
TZEI 32 x TZEI 22	5949	54.86	53.71	1.06	3.90	2.00	4.87	2.16	0.95	4.26	6.25
TZEI 175 x TZEI 142	5946	56.22	54.61	1.59	2.82	2.13	2.70	1.49	0.91	3.86	4.31
TZEI 32 x TZEI 168	5941	53.11	52.25	0.80	4.01	0.31	3.65	2.21	1.03	3.77	0.60
TZEI 33 x ENT 12	5908	55.09	54.84	0.30	3.89	0	16.07	1.79	0.98	4.33	3.50
TZEI 4 x ENT 16	5760	54.15	52.77	1.34	3.22	1.69	4.26	1.83	0.98	3.20	5.95
TZEI 142 x TZEI 173	5698	56.05	55.05	1.49	3.19	0	4.77	1.56	0.98	3.42	2.94
TZEI 4 x TZEI 89	5682	53.49	52.18	1.54	3.99	0	2.77	1.91	1.00	4.03	4.11
ENT 16 x ENT 11	5621	55.44	54.65	0.78	3.51	2.46	5.36	1.86	0.97	4.34	0
TZEI 184 x TZEI 173	5620	53.72	52.63	1.10	3.09	1.86	4.09	1.47	0.99	3.75	7.00
TZEI 142 x TZEI 146	5588	53.62	53.21	0.42	3.27	0	0	1.70	0.97	2.99	2.34
TZEI 17 x TZEI 9	5548	53.60	52.83	0.80	3.56	0.65	14.43	2.19	1.00	3.29	4.95
ENT 16 x TZEI 108	5546	52.67	51.98	0.56	2.92	0.12	7.30	1.45	0.97	4.00	3.17
ENT 3 x ENT 12	5545	55.87	55.09	0.96	3.42	2.68	18.28	1.86	0.96	4.03	1.76
ENT 11 x TZEI 168	5523	53.29	53.31	0.49	3.37	0.54	6.08	1.92	0.95	3.37	1.30
ENT 12 x TZEI 39	5509	53.42	53.07	0.28	3.67	0.91	8.68	1.76	0.96	4.00	7.16
TZEI 168 x ENT 16	5499	53.03	52.36	0.69	3.31	0	3.27	1.62	1.00	3.72	3.94
TZEI 10 x TZEI 24	3076	54.66	53.63	1.15	5.33	0.97	4.72	2.28	0.95	5.04	7.75
TZEI 9 x TZEI 177	3050	52.31	51.83	0.82	4.87	12.81	27.24	2.25	0.96	4.87	9.17
TZEI 56 x TZEI 54	2998	55.29	53.81	1.56	5.55	0.29	3.33	2.34	1.00	5.56	11.26
TZEI 24 x TZEI 177	2862	51.67	51.30	0.61	5.53	1.67	14.63	2.38	0.95	5.19	6.78
TZEI 9 x TZEI 23	2812	52.08	51.44	0.60	5.01	5.86	31.31	2.31	0.92	5.20	10.40
TZEI 173 x TZEI 175	2736	59.58	55.88	3.69	6.13	0	0.77	2.31	0.89	5.59	11.85
TZEI 184 x TZEI 10	2511	56.39	54.64	1.81	6.15	0	7.14	2.27	0.96	5.71	14.87
TZEI 24 x TZEI 184	2134	56.60	54.34	2.18	6.09	1.19	10.39	2.08	0.81	6.22	17.89
TZEI 149 x TZEI 23	2134	52.79	52.09	0.62	6.15	0	19.42	2.40	0.90	5.95	10.18
TZEI 149 x TZEI 157	1915	53.20	53.05	0.73	6.25	7.66	22.24	2.33	0.96	5.46	9.04
Mean	4640	54.01	53.11	0.99	4.19	1.35	9.03	1.99	0.97	4.36	5.28
Min	1915	51.44	51.15	0.11	2.82	0	0	1.45	0.81	2.88	0
Max	6426	59.58	56.54	3.69	6.25	12.81	38.33	2.53	1.03	6.22	17.89
Lsd	719	1.28	1.16	0.82	0.74	3.03	9.66	0.35	0.06	0.73	5.25
SE	517	0.92	0.84	0.59	0.54	4.22	6.96	0.25	0.04	0.52	3.78

Table 5. 15 Performance of the best 20 and worst 10 early maturing maize hybrids across all environments

HYBRID	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Root lodging (%)	Stalk Lodging (%)	Ears per plants	Ear aspect (1-9)
ENT 11 x TZEI 4	4806	55.81	55.43	0.53	3.44	5.29	0.93	3.96
TZEI 32 x ENT 12	4651	56.21	55.03	1.26	2.12	4.79	0.96	4.24
ENT 11 x ENT 12	4570	56.93	56.06	1.01	5.75	11.62	0.93	3.96
ENT 16 x ENT 11	4568	56.32	55.21	1.11	5.73	6.61	0.95	4.11
TZEI 65 x ENT 11	4514	55.34	54.83	0.83	4.55	7.87	0.95	4.19
TZEI 146 x TZEI 175	4498	55.52	54.39	1.15	1.66	3.84	0.93	4.09
ENT 16 x TZEI 32	4497	56.71	54.96	1.74	0.88	3.94	0.92	4.15
TZEI 175 x TZEI 184	4411	55.59	53.90	1.64	1.43	3.01	0.91	4.40
ENT 11 x TZEI 22	4378	57.28	56.87	0.65	3.04	12.66	0.95	4.00
Check 2 TZEI 5 x TZEI 98	4352	56.50	54.93	1.63	3.55	7.62	0.89	4.46
TZEI 33 x ENT 12	4338	55.86	54.81	1.09	0.65	11.15	0.89	4.53
TZEI 184 x TZEI 173	4334	55.25	53.82	1.61	1.55	4.95	0.95	4.19
ENT 11 x TZEI 168	4332	54.15	53.38	0.97	2.98	8.91	0.94	4.17
TZEI 142 x TZEI 146	4323	55.20	54.06	1.16	1.16	4.55	0.93	3.85
ENT 12 x TZEI 89	4309	57.12	56.25	0.96	3.43	9.79	0.91	4.08
ENT 11 x TZEI 56	4295	55.85	54.92	1.05	4.48	13.41	0.92	4.08
TZEI 32 x TZEI 168	4264	54.35	52.83	1.57	1.77	7.26	0.87	4.63
TZEI 89 x ENT 11	4257	56.34	55.45	1.05	6.11	10.77	0.90	4.48
TZEI 32 x TZEI 22	4242	56.40	54.35	1.97	0.85	7.48	0.86	4.90
TZEI 54 x ENT 11	4238	55.99	54.90	1.09	2.34	9.19	0.93	4.41
TZEI 10 x TZEI 24	2765	55.39	54.06	1.48	0.21	7.01	0.93	5.36
TZEI 65 x TZEI 108	2729	53.43	52.60	0.91	1.91	13.49	0.88	5.17
TZEI 54 x TZEI 33	2644	55.36	52.83	2.57	1.95	16.69	0.82	5.55
TZEI 177 x TZEI 135	2507	53.12	52.04	1.20	4.52	14.55	0.84	5.41
TZEI 56 x TZEI 54	2341	56.16	54.29	1.85	2.47	3.61	0.86	5.68
TZEI 149 x TZEI 23	2225	52.76	52.15	0.81	3.22	15.68	0.92	5.62
TZEI 184 x TZEI 10	2129	57.18	55.31	1.83	1.95	6.51	0.86	5.79
TZEI 173 x TZEI 175	2080	60.84	56.91	3.96	0.00	3.11	0.84	5.86
TZEI 24 x TZEI 184	1860	57.22	55.17	2.01	0.83	9.13	0.93	6.17
TZEI 149 x TZEI 157	1786	54.23	53.60	1.02	5.34	21.11	0.81	5.70
Mean	3543	55.21	53.79	1.51	2.69	10.76	0.89	4.78
Min	1786	51.80	51.41	0.48	0.00	2.85	0.80	3.83
Max	4806	60.84	56.91	3.96	10.43	39.30	0.99	6.17
Lsd	484	0.97	0.65	0.76	4.00	5.80	0.07	0.42
SE	605	1.20	0.81	0.95	4.95	7.24	0.08	0.50

under *Striga*-infested environments while 88 had positive base indices under low N environments. Out of the 74 *Striga* resistant/tolerant hybrids, 31 hybrids (41.9%) were also tolerant to low N.

5.3.5 Relationship between performance of parental inbred lines and their hybrids

The mid and high parent heterosis values for grain yield were higher under low N than under *Striga*-infested environment. The mid-parent heterosis for grain yield ranged from -10 to 355% in the *Striga* environment with an average of 151% (Table 5.16).TZEI 168 x TZEI 54 (grain yield of 775 kg ha^{-1}) had the least mid-parent heterosis value for grain yield while TZEI 142 x TZEI 146 (grain yield of 3710 kg ha^{-1}) had the largest mid-parent heterosis value but was not among the best 20 hybrids under *Striga*-infested environments. The high parent heterosis value for grain yield under *Striga*-infested environment ranged from -34 for TZEI 168 x TZEI 54 to 262% for TZEI 17 x TZEI 9 with an average of 119% (Table 5.16). TZEI 17 x TZEI 9 (yielded 3.0 ton/ha) had the largest high parent heterosis value but was not among the best 20 hybrids. Under low N, TZEI 24 x TZEI 142 had the highest mid and high parent heterosis values for grain yield but was not the best yielder (TZEI 24 x TZEI 142 yielded 4 ton/ha while ENT16 x TZEI 32 yielded 5.5 ton/ha) while TZEI 173 x TZEI 175 had the least mid and high parent heterosis values. Mid-parent heterosis ranged from -18 to 851% with an average of 220% while the high parent heterosis ranged from -33 to 636% with a mean of 169%. Negative mid-parent heterosis values were recorded for days to silking across *Striga* and low N environments while positive values were observed for ears per plant. Positive mid and high parent heterosis values were observed for *Striga* damage ratings and *Striga* emergence count. The mid-parent heterosis value for grain yield was positively correlated with grain yield of hybrids under *Striga*, low N and across stress environments (Table 5.16). Grain yield of inbred lines was positively correlated

Table 5. 16 Estimates of heterosis for grain yield and other traits and correlation between performance of parental inbreds and hybrids, under *Striga* -infested and low N environments.

Traits	Mid-parent heterosis			High parent heterosis			Correlation coefficient (r)	
	Striga infestation	Low N	Across Stress	*Striga* infestation	Low N	Across Stress	*Striga* infestation	Low N
Grain yield kg/ha	151	156	160	119	112	130	0.35**	0.07
Days to silking	-5	-7	-6	-3	-6	-3	-0.26**	0.07
Anthesis-silking interval	-12	10	-13	9	152	10	-0.33**	0.07
Striga damage rating at 8 WAP	2	-	-	23	-	-	-0.39**	-
Striga damage rating at 10 WAP	2	-	-	14	-	-	-0.38**	-
Striga emergence count at 8 WAP	73	-	-	161	-	-	0.06	-
Striga emergence count at 10 WAP	75	-	-	156	-	-	0.11	-
Plant aspect	-	9	-	-	20	-	-	0.04
Stay-green characteristics	-	-5	-	-	2	-	-	0.06
Ears per plant	13	14	12	2	8	5	0.34**	0.07
Ear aspect	9	0	4	19	9	11	-0.30**	0.05

with grain yield and ears per plant of hybrids and negatively correlated with days to silking, anthesis-silking interval, *Striga* damage ratings and ear aspect of hybrids under *Striga*-infested environments. Grain yield of inbred lines was not significantly correlated with grain yield of hybrids and other traits under low N (Table 5.16).

5.3.6 Interrelationship among traits

Under *Striga* infestation, a significant and negative correlation was observed between grain yield of hybrids and *Striga* damage ratings at 8 WAP (r = -0.72) and 10 WAP (r = -0.71). as well as the number of emerged *Striga* plants at 8 WAP (r = -0.46) and 10 WAP (r = -0.45). In contrast, the correlation between grain yield and ears per plant was significant and positive (r = 0.64) (Table 5.17a). Anthesis-silking interval, plant aspect, stay-green characteristic and ear aspect were significant and negatively correlated with grain yield of hybrids under low N. On the other hand, grain yield of hybrids was positively correlated with ears per plant. Also, significant correlation existed among most of the traits under low N (Table 5.17b).

5.3.7 Stability analysis of the hybrids

The GGE biplot analysis for grain yield of the best 19 and worst five hybrids and three checks across 12 environments revealed that the principal component axis 1 (PC1) explained 53.2% of total variation and PC2 16.5% of the total variation in grain yield across the environments with both PC1 and PC2 explaining 69.7% of the total variation in grain yield. In Fig. 5.4, there are eight vectors with hybrids 10, 14, 18, 26, 25, 3, 9 and 7 as the vertex cultivars. The vertex cultivar in each sector of the polygon view represents the highest yielding cultivar in the location that falls within that particular sector (Fig. 5.4).

Table 5. 17a Correlation coefficients of traits used as indices for *Striga* resistance in early maturing maize hybrids

Traits	SDR1	SDR2	SEC1	SEC2	EPP
GY	-0.72**	-0.71**	-0.46**	-0.45**	0.64**
SDR1		0.80**	0.33**	0.28**	-0.68**
SDR2			0.33**	0.27**	-0.64**
SEC1				0.91**	-0.33**
SEC2					-0.30**

** indicates significant differences at P < 0.01
GY= grain yield, SDR1 = *Striga* damage rating at 8 WAP, SDR2 = *Striga* damage rating at 10 WAP, SEC1 = *Striga* emergence count at 8 WAP, SEC2 = *Striga* emergence count at 10 WAP and EPP = ears per plant

Table 5. 17b Correlation coefficients of traits used as indices for low N tolerance in early maturing maize hybrids

Traits	ASI	Plant aspect	Stay-green	Ears per plant	Ear aspect
Grain yield	-0.35**	-0.64**	-0.29**	0.38**	-0.78**
ASI		0.22**	0.16**	-0.29**	0.32**
Plant aspect			0.12**	-0.16**	0.62**
Stay-green				-0.19**	0.22**

** indicates significant differences at P < 0.01
ASI = Anthesis-silking interval

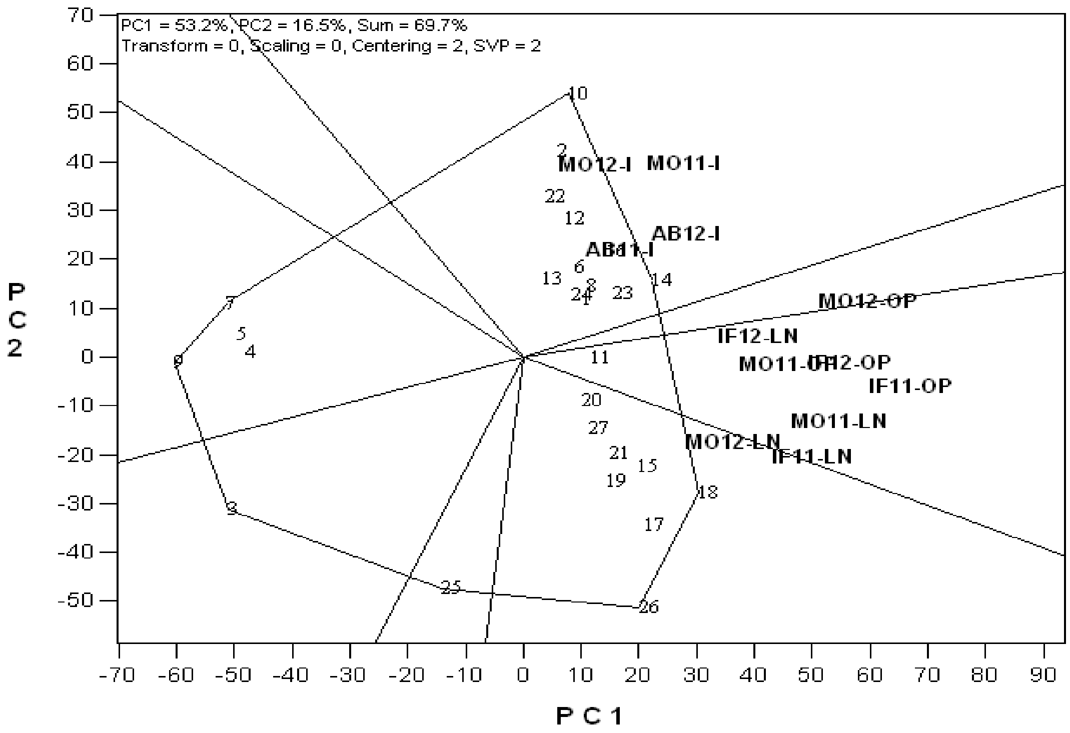

Figure 5. 4. A 'which won where' GGE biplot of grain yield of 27 early maturing maize hybrids evaluated across *Striga*-infested, low N and optimum environments in 2011 and 2012.

Code	Hybrid	code	Hybrid	Code	Environment
1	TZEI 142 X TZEI 146	15	ENT 12 X TZEI 89	AB11-I	Abuja *Striga*-infested 2011
2	TZEI 146 X TZEI 175	16	ENT 16 X ENT 11	AB12-I	Abuja *Striga*-infested 2012
3	TZEI 149 X TZEI 157	17	ENT 16 X TZEI 32	MO11-I	Mokwa *Striga*-infested 2011
4	TZEI 149 X TZEI 23	18	TZEI 32 X ENT 12	MO12-I	Mokwa *Striga*-infested 2012
5	TZEI 173 X TZEI 175	19	TZEI 32 X TZEI 168	MO11-OP	Mokwa optimum 2011
6	TZEI 175 X TZEI 184	20	TZEI 32 X TZEI 22	MO12-OP	Mokwa optimum 2012
7	TZEI 184 X TZEI 10	21	TZEI 33 X ENT 12	MO11-LN	Mokwa low N 2011
8	TZEI 184 X TZEI 173	22	TZEI 54 X ENT 11	MO12-LN	Mokwa low N 2012
9	TZEI 24 X TZEI 184	23	TZEI 65 X ENT 11	IF11-LN	Ile-Ife low N 2011
10	ENT 11 X ENT 12	24	TZEI 89 X ENT 11	IF12-LN	Ile-Ife low N 2012
11	ENT 11 X TZEI 168	25	Check 1- TZEI 26 x TZEI 5	IF11-OP	Ile-Ife optimum 2011
12	ENT 11 X TZEI 22	26	Check 2 - TZEI 5 X TZEI 98	IF12-OP	Ile-Ife optimum 2012
13	ENT 11 X TZEI 56	27	Check 6 - TZEI 1 X TZEI 5		
14	ENT 11X TZEI 4				

Environments MO12-I, MO11-I, AB11-I and AB12-I (*Striga*-infested environment) were in the sector where hybrid ENT 11 x ENT 12 and ENT 11 x TZEI 4 (designated 10 and 14) were the vertex cultivars. Therefore, ENT 11 x ENT 12 and ENT 11 x TZEI 4 were the highest yielding hybrids over all *Striga*-infested environment while TZEI 32 x ENT 12 (18) and a check TZEI 5 x TZEI 98 (26) were the highest yielding in MO12-LN (Fig. 5.4). The entries 25, 3, 9 and 7 were the vertex cultivar in some sectors, but did not fall into any environment and thus are the lowest in most or all the test environments. There was no vertex cultivar where IFE11-LN, IFE12-LN, MO11-LN, IFE11-OP, IFE12-OP, MO11-OP were the test environments. In the GGE biplot displays the double-arrow line (ATC ordinate) separates entries with below average means from those with above average means (Fig. 5.5). The average yield of a genotype is approximated by the projections of their markers on the average-tester axis while, stability of the genotypes is measured by their projection onto the average-tester coordinate y axis single-arrow line (ATC abscissa). The greater the absolute length of the projection of a genotype, the less stable it is. The entry/tester GGE biplot revealed ENT 11 x TZEI 4 (14), TZEI 32 x ENT 12 (18), ENT 11 x ENT 12 (10), ENT 16 x ENT 11 (16) and TZEI 65 x ENT 11 (23) as the highest yielding while, TZEI 149 x TZEI 157 (3) and TZEI 24 x TZEI 184 (9) are the lowest-yielding hybrids (Fig. 5.5). The hybrids TZEI 32 x ENT 12 (18) and ENT 11 x ENT 12 (10) were high yielding but highly unstable while, ENT 11 x TZEI 4 (14) was the most stable hybrid across the test environments followed by TZEI 65 x ENT 11 (not among the best 20 under optimum environments but did not significantly differ from the best check) and ENT 16 x ENT 11 (not among the best 20 under *Striga*-infested environments but did not significantly differ from the best *Striga* susceptible check). TZEI 32 x ENT 12 was not among the best 20 under *Striga*-infestation while ENT 11 x ENT 12 was not among the best 20 under both low N and optimum environments.

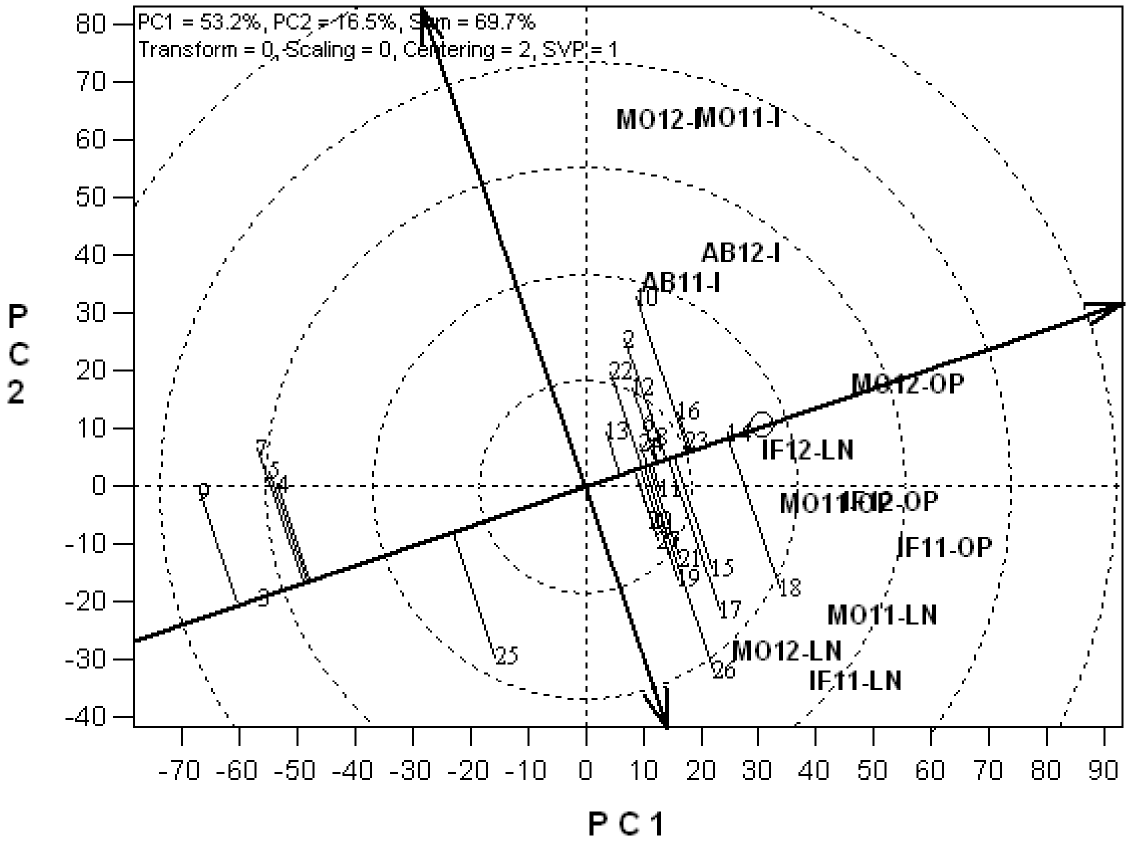

Figure 5. 5. An entry/tester genotype main effect plus genotype x environment biplot of grain yield of 27 selected early maturing hybrid maize across *Striga*-infested low N and optimum environments in 2011 and 2012.

The check, TZEI 5 x TZEI 98(26), was high yielding across environments but was not among the best 20 nor was it the best check under *Striga*-infested environments. ENT 11 x TZEI 4 and TZEI 65 x ENT 11 were highly consistent across the test environments. These hybrids produced grain yield greater than the mean grain yield.

The representativeness and discriminating ability of the environments is represented in Fig. 5.6. The straight line from the origin to the coordinates where an environment falls is called the research environment vector while the straight line with a single arrow which passes through the origin and the average environment represents the average environment axis (AEA). The vector length measures its discriminating power to assess cultivars under the test environments that is, the longer the vector length the more discriminating the environment. The angle between an environment and AEA measures its representativeness, therefore, the shorter the projection is from the marker of an environment, the more representative the environment. According to Yan *et al.* (2010b), the shorter environmental vectors indicate that the specific environments were not strongly correlated with environments having longer vectors and were probably not strongly correlated with one another. On this basis, IF11-OP, MO12-OP and MO11-I with longer vectors were more powerful in discriminating among the hybrids while MO12-OP and IF12-LN with small angles were the most representative of the test environments. MO12-OP with long vector and smaller angle was most powerful in discriminating among hybrids and was as well the most representative of all environments (Fig. 5.6).

The GGE biplots in Figs. 5.4, 5.5 and 5.6 clearly separated the *Striga*-infested environments (MO12-I, MO11-I, AB11-I and AB12-I) from the low N and optimum environments (IFE11-LN, IFE12-LN, MO11-LN, MO12-LN, IFE11-OP, IFE12-OP, MO11-OP and MO12-OP) suggesting the use of a separate biplot for low N and optimum environments. Due to the absence of significant genotype x environment interaction under low N, it was not necessary to separate the low N environments from optimum hence the combined biplot (Figs. 5.7 and 5.8). The PC1 and PC2 of the biplots in Figs. 5.7 and 5.8 explained 79.7% of the total variation in grain yield across low N and optimum environments. The polygon view in Fig. 5.7 revealed TZEI 33 x ENT 12 and TZEI 5 x TZEI 98 as the vertex cultivar for MO12-LN and MO12-OP; TZEI 32 x ENT 12 for IF11-OP, IF12-OP, MO11-OP, MO11-LN, IF11-LN, IF11-LN; while TZEI 1 X TZEI 5 was the vertex cultivar at IF12-LN. The GGE biplot in Fig. 5.8

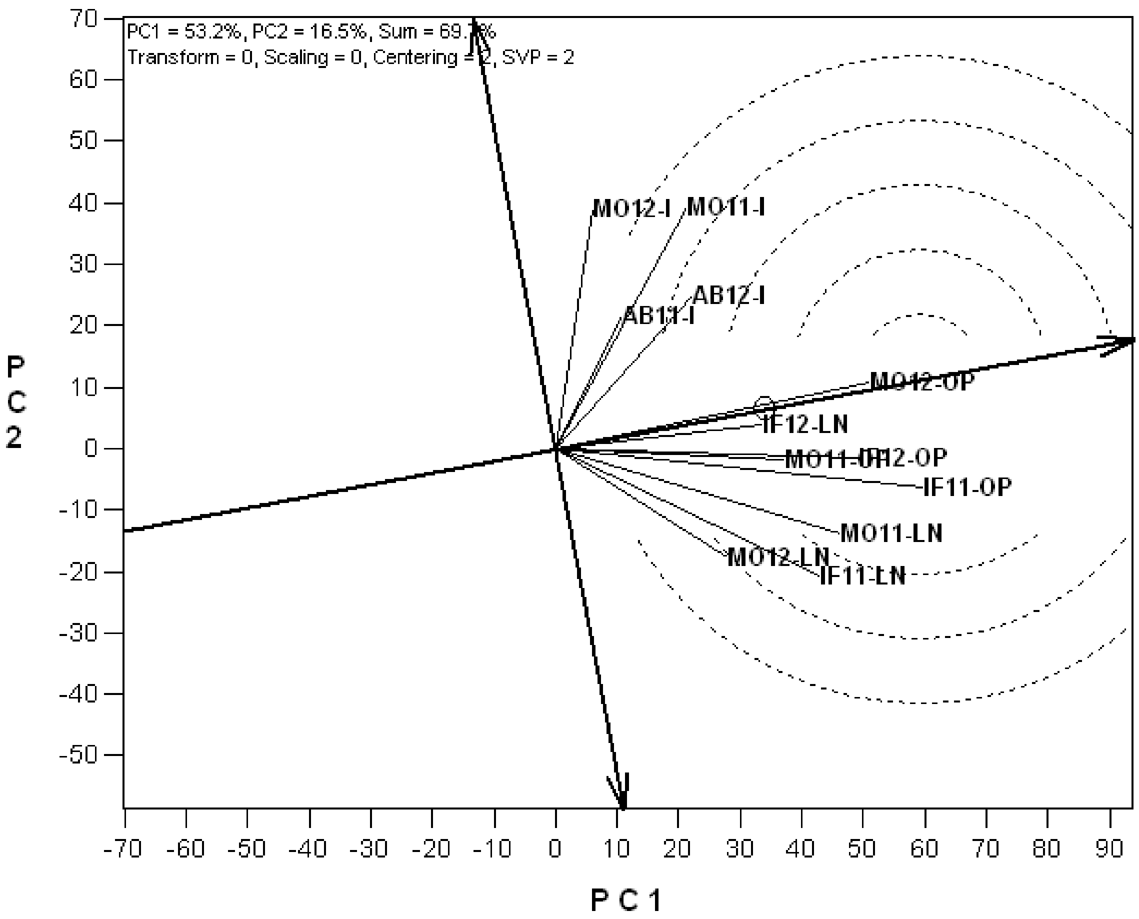

Figure 5. 6. A vector view of genotype plus genotype x environment biplot showing the relationship among 12 stress and nonstress test environments used for the evaluation of North Carolina design II crosses involving 30 inbred parents in Nigeria.

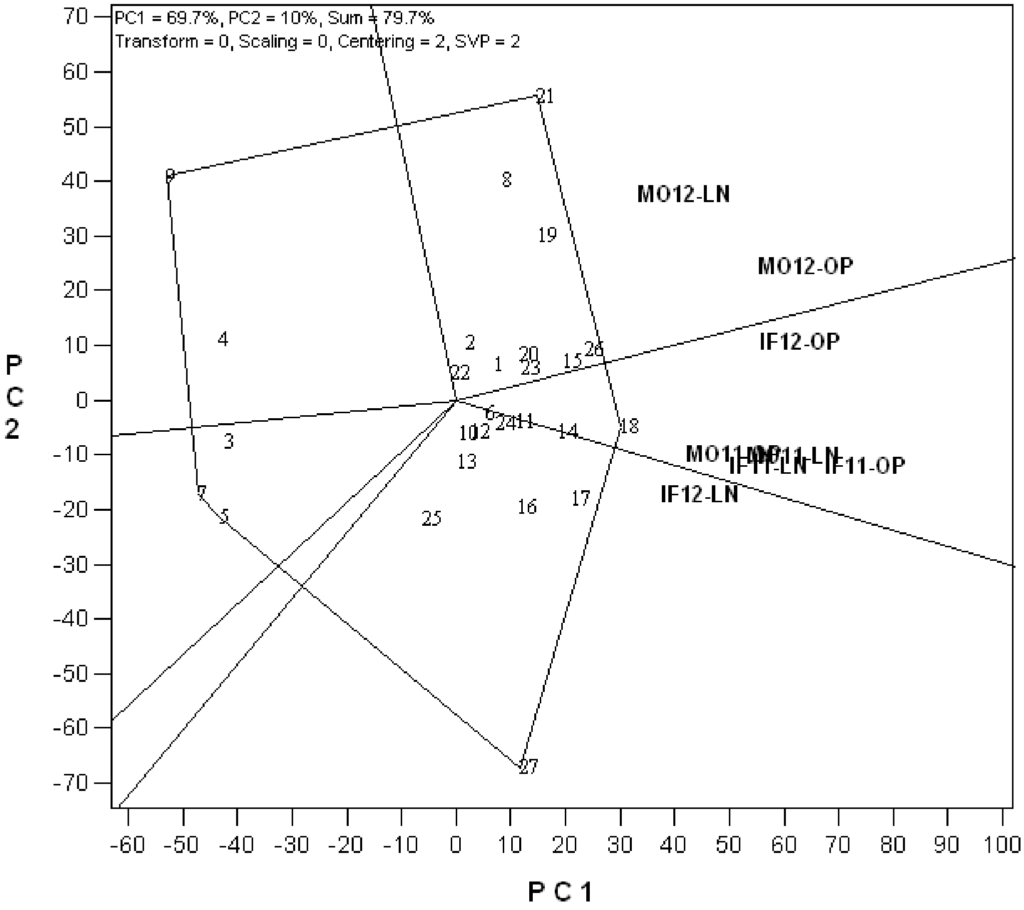

Figure 5. 7. A ‘which won where’ GGE biplot of grain yield of 27 early maturing maize hybrids evaluated across low N and optimum environments in Ile-Ife and Mokwa in 2011 and 2012.

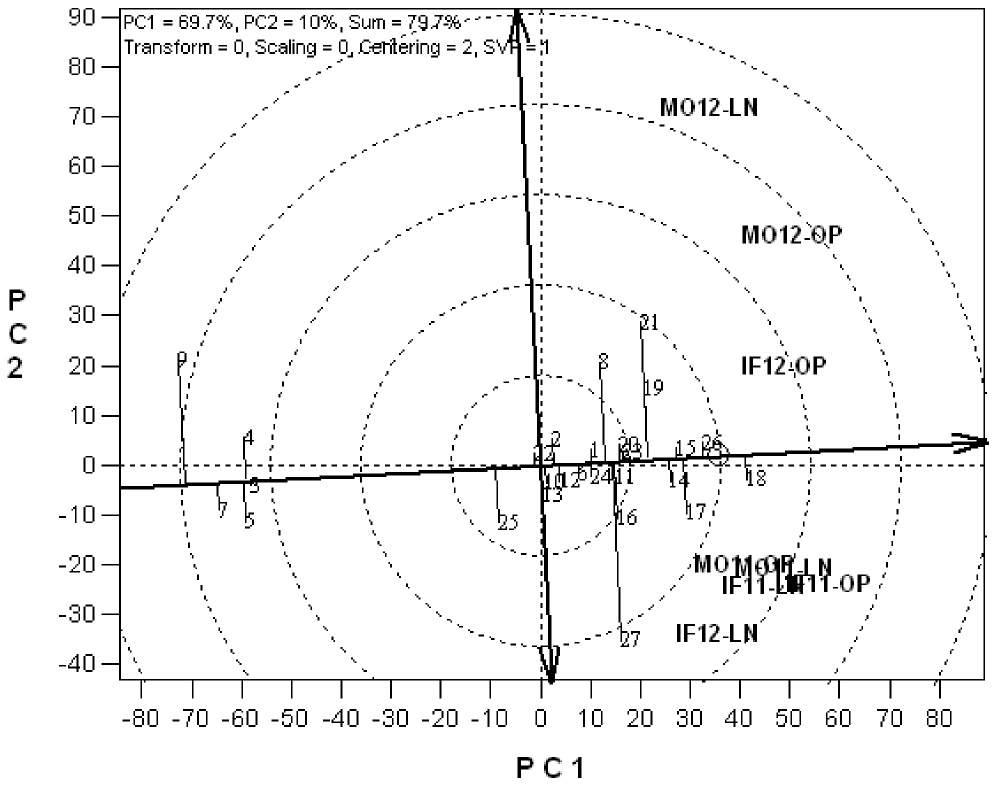

Figure 5. 8. An entry/tester genotype main effect plus genotype x environment biplot of grain yield of 27 selected early maturing hybrid maize across low N and optimum environments in 2011 and 2012.

revealed TZEI 32 X ENT 12 (18) as the highest yielding followed by TZEI 5 x TZEI 98 (26), ENT 16 x TZEI 32 (17), ENT 12 x TZEI 89 (15) and then ENT 11 x TZEI 4 (14) across low N and optimum environments. The most stable hybrids across low N and optimum environments were ENT 11 x TZEI 4 (14) and ENT 12 x TZEI 89 (15) followed by TZEI 5 x TZEI 98 (26) then TZEI 32 x ENT 12 (18).

5.4 Discussion

The significant genotype variation observed for all traits under *Striga* infestation, low N and optimum environments indicate that large genetic variation exists among the hybrids which should allow good progress from selection under the three contrasting environments. The significant environmental variation for all traits under *Striga* infestation, low N and optimum environments indicates that each environment was unique and highly variable emphasizing the need for testing in more than one environment over several years for each of the contrasting environments. This is in agreement with findings of Badu-Apraku *et al.* (2007a). The significant genotype x environment interactions for grain yield, *Striga* damage ratings and emerged *Striga* plants under *Striga* infestation is an indication that the hybrids responded differently to *Striga* infestation at the different sites suggesting that the strains of *S. hermonthic*a at the different sites were different. Similar findings have been reported by several authors in West and Central Africa (Yallou *et al.*, 2009; Menkir *et al.*, 2010; Badu-Apraku and Lum, 2010; Badu-Apraku *et al.*, 2010). The genotype x environment interactions for grain yield and ear aspect under low N environment was not significant; an indication that the expression of the hybrids in the different low N environments for the mentioned traits was not influenced by the environment. This is contrary to the findings of Makumbi *et al.* (2011) who reported significant genotype x environment interactions for grain yield and Badu-Apraku *et al.* (2013b) who reported significant genotype x environment interactions for grain yield and most traits under low N stress. The environment and genotype x environment interaction effects across research environments (*Striga*-infested, low N and optimum environments) were significant for grain yield, days to silking, days to anthesis, anthesis-silking interval, root lodging, stalk lodging, ears per plant and ear aspect indicating that the individual environments were unique and that hybrid selection would not be consistent across the environments.

The significant GCA_m, GCA_f and SCA for grain yield and other traits under *Striga* infestation indicates that there were differences in the performance of the inbred lines as parents in hybrid combinations. This also suggests that additive and non-additive gene actions were important for the inheritance of grain yield and other traits across *Striga* infestation. Similar findings were reported by Kim (1994), Akanvou *et al.* (1997), Gethi and Smith (2004) and Badu-Apraku (2007), who reported significant GCA and SCA effects for grain yield, *Striga* damage ratings and the number of emerged *Striga* plants. The larger proportion of the GCA sum of squares over SCA for grain yield and most traits under *Striga* infestation indicates the importance of additive genetic effects over non-additive effects. This agrees with the results of Badu-Apraku *et al.* (2013b). The larger proportion of GCA sum of squares over SCA for *Striga* damage and number of emerged *Striga* plants both at 8 and 10 WAP indicates that additive gene action played a major role in the inheritance of the *Striga* damage and *Striga* emergence under *Striga* infestation. This result is contrary to the reports of Kim (1994), Akanvou *et al.* (1997) and Badu-Apraku (2007). Kim (1994) reported additive gene action to be more important in the inheritance of *Striga* damage while non-additive was more important for *Striga* emergence. Similarly, Akanvou *et al.* (1997) and Badu-Apraku, (2007) reported that non-additive gene action was more important for *Striga* emergence. The result of this study is consistent with that of Yallou *et al.* (2009) and Badu-Apraku *et al.* (2011a), who reported additive gene action to be more important than non-additive gene action for all traits under artificial *Striga* infestation. Gethi and Smith (2004) have also reported that additive gene action was more important than non-additive in the inheritance of *Striga* emergence. The differences in the results of this study and those of some earlier workers may be attributed to the differences in the germplasm used. It is likely that the inbred lines used in the present study possess some genes with different modes of action for *Striga* resistance.

The significant GCA_m, GCA_f and SCA for grain yield and other traits under low N, except SCA for stay-green characteristic, is an indication that there were differences in the performance of the inbred lines as parents in hybrid combinations. This suggests that additive and non-additive gene actions were important in the inheritance of grain yield and other traits under low N, except stay-green characteristic. Similar findings were reported by Meseka *et al.* (2006), who showed significant GCA_m, GCA_f and SCA for grain yield and other traits including significant SCA for stay-green characteristic. The non-significant SCA mean squares for stay-green characteristic in the present study indicates that non-additive gene effects were not important in the inheritance of stay-green characteristic in the inbred lines used in this study. However, the differences reported in both studies suggest there are conflicting results on the inheritance of stay-green characteristics thus indicating the importance of both additive and non-additive gene action in the control of stay-green characteristic. The results of this study are in agreement with those of Badu-Apraku *et al.* (2013b), who reported non-significant SCA effects for stay-green characteristics under low N. The GCA_m and GCA_f mean squares for grain yield were two times larger than those of SCA under low N further confirming the importance of additive gene action over non-additive effects in the inheritance of grain yield in this set of inbred lines. This observation is in agreement with the results of several studies (Rizzi *et al.*, 1993; Below *et al.*, 1997; Kling *et al.*, 1997) that reported that additive gene action was more important in the inheritance of grain yield under low N. On the contrary, Katsantonis *et al.* (1988), Betrán *et al.* (2003b), Meseka *et al.* (2006) and Makumbi *et al.* (2011) reported that non-additive gene action is more important in the inheritance of grain yield under low N. The differences in the results of this study and those of some earlier workers may be attributed to the differences in the germplasm used. It is likely that the inbred lines used in the present study possess some genes with different modes of action for low N tolerance. Comparison of the results of the combining ability analysis obtained under *Striga* infestation and low N revealed consistent trends in the gene action controlling the inheritance of resistance to *Striga* and tolerance to low N in the set of early maturing inbred lines studied. Additive genetic effects were more important than non-additive genetic effects for grain yield and most 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.*, 2011a) and extra-early (Badu-Apraku and Oyekunle, 2012) maturing maize inbred lines. The implication of having significant GCA_m, GCA_f and SCA variation is that appreciable breeding progress could be made using hybridization, backcrossing, and recurrent selection for the development of hybrids and synthetic varieties as well as in population improvement.

The significant GCA_m, GCA_f and SCA for grain yield and other traits under optimum environments, except GCA_m and GCA_f for ears per plant, indicates that both additive and non-additive gene action were important in the inheritance of grain yield and other traits under optimum environments. The significant SCA effects observed for ears per plant is an indication that non-additive gene action is important in the inheritance of ears per plant under optimum environments in this set of inbred lines. The GCA_m and GCA_f mean squares for grain yield were about two to three times larger than SCA mean squares under optimum environments, an indication that additive gene action was more important for the inheritance of grain yield under optimum environments. This is in agreement with the findings of Katsantonis *et al.* (1988), who reported that additive genetic effects control grain yield under high N. On the contrary, Rizzi *et al.* (1993); Below *et al.* (1997) and Kling *et al.* (1997) reported that non-additive genetic effects control yield under high N environments. The predominance of GCA over SCA variance suggests that most traits could be improved through selection.

The significant GCA$_m$ x environment and GCA$_f$ x environment interactions for most traits under *Striga* infestation, indicates that the performance of crosses between parental lines was not stable across the *Striga* environments. This suggests that the selection of *Striga* resistant/tolerant hybrids would be more effective if based on performance across a range of *Striga* environments. The nonsignificant GCA$_m$ x environment interaction for grain yield indicates that the GCA effects associated with the male parents were consistent over the different low N environments. The nonsignificant SCA x environment interaction effects for grain yield, *Striga* damage, *Striga* emergence and ear aspect indicates that the response of the hybrids in terms of the mentioned traits did not vary in the *Striga* infested environments. This result is similar to that of Badu-Apraku *et al.* (2013b) except that SCA x environment interactions for ear aspect and *Striga* damage rating at 10 WAP were significant. Similarly, the non significant SCA x environment interactions for grain yield, anthesis-silking interval, plant aspect, stay-green characteristics and ear aspect indicates that the expression of these traits in specific hybrids would not vary in the different low N environments. This result is consistent with the the findings of Meseka *et al.* (2006) who reported non-significant SCA x environment interactions for grain and most secondary traits under low N. On the contrary, Makumbi *et al.* (2011) reported significant SCA x environment interactions for grain yield under low N.

In addition to providing information on GCA and SCA effects, the North Carolina design II is useful for estimating maternal effects and it also has advantage over the diallel design when many parents are used (Hallauer and Miranda 1988). The small difference between GCA$_m$ and GCA$_f$ sum of squares for grain yield under *Striga* infestation, low N and optimum environments indicates that both male and female parents had similar contribution to grain yield. Under *Striga* infestation, the larger GCA_f sum of squares over GCA_m for days to silking suggests the role of maternal effects in the control of days to silking while the larger GCA_m sum of square over GCA_f sum of squares for ears per plant suggest the role of paternal effects in the control of ears per plant under *Striga*-infested environments. There were no cases of maternal or paternal effects on traits under low N and optimum environments. Derera *et al*. (2008) reported that maternal effects modified 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.

Inbred lines TZEI 173, TZEI 175, ENT 11 and TZEI 39 had superior positive GCA (GCA_m and GCA_f) effects for grain yield under *Striga* infestation indicating that the inbred lines contributed to higher grain yield of their hybrids under *Striga* infestation. TZEI 39 unlike the other inbred lines did not produce any hybrid among the best 20 but produced hybrids that were tolerant to *Striga*. Inbred lines ENT 13, TZEI 142, ENT 11, ENT 12, ENT 16 and TZEI 32 had superior positive GCA effects for grain yield under low N environments suggesting that the inbred lines contributed to higher grain yield of their hybrids under low N. However, ENT 13 unlike the other inbred lines did not produce any hybrid among the best 20, but produced hybrids that were low N tolerant while, TZEI 142 had only one hybrid among the best 20 yielders. ENT 13, TZEI 142 and ENT 12 had superior positive GCA effects for grain yield under optimum environments. These inbred lines are expected to contribute to higher grain yield of their hybrids under optimum environments. However, ENT 13 did not produce any hybrid among the best 20 yielders under optimum as well as low N environments. Across the research environments, ENT

11 was the only inbred line with superior GCA effects for grain yield and number of ears per plant. ENT 12 had consistent superior GCA effects for grain yield under low N, *Striga*-infested and optimum environments an indication that ENT 12 contributed to higher grain yield of its hybrids across the three contrasting environments. The inbred lines identified with superior GCA effects for grain yield may likely contribute favorable alleles in a recurrent selection program and such lines could be used as parents to form a synthetic population that would be improved for *Striga* resistance and low N tolerance while taking the heterotic orientations into consideration to avoid mixing up heterotic groups. Also, new inbred lines with improved level of *Striga* resistance and low N tolerance could be extracted from it.

A *Striga* resistant genotype will support significantly fewer *Striga* plants and produce higher yield than the susceptible genotype. Using the base index TZEI 175 x TZEI 177, was identified to have the highest level of *Striga* resistance followed by TZEI 173 x TZEI 24, TZEI 146 x TZEI 175. These hybrids supported fewer *Striga* plants and were high yielding and thus identified to be resistant to *Striga*. A variety is tolerant to *Striga* if it germinates and supports as many *Striga* plants as the susceptible genotype, produces more grain and stover, and shows fewer damage symptoms (Badu-Apraku *et al*., 2007a). The hybrids ENT 11 x ENT 12 and ENT 11 x TZEI 4 were high yielding and supported as much number of emerged *Striga* plants as the susceptible hybrid, had reduced *Striga* damage and also out-yielded the best check. Therefore, they were identified as *Striga* tolerant. The ten most promising hybrids identified using the base index were TZEI 175 × TZEI 177, TZEI 173 × TZEI 24, TZEI 146 × TZEI 175, ENT 11 × ENT 12, TZEI 10 × TZEI 175, TZEI 10 × TZEI 24, TZEI 184 × TZEI 173, TZEI 17 × TZEI 24, TZEI 175 × TZEI 23, and TZEI 23 × TZEI 173. The highest yielding hybrid ENT 11 x ENT 12 under *Striga* infestation is a cross between two inbred parents developed from CIMMYT maize breeding program. It is however, important to note that the CIMMYT lines were not intentionally developed for resistance to *Striga* but rather for tolerance to drought and low N. This suggests the presence of *Striga* resistance/tolerance alleles in the inbred lines. This is in agreement with the findings by Karaya *et al.* (2012a), who found *Striga* resistance in CIMMYT inbreds that were not intentionally selected for *Striga* resistance. Of the best ten hybrids identified as *Striga* resistant/tolerant using the base index under *Striga* infestation, eight involved resistant x resistant inbred lines and two resistant x susceptible. This is consistent with the findings of Kim (1991) and Badu-Apraku *et al.* (2011a), who reported that the highest level of tolerance based on *Striga* damage rating was achieved in crosses involving two resistant inbred parents. Similarly, Menkir *et al.* (2010) reported that the highest level of *Striga* resistance among hybrids was achieved in crosses involving two highly resistant inbred parents. Furthermore, the significantly higher grain yield, reduced *Striga* damage, fewer emerged *Striga* plants, higher ears per plant and better ear aspect of the hybrids with both resistant parents compared to those of resistant x susceptible and susceptible x susceptible indicates that resistance is higher when both parents are resistant. Among the worst ten hybrids, five involved crosses between two susceptible parents, four involved resistant x susceptible parents and one resistant x resistant parents. TZEI 54 x TZEI 33 is a hybrid composed of two resistant parents but was classified as susceptible using the base index. This may be due to the fact that both parents of the hybrid are sister lines and therefore could not exhibit heterosis when used in a cross although resistant to *Striga*. This is consistent with the result of Akaogu *et al.* (2012).

Striga infestation reduced grain yield by 44% relative to performance under optimum environments. The yield reduction due to *Striga* infestation reported in this study is quite similar to the findings of Badu-Apraku *et al.* (2004), who reported a yield reduction of 42%. However, it is lower than the 53.7% reported by Adetimirin *et al.* (2000) , 68% by Kim *et al.* (2002), and 65% by Badu-Apraku *et al.* (2010). It is however higher than the yield reduction of 23% reported by Badu-Apraku *et al.* (2011b). The yield loss of 44% suggests that the level of infestation in this study was high enough to allow the identification of hybrids that possess genes for *Striga* resistance/tolerance. However, the differences observed in this study may be due to the level of *Striga* resistance/tolerance in the set of inbred lines used in this study.

Nitrogen stress resulted in varying level of yield reduction among the hybrids. For some hybrids such as TZEI 149 x TZEI 157 and TZEI 149 x TZEI 23, yield under low N was higher than under optimum condition indicating that such hybrids do not make efficient use of nitrogen. However, in most of the hybrids, grain yield reduction as a result of low N stress was higher in the susceptible hybrids. The mean grain yield reduction of hybrids under low N stress was 27% of the optimum condition. This reduction in grain yield is lower than that reported by several authors (Betrán *et al.*, 2003b; Meseka *et al.*, 2006; Makumbi *et al.*, 2011; Badu-Apraku *et al.*, 2010). Meseka *et al.* (2006) observed 52% reduction in grain yield for hybrids under low N. Makumbi *et al.* (2011) reported that nitrogen stress reduced grain yield by 51% among hybrids. Differences in germplasm used in the different studies may account for the differences observed. It may also indicate that only moderate levels of N stress was achieved in the present study. The yield reduction of 27% under low N falls within the range reported by Bänziger *et al.* (1999), who found yield reduction of 20-50% among populations relative to high N environment.

Using the base index for selection under low N, ENT 16 x TZEI 32 was identified as the highest yielding hybrid across low N environments. Although grain yield of ENT 16 x TZEI 32 did not significantly differ from the best check, it out-yielded the best low N tolerant hybrid check TZEI 5 x TZEI 98 by 8%. The ten most promising hybrids identified under low N using the base index were ENT 16 × TZEI 32, TZEI 33 × ENT 12, ENT 11 × TZEI 22, ENT 11 × TZEI 4, ENT 12 × TZEI 39, TZEI 33 × TZEI 168, TZEI 32 × TZEI 168, TZEI 4 × ENT 16, TZEI 32 × TZEI 56 and TZEI 24 × TZEI 142. Six out of the ten best hybrids under low N had both IITA and CIMMYT inbreds as parents. This is in agreement with the report of Makumbi *et al.* (2011) that the use of germplasm between different breeding programs may result in in the identification of outstanding hybrids. The IITA inbred lines were developed from *Striga* resistant populations and have not been intentionally selected for low N tolerance. Therefore, the identification of low N tolerance in crosses involving IITA inbred lines such as TZEI 33 × TZEI 168, TZEI 32 × TZEI 168, TZEI 32 × TZEI 56 and TZEI 24 × TZEI 142 suggests that, in the process of selecting for *Striga* resistance, low N tolerance was indirectly selected for. This corroborates the findings of Badu-Apraku *et al.* (2009), who reported that recurrent selection for *Striga* resistance under artificial infestation resulted in selection gains in grain yield under low and high N environments.

Out of the 74 hybrids identified with positive base indices (*Striga* resistant/tolerant) under *Striga*-infested environments, 41.9% were also found to be tolerant to low N. This further confirms that selection for *Striga* resistance in the early maturing inbred lines used in this study indirectly resulted in some level of tolerance to low N. Furthermore, the presence of low N tolerance in some of the *Striga* resistant/tolerant hybrids may be accountable for the low yield reduction observed under low N.

The mid-parent and high parent heterosis values for grain yield were higher under low N than under *Striga*-infested environment. The average mid-parent heterosis for grain yield was 151% under *Striga* infestation and 220% under low N while the average high parent heterosis for grain yield was 119% under *Striga* infestation and 169% under low N. Negative mid and high parent heterotic values obtained for days to silking indicate that the hybrids matured earlier than their corresponding inbred parents under both low N and *Striga*-infested environments. Positive heterotic values obtained for grain yield and ears per plant suggest that the hybrids produced higher grain yield and more ears than the inbred parents. This is in agreement with the findings of Meseka *et al.* (2006), who reported negative heterotic value for days to silking and positive values for plant height and grain yield under low and high N. *Striga* damage and number of emerged *Striga* plants at 8 and 10 WAP were positive indicating that hybrids had higher *Striga* damage and allowed the emergence of more *Striga* plants than their corresponding parents.

The correlation between yields of parental lines and their hybrids under *Striga* infestation was low while the relationship between grain yield of inbred lines and their hybrids under low N was not significant thus indicating that the performance of a hybrid cannot be effectively predicted using the performance of the parental lines. The weak and non significant correlations observed under *Striga* and low N environments emphasize the need to evaluate hybrids under stresses which will identify superior hybrids under the stress environments. In cases such as this, selection for combining ability in the final analysis should be based on performance of the lines in crosses and not on the inbred lines (Hallauer and Miranda, 1988). The weak correlations observed under *Striga* is consistent with findings of Meseka *et al.* (2006) who reported weak correlations between grain yield of parental lines and their crosses under low N. This suggests that crosses between high yielding inbred lines under *Striga*-infested environments may not result in high yielding hybrids. The lack of significant correlation observed under low N in this study is in agreement with findings of Lafitte and Edmeades (1995) who reported no significant correlations between grain yield of S_2 line and that of topcross under low N.

The significant negative correlation between grain yield and *Striga* damage ratings at 8 and 10 WAP indicates that there is a strong negative relationship between grain yield and *Striga* damage at 8 and 10 WAP under *Striga* infestation. This is similar to reports of Amusan *et al.* (2008), Badu-Apraku *et al.* (2012b) and Karaya *et al.* (2012b). A moderately significant negative correlation was observed between grain yield and *Striga* emergence count at 8 and 10 WAP. This is contrary to the findings of Badu-Apraku *et al.* (2012b) and Karaya *et al.* (2012b) who reported that the relationship between grain yield and *Striga* emergence count was not significant. Also, grain yield of hybrids was positively correlated with the number of ears per plant. Overall, grain yield of hybrids was significantly correlated with all the traits used in computation of the base index for selection of *Striga* resistant varieties. The moderate to high correlation coefficients observed in this study between grain yield and *Striga* damage ratings, *Striga* emergence count and number of ears per plant justifies the use of these traits in the base index for identification of *Striga* resistance in maize. The correlation between *Striga* damage ratings and *Striga* emergence was low. This is in agreement with the findings of several studies (Kim, 1994; Akanvou *et al.*, 1997; Kim *et al*,. 2002; Badu-Apraku *et al.*, 2007b). These authors reported that the genetic correlation between *Striga* emergence and level of plant damage was low, suggesting that different genes control *S. hermonthica* emergence and level of host plant damage in maize. On the contrary, Badu-Apraku *et al.* (2012b) reported a strong genotypic correlation between *Striga* damage and number of emerged *Striga* plants. Under low N, grain yield was significantly correlated with anthesis-silking interval, plant aspect, stay-green characteristics, number of ears per plant and ear aspect. These traits have been identified to be among the best traits for selecting for improved yield under low N (Badu-Apraku *et al.*, 2011c). The significant correlation among the traits used in estimating the base index for selection of low N tolerant varieties confirms the effectiveness of the base index for identification of tolerance to low N.

The GGE biplot is a powerful statistical tool for identifying the best performing genotype in a given environment and the most suitable environment for each genotype, average yield and stability of the genotypes and the discriminating ability and representativeness of the environments (Yan *et al.*, 2000). The PC1 and PC2 of the GGE biplot analysis explained 69.7% and 79.7% of the total variation in grain yield across test environments and the combined low N and optimum environments. This indicates that both PC1 and PC2 of the biplot adequately approximated the environment-centered data. The biplot analysis separated the *Striga*-infested environment from low N and optimum environments indicating that the *Striga*-infested environments were different from the other environments. This is similar to the findings of Badu-Apraku *et al*. (2010) who reported the separation of well-watered, drought, low and high N conditions from the *Striga*-infested conditions. As described by Yan *et al.* (2007), an ideal genotype (large contribution to G and a small contribution to GE) should have high grain yield and high stability. The GGE biplot identified ENT 11 x TZEI 4 as the highest yielding and most stable hybrid across *Striga* infestation, low N and optimum environments followed by TZEI 65 x ENT 11.

5.5 Conclusions

In this study, single cross hybrids were evaluated under *Striga* infested, low N and optimum environments in an effort to examine the mode of gene action conditioning *Striga* resistance and tolerance to low N, and also to identify hybrids with consistent performance across the three contrasting environments. The findings of this study are summarized below:

Striga infested, low N and optimum environments were unique and adequate genetic variability exists among the hybrids to allow the selection of *Striga* resistant/tolerant and low N tolerant hybrids. Additive gene action played a predominant role in the inheritance of grain yield and most traits under *Striga* infestation and low N environments. The results revealed consistent trends in the gene action controlling the inheritance of resistance to *Striga* and tolerance to low N in the set of early maturing inbred lines studied. Under *Striga* infestation, maternal effects modified days to silking while paternal effects modified the inheritance of ears per plant.The four inbred lines (TZEI 173, TZEI 175 ENT 11 and TZEI 39) with significant positive GCA (GCA_m and GCA_f) effects for grain yield under *Striga* infestation would be useful in contributing favorable alleles for breeding for *Striga* resistance. While ENT 13, ENT 11, ENT 12, ENT 16, TZEI 142 and TZEI 32 with significant positive GCA effects under low N would be useful in contributing favorable alleles for breeding for tolerance to low N. These lines identified in both groups, if used in crosses, could be useful for contributing favourable alleles for breeding for improved grain yield under low N and *Striga* infestation.

Striga tolerance was observed in the cross between two CIMMYT lines (ENT 11 x ENT 12) not intentionally selected for resistance to *Striga* suggesting the presence of *Striga* resistant/tolerant alleles in some CIMMYT lines. The identification of low N tolerance in crosses involving two IITA inbred lines such as TZEI 33 × TZEI 168, TZEI 32 × TZEI 168, TZEI 32 × TZEI 56 and TZEI 24 × TZEI 142 suggested selection for *Striga* resistance resulted in improved tolerance to low N. Furthermore, the high proportion of *Striga* resistant hybrids that were tolerant to low N emphasizes that selection for *Striga* resistance in early maturing inbred lines indirectly resulted in some level of tolerance to low N.

The highest yielding and most stable hybrids across low N and optimum environments were ENT 11 x TZEI 4, ENT 12 x TZEI 89, TZEI 5 x TZEI 98 (Check) and TZEI 32 x ENT 12. The highest yielding hybrids across *Striga* infestation, low N and optimum environments were ENT 11 x TZEI 4 and TZEI 65 x ENT 11. Thus, ENT 11 x TZEI 4 and TZEI 65 x ENT 11 are the ideal hybrids across *Striga*-infested, low N and optimum environments. The hybrids should be extensively tested in mutilocation and promoted for adoption. These hybrids will be useful in areas where *Striga* and low N are constraints to production. These hybrids would be useful a female parent for the development of three-way or double cross hybrids.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

The savanna agro-ecologies of WCA have the highest potential for maize grain yield production because of low night temperatures, low incidence of pests and diseases and high solar radiation, all of which favour maize production and productivity. However, *Striga hermonthica* parasitism, declining soil fertility, particularly low soil nitrogen and recurrent drought are the major limiting factors to maize production and productivity in the savannas of the subregion. These stresses, when present together, drastically reduce maize production. Several studies have reported that *Striga* parasitism is more severe in soils depleted of nutrients particularly low N which is typical of most soils in sub-Saharan Africa where *Striga* is endemic and farmers are generally applying fertilizer at suboptimal levels. SSR and SNP markers were used to assess the extent of genetic diversity present in the early maturing maize inbred lines. In order to identify lines with *Striga* resistance and/or low N tolerance one hundred lines from the IITA and CIMMYT were evaluated under *Striga*-infested and low N environments in Nigeria for 2 years. The objective was to identify inbred lines that could be used in hybrid combinations to obtain superior hybrids with *Striga* resistance and low N tolerance. In WCA, selection for *Striga* resistance in maize is done under artificial *Striga* infestation with a low dose of N fertilizer (30-40 kg N ha^{-1}) similar to that used for selecting for low N tolerance. Another important objective of this study was to test the hypothesis that selection for *Striga* resistance will result in low N tolerance. Furthermore, the performance of inbreds is not a good predictor of their performance in hybrid combinations. Therefore, the combining ability of the inbred lines for *Striga* resistance and low N and the stability of the hybrids were investigated under low N, *Striga*-infested and optimum environments.

The average genetic diversity among the IITA and CIMMYT inbred lines were relatively high (64%) suggesting that high levels of polymorphism exist among the inbred lines. There was correspondence between cluster analysis and pedigree of the inbred lines with both marker types used in the study. Although some discrepancies were observed, use of more markers may have provided better classification of the inbred lines into clusters. The structure analysis consistently grouped inbred lines from TZE Comp-5 Y into a distinct group and was more effective than the dendrogram in classifying inbred lines into clusters based on their pedigree.

The significant environmental and genotypic variations observed among the inbred lines across low N and *Striga*-infested environments for grain yield and the other traits indicated that the environments were unique and significant progress can be made in selecting lines for *Striga* resistance and low N tolerance. The significant genotype x environment interactions indicated that the performance of the inbred lines was not consistent in the contrasting environments confirming the need for testing genotypes in contrasting environments to identify stable, *Striga* resistant and low N tolerant inbred lines for hybrid production. Using the base indices as criteria for selection, 50 *Striga* resistant, 52 low N tolerant and 27 inbred lines that combined resistance/tolerance to both stresses were identified. The implication is that selection for *Striga* resistance may have resulted in improved grain yield under low N. Interestingly, *Striga* resistance was observed in three CIMMYT lines which had not been intentionally selected for *Striga* resistance. This suggests that *Striga* resistant alleles must have been present in the germplasm sources from which the inbreds were extracted. This is not surprising since CIMMYT had a *Striga* resistance breeding program in the IITA Savanna Station in Cote d'Ivoire in the

1990's and several *Striga* resistant inbreds were developed in the program. Among the lines identified with combined *Striga* resistance and low N tolerance, 18 are also drought tolerant. The *Striga* resistant, drought and low N tolerant inbred lines included one CIMMYT and 17 IITA lines. This is not surprising since most of the lines were developed from *Striga* resistant and drought tolerant populations.

Significant environment, genotype and genotype x environment variations observed among the hybrids for grain yield and other traits under *Striga*-infestation further confirmed the need to test genotypes in the different environments. This is also an indication of the variability present in *S. hermonthic*a species. The genotype x environment interactions for grain yield and ear aspect across low N environments was not significant; an indication that expression of the hybrids for the mentioned traits was not influenced by the environment. The significant GCA_m, GCA_f and SCA for grain yield, number of emerged *Striga* plants and *Striga* damage ratings indicated that performance of the inbred lines as parents in hybrid combinations was influenced by maternal and paternal effects under *Striga* infestation. This also suggests that additive and non-additive gene actions were important in the inheritance of grain yield and other traits under *Striga* infestation. The larger proportion of GCA sum of squares over SCA for grain yield, *Striga* damage and number of emerged *Striga* plants both at 8 and 10 WAP indicates that additive gene action played a major role in the inheritance of *Striga* resistance. The significant GCA_m, GCA_f and SCA for grain yield and other traits under low N, except SCA for stay-green characteristic, suggests that additive and non-additive gene actions were important in the inheritance of grain yield and the other traits under low N, while non-additive gene action was not important in the inheritance of the stay-green characteristic. Across the three contrasting environments, the small differences observed between GCA_m and GCA_f sum of squares for grain yield indicates that both male and female parents had similar contribution to grain yield. The GCA_f sum of squares was larger than GCA_m for days to silking suggesting maternal effects played a more important role in the control of days to silking, while that of GCA_m was larger than that for GCA_f for ears per plant suggesting that paternal effects played a more important role in the control of ears per plant under *Striga*-infested environments. No cases of maternal or paternal effects were observed for traits under low N and optimum conditions. Some inbred lines showed positive GCA effects for grain yield under *Striga*-infested (TZEI 173, TZEI 175 and ENT 11) and low N environments (ENT 11, ENT 12, ENT 16 and TZEI 32). These inbred lines could be used to form synthetics or open-pollinated varieties or crossed according to heterotic groups to develop source populations from which new inbred lines would be extracted. Furthermore, favorable alleles from the inbreds could be introgressed into breeding populations of national maize programs of West Africa for improvement.

Striga infestation reduced grain yield by 44% relative to yield under optimum environments. This suggests that the level of infestation in this study was high enough to identify hybrids that possess genes for *Striga* resistance/tolerance. The grain yield reduction of hybrids under low N stress was 27% of the optimum environments. The inbred lines from IITA were developed from *Striga* resistant and drought tolerant populations while the CIMMYT lines are drought and low N tolerant. It appears that selection for *Striga* resistance improves performance under low N. Similarly, drought tolerance improves performance under low N. This may account for the low reduction in yield observed in the hybrids. It is also possible that only moderate level of N stress was achieved in the present study. Out of the 74 hybrids identified with positive base indices (*Striga* resistant/tolerant) under *Striga*-infested environments, 41.9% were found to be tolerant to low N. This confirms the findings that selection for *Striga* resistance in the early maturing inbred lines used in this study indirectly resulted in some level of tolerance to low N. Furthermore, the presence of low N tolerance in some of the *Striga* resistant/tolerant hybrids may account for the low yield reduction observed under low N.

The stability analysis revealed ENT 11 x TZEI 4 as the highest yielding and most stable hybrid across low N, *Striga*-infested and optimum environments. The hybrid involved a cross between CIMMYT and IITA inbred lines, indicating that the genetic diversity existing between IITA and CIMMYT inbred lines could be exploited to obtain superior hybrids with outstanding performance across *Striga*-infested, low N and optimum environments.

6.1 Recommendations

✓ SSR and SNP markers revealed a relatively high level of genetic diversity among the IITA and CIMMYT early maturing maize inbred lines that could be exploited for population improvement, hybrid production and development of new lines.

✓ Although selection for *Striga* resistance under artificial *Striga* infestation resulted in improved performance of genotypes under low N, it is important to test genotypes under low N to identify genotypes with outstanding performance under the stress.

✓ The inbred lines identified, which combine resistance to *Striga* and tolerance to low N, would be useful sources of alleles for introgression of genes for resistance/tolerance to both stresses in population improvement, hybrid production and development of inbred lines.

✓ The inbred lines that exhibited positive GCA effects for grain yield under *Striga*-infested and low N environments could be used to form synthetics and other open-pollinated varieties.

✓ The hybrid ENT 11 x TZEI 4 and TZEI 65 x ENT 11 identified as the highest yielding and most stable across the three contrasting environments should be tested in multilocation trials and promoted for adoption and commercialization in the sub region.

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APPENDICES

Appendix 3.3. Performance of the top 20 and worst 10 inbred lines evaluated across low N environments in Ile-Ife and Mokwa, 2010 and 2011.

Inbreds	Grain yield (Kg ha^{-1})	Days to silking	Anthesis-silking interval	Husk cover (1 – 5)	Plant aspect (1 – 5)	Stay-green (1 – 9)	Ears per plant	Ear aspect (1 – 9)	Low N base index
TZEI 56	1581	57.05	0.34	2.74	2.36	3.35	0.89	3.70	9.73
TZEI 7	1581	59.45	0.19	3.05	2.53	3.03	0.91	3.98	9.60
TZEI 32	1859	60.70	0.88	3.11	2.53	3.48	0.93	4.25	9.38
TZEI 75	1598	60.24	1.18	2.83	2.33	3.78	0.93	4.01	8.10
ENT 13	1701	58.48	1.85	2.66	2.24	3.20	0.89	4.51	7.76
ENT 11	1377	61.00	0.74	2.18	2.19	3.89	0.85	3.43	7.63
TZEI 18	1449	60.35	1.58	3.28	2.31	2.96	0.90	4.20	7.50
TZEI 157	1525	59.01	0.19	2.76	2.57	3.34	0.89	4.49	7.42
ENT 3	1856	62.93	2.55	2.99	2.32	3.44	0.80	3.94	7.35
TZEI 106	1549	54.96	0.20	3.13	2.36	4.03	0.94	4.76	7.08
TZEI 178	1596	55.61	0.00	3.34	2.90	3.30	0.90	4.95	6.96
TZEI 177	1369	57.61	0.78	2.78	2.51	2.88	0.92	4.90	6.35
TZEI 146	1587	58.88	1.75	2.96	2.66	3.66	0.91	4.33	5.64
TZEI 1	1664	60.05	0.94	2.80	2.46	4.23	0.77	4.23	5.30
TZEI 86	1371	59.06	-0.10	3.19	2.89	4.11	0.89	4.08	5.19
TZEI 173	1710	61.86	2.46	2.43	2.62	3.59	0.90	4.59	5.17
TZEI 2	1518	59.53	1.31	3.09	2.64	4.36	0.94	4.18	5.11
TZEI 22	1352	59.85	1.09	3.60	2.41	3.90	0.92	4.51	5.09
TZEI 174	1517	63.15	2.73	2.61	2.33	3.78	0.93	4.36	5.02
TZEI 19	1387	62.73	2.34	2.70	2.56	3.25	0.87	4.01	4.95
TZEI 188	1630	61.35	1.14	3.19	2.73	3.74	0.85	4.70	4.85
TZEI 98	1492	60.96	0.99	3.28	2.66	4.06	0.93	4.70	4.72
TZEI 135	1517	58.11	1.55	3.14	2.69	3.66	0.86	4.94	3.56
TZEI 149	1359	56.81	0.65	3.16	2.71	3.63	0.78	4.63	3.41
TZEI 83	1666	63.66	2.20	2.93	2.68	4.44	0.90	4.70	3.35
TZEI 159	1393	63.64	1.40	3.01	2.58	3.89	0.81	4.53	3.23
TZEI 129	1225	59.75	1.33	2.83	2.40	4.08	0.84	4.35	3.22
TZEI 175	1202	62.81	1.80	2.71	2.54	3.41	0.80	4.13	3.19
ENT 15	1285	61.90	1.65	2.75	2.81	3.25	0.93	5.00	3.10
TZEI 14	1408	62.65	2.56	2.90	2.68	3.91	0.87	4.19	2.91
TZEI 158	1237	58.19	0.33	3.03	2.95	3.99	0.87	4.56	2.75
TZEI 60	1087	63.21	1.26	2.39	2.59	3.35	0.87	4.76	2.61
TZEI 4	1412	60.93	0.49	3.13	3.21	3.58	0.78	4.56	2.58
TZEI 161	1132	59.05	0.23	2.80	2.94	3.24	0.86	5.04	2.53
TZEI 10	1439	60.49	2.74	2.31	2.68	3.76	0.82	4.35	2.20
TZEI 16	1346	63.70	2.85	2.70	2.84	3.56	0.89	4.54	1.82
TZEI 140	1343	62.61	2.50	2.49	2.59	3.91	0.90	4.93	1.75
ENT 17	1092	58.83	0.98	2.63	2.49	4.01	0.72	4.29	1.32
TZEI 108	1343	59.11	0.35	3.28	2.63	4.76	0.84	5.29	1.30
TZEI 5	1283	61.03	1.09	2.65	2.73	3.88	0.73	4.69	1.25
TZEI 128	1431	61.35	1.84	2.53	2.86	3.90	0.82	5.03	1.24
TZEI 200	1387	63.84	2.65	2.65	2.60	4.03	0.81	4.63	1.16
TZEI 11	1422	63.00	2.71	2.50	2.89	3.05	0.77	4.90	1.13
TZEI 156	1058	59.71	0.56	2.55	2.93	3.93	0.89	4.94	1.09
TZEI 23	1015	59.10	0.21	2.58	2.99	3.14	0.84	5.38	1.02
TZEI 12	1191	62.56	2.76	2.51	2.56	3.61	0.78	4.39	0.84
TZEI 130	1149	59.94	1.11	2.41	2.83	3.48	0.82	5.21	0.83
ENT 16	1190	61.31	1.61	2.66	3.02	3.20	0.78	4.90	0.53
TZEI 63	1144	61.64	1.58	3.11	2.99	3.83	0.83	4.61	0.31
TZEI 150	872	57.11	0.85	3.94	3.31	2.64	0.86	4.95	0.28
Mean	1148.8	60.82	1.55	2.98	2.87	3.87	0.82	4.91	
Min	484.55	54.96	0.00	2.18	2.19	2.64	0.36	3.43	
Max	1858.71	64.38	3.81	4.01	3.54	5.68	0.96	6.36	
Lsd	364.94	1.65	0.86	0.60	0.40	0.59	0.14	0.79	

Appendix 3.3. continued. Performance of the top 20 and worst 10 inbred lines evaluated across low N environments in Ile-Ife and Mokwa, 2010 and 2011.

Inbreds	Grain yield (Kg ha^{-1})	Days to silking	Anthesis-silking interval	Husk cover (1 – 5)	Plant aspect (1 – 5)	Stay-green (1 – 9)	Ears per plant	Ear aspect (1 – 9)	Low N base index
TZEI 120	1070	60.46	1.00	2.96	3.06	3.73	0.93	5.36	0.21
TZEI 126	1094	61.16	1.28	3.24	2.90	3.66	0.92	5.58	0.14
TZEI 13	1066	64.01	2.01	2.59	2.86	3.76	0.84	4.71	-0.17
ENT 8	1324	58.94	1.00	3.58	2.91	4.20	0.80	5.48	-0.23
TZEI 112	1022	58.35	0.93	3.55	2.88	4.46	0.96	5.33	-0.30
TZEI 89	1197	62.04	1.73	3.13	2.96	3.89	0.80	5.03	-0.65
TZEI 148	945	59.71	0.44	2.83	3.04	3.21	0.90	6.16	-0.74
TZEI 80	1129	60.23	0.84	3.09	2.76	5.13	0.82	4.74	-0.84
TZEI 79	1292	59.45	0.90	3.24	3.04	5.00	0.82	4.98	-0.94
TZEI 76	1155	60.44	1.19	3.14	2.94	4.31	0.70	4.45	-0.97
TZEI 167	1021	63.38	2.36	2.91	2.83	3.79	0.90	5.14	-1.03
TZEI 25	997	62.33	1.26	2.80	2.80	3.64	0.80	5.66	-1.53
ENT 10	840	61.69	1.89	3.75	3.06	3.20	0.88	5.29	-1.75
TZEI 104	1229	59.68	1.18	3.00	3.06	4.58	0.78	5.15	-1.76
TZEI 190	1107	61.00	1.33	3.33	3.18	4.05	0.70	4.46	-1.78
TZEI 15	1021	64.38	2.30	2.95	2.93	3.73	0.76	4.73	-1.84
TZEI 160	866	60.38	0.88	3.06	2.95	3.69	0.77	5.16	-1.86
ENT 12	999	62.41	2.53	2.65	2.64	3.56	0.85	5.69	-1.87
TZEI 114	1054	61.09	1.20	2.99	3.02	4.06	0.78	5.15	-1.88
TZEI 91	696	62.64	1.88	2.64	3.09	3.20	0.93	5.25	-2.12
TZEI 33	922	61.34	1.59	3.31	3.06	2.94	0.72	5.30	-2.21
TZEI 39	1005	59.95	0.78	2.78	3.13	3.70	0.78	5.80	-2.60
TZEI 136	903	60.29	2.13	2.79	2.93	3.63	0.79	5.19	-2.76
TZEI 115	985	62.19	1.69	3.10	3.17	3.84	0.80	5.24	-2.88
ENT 7	963	59.68	1.75	3.18	3.05	3.45	0.68	5.25	-3.33
TZEI 103	888	59.25	1.69	3.38	3.14	4.25	0.82	5.05	-3.54
TZEI 111	868	60.66	1.29	3.54	2.81	4.94	0.81	5.15	-3.66
TZEI 163	819	61.51	1.36	2.70	3.13	3.94	0.78	5.16	-3.69
TZEI 65	832	60.73	2.25	3.68	3.23	4.06	0.86	4.96	-3.88
TZEI 189	701	60.36	1.79	3.20	3.36	3.28	0.80	5.10	-4.08
TZEI 17	786	61.69	2.26	2.86	2.93	3.98	0.82	5.30	-4.15
TZEI 3	745	60.65	0.70	3.21	3.21	4.09	0.78	5.40	-4.24
TZEI 54	937	60.55	2.30	2.90	2.84	3.74	0.65	5.28	-4.40
TZEI 202	1067	62.59	1.65	2.96	3.23	4.56	0.76	5.39	-4.46
TZEI 87	1029	59.65	1.83	2.78	3.11	4.63	0.75	5.26	-4.57
TZEI 184	862	62.86	3.79	2.59	2.85	3.64	0.76	5.11	-4.98
TZEI 68	973	61.00	2.26	3.03	3.31	4.18	0.77	5.29	-5.14
TZEI 131	655	62.84	2.35	2.91	3.24	3.41	0.85	5.56	-5.27
TZEI 9	648	62.70	2.24	3.55	3.21	4.01	0.74	4.98	-6.21
TZEI 168	811	59.68	1.59	3.79	3.38	4.65	0.81	5.44	-6.22
TZEI 24	749	61.65	2.99	2.80	3.10	3.66	0.72	5.45	-6.61
TZEI 82	701	60.66	1.09	4.01	3.37	4.84	0.70	4.88	-6.78
TZEI 37	781	58.30	1.66	3.31	3.29	4.91	0.76	5.24	-6.81
TZEI 27	533	64.20	2.26	2.73	3.16	4.20	0.75	5.61	-8.20
TZEI 132	642	61.83	2.79	3.66	3.32	4.38	0.74	5.29	-8.47
ENT 4	907	63.66	3.81	2.86	3.41	4.43	0.71	5.24	-8.72
TZEI 53	513	60.16	2.80	2.89	3.04	4.03	0.65	5.84	-9.84
TZEI 142	646	62.63	1.63	2.73	3.48	5.68	0.62	5.35	-11.35
TZEI 26	485	60.79	2.21	3.36	3.52	5.21	0.62	5.54	-12.64
TZEI 143	506	63.53	1.89	3.13	3.54	5.29	0.36	6.36	-16.82
Mean	1148.8	60.82	1.55	2.98	2.87	3.87	0.82	4.91	
Min	484.55	54.96	0.00	2.18	2.19	2.64	0.36	3.43	
Max	1858.71	64.38	3.81	4.01	3.54	5.68	0.96	6.36	
Lsd	364.94	1.65	0.86	0.60	0.40	0.59	0.14	0.79	

Appendix 3.5. Performance of best 20 and worst 10 inbred lines across *Striga*-infested environments in Abuja and Mokwa, 2010 and 2011.

Inbreds	Grain yield kg/ha	Days to silking	*Striga* damage rating		*Striga* emergence count		Ears per plant	Ear aspect	*Striga* index
			8 WAP	10 WAP	8 WAP	10 WAP			
TZEI 23	1298	54.19	1.70	3.38	6.41	8.64	0.98	4.14	8.95
ENT 11	1553	60.75	2.01	3.13	17.70	24.65	0.89	3.33	8.53
TZEI 175	1451	60.68	2.44	3.73	5.38	7.76	0.86	3.43	8.26
TZEI 2	1574	56.21	2.94	4.08	13.53	19.45	0.85	4.13	7.01
TZEI 173	1293	61.21	2.76	3.66	5.88	8.01	0.86	4.35	6.80
TZEI 174	1361	60.85	2.69	3.93	6.39	13.24	0.84	4.19	6.65
TZEI 167	1506	62.30	2.41	4.53	10.90	19.59	0.79	4.49	6.30
TZEI 136	1276	56.74	2.23	3.64	8.15	12.06	0.76	4.48	6.21
TZEI 16	1390	61.20	2.74	4.18	12.93	18.46	0.89	4.19	6.15
TZEI 148	1204	55.69	2.23	3.96	6.76	11.99	0.87	5.03	6.14
TZEI 177	1298	54.56	2.59	3.71	13.50	16.69	0.86	4.05	5.94
TZEI 103	1225	58.09	2.89	4.03	5.85	14.04	0.92	4.86	5.91
TZEI 178	1252	53.73	2.86	3.68	14.49	20.10	0.97	4.39	5.87
TZEI 13	1532	62.68	3.01	4.33	11.73	20.65	0.76	4.63	5.84
TZEI 159	1208	59.66	2.50	3.55	9.01	19.71	0.84	4.25	5.54
TZEI 75	1333	57.50	2.59	3.94	14.68	17.31	0.81	3.94	5.52
TZEI 14	1109	61.93	2.23	3.98	3.71	9.74	0.80	3.96	5.31
TZEI 150	967	54.43	2.00	3.69	5.69	8.71	0.88	4.73	5.31
TZEI 24	1073	57.25	2.46	3.38	7.60	11.41	0.81	3.75	5.19
TZEI 15	1101	61.93	2.76	3.63	9.78	15.19	0.86	3.61	4.76
TZEI 161	1305	54.04	2.69	4.45	9.58	16.01	0.74	4.06	4.62
TZEI 54	1187	58.50	2.25	3.94	12.79	20.40	0.76	4.46	4.46
TZEI 160	1084	55.59	2.29	3.81	11.50	16.51	0.80	4.31	4.32
TZEI 184	1105	59.19	2.44	4.13	8.95	16.05	0.77	5.18	4.01
TZEI 83	1239	60.60	3.20	4.34	9.44	15.31	0.77	4.91	4.00
TZEI 131	1055	59.25	2.10	3.38	10.81	20.13	0.69	4.88	3.89
TZEI 11	1143	60.95	3.04	4.08	6.40	10.84	0.67	4.06	3.53
TZEI 65	1053	57.24	2.65	3.98	13.06	20.01	0.82	4.84	3.44
TZEI 10	974	56.04	2.68	4.30	11.16	12.99	0.85	4.94	3.21
TZEI 39	1510	56.48	4.08	5.05	20.81	26.10	0.77	4.68	3.00
TZEI 33	1256	59.95	3.44	4.74	9.83	10.96	0.66	5.23	2.98
TZEI 111	1255	58.13	3.70	4.53	8.94	14.61	0.69	4.69	2.97
TZEI 158	883	55.89	2.73	3.83	14.78	18.99	0.91	4.13	2.80
TZEI 68	1106	56.30	3.38	4.69	11.50	14.28	0.82	4.96	2.77
TZEI 7	1304	56.28	3.58	4.65	13.10	22.06	0.69	4.93	2.61
ENT 10	1089	59.89	3.00	3.73	13.39	26.66	0.73	4.71	2.60
TZEI 25	1203	58.93	3.10	4.48	13.44	20.74	0.68	4.86	2.54
TZEI 190	958	58.91	2.65	4.39	7.74	20.44	0.79	5.01	2.42
TZEI 12	1075	62.03	3.08	4.53	13.84	17.84	0.78	3.89	2.35
TZEI 98	1109	58.23	3.39	5.18	9.00	13.89	0.81	5.21	2.34
TZEI 106	1165	54.06	3.65	5.13	12.56	15.86	0.80	4.88	2.17
TZEI 56	1278	56.93	3.86	4.73	12.00	18.94	0.63	4.15	1.90
TZEI 3	987	57.74	3.93	4.69	8.25	11.18	0.84	4.81	1.87
TZEI 91	781	59.06	2.89	4.16	5.16	6.05	0.75	5.26	1.84
TZEI 157	1061	55.66	2.95	4.39	17.34	23.55	0.73	4.34	1.67
ENT 12	1141	59.65	2.89	4.56	22.65	28.76	0.67	5.34	1.06
TZEI 146	1102	56.01	3.53	4.23	20.11	28.80	0.72	3.75	0.99
TZEI 188	1189	57.99	3.79	4.61	30.30	35.20	0.86	4.79	0.85
TZEI 130	959	57.30	2.86	4.54	15.93	18.16	0.65	5.34	0.70
TZEI 189	766	59.19	3.01	4.44	11.43	18.34	0.76	5.16	0.29
Mean	993.42	58.87	3.61	4.91	14.27	20.26	0.68	5.02	
Min	355.72	53.73	1.7	3.13	3.71	6.05	0.34	3.33	
Max	1573.61	64.46	5.81	6.99	39.5	43.4	0.98	6.45	
Lsd	327.63	1.90	0.76	0.83	9.40	11.08	0.18	0.81	

Appendix 3.5 continued. Performance of best 20 and worst 10 inbred lines across *Striga*-infested environments in Abuja and Mokwa, 2010 and 2011.

Inbreds	Grain yield kg/ha	Days to silking	*Striga* damage rating		*Striga* emergence count		Ears per plant	Ear aspect	*Striga* index
			8 WAP	10 WAP	8 WAP	10 WAP			
TZEI 1	1214	58.34	4.21	5.29	19.03	24.40	0.67	5.15	-0.01
TZEI 135	1320	57.85	4.94	5.46	17.73	21.30	0.64	5.11	-0.10
ENT 16	976	61.01	3.56	5.05	14.80	17.06	0.67	5.46	-0.13
ENT 13	1169	56.93	3.56	4.36	32.08	37.06	0.68	4.65	-0.23
TZEI 53	878	57.83	2.94	4.66	18.00	21.81	0.67	5.20	-0.29
TZEI 22	1145	56.15	3.48	4.99	30.41	42.10	0.75	5.28	-0.70
TZEI 115	853	60.66	3.38	4.99	11.21	17.61	0.62	5.31	-0.93
TZEI 114	1069	57.26	3.84	4.86	25.10	31.45	0.65	4.96	-1.22
TZEI 108	946	57.18	4.16	5.01	11.65	18.41	0.60	5.04	-1.26
TZEI 163	828	57.71	3.79	4.99	7.29	13.83	0.57	5.46	-1.37
ENT 17	983	59.48	3.56	4.74	27.34	29.64	0.66	5.13	-1.42
TZEI 87	878	56.51	4.23	5.26	13.11	14.23	0.63	5.89	-1.74
TZEI 149	934	55.46	3.46	4.95	25.63	33.74	0.70	4.86	-1.74
TZEI 18	849	57.50	3.76	4.88	20.04	30.16	0.71	4.20	-1.93
TZEI 4	999	60.00	3.33	5.18	25.91	36.63	0.61	5.33	-2.14
TZEI 86	991	55.50	5.28	6.30	8.06	15.76	0.71	5.13	-2.30
TZEI 120	1008	60.06	4.04	5.25	22.31	28.28	0.58	6.19	-2.34
TZEI 32	700	59.64	2.80	4.73	17.14	25.81	0.58	5.86	-2.35
TZEI 60	868	63.65	3.49	5.08	17.78	26.98	0.56	5.60	-2.38
TZEI 9	831	58.96	3.71	5.73	19.73	24.68	0.74	4.84	-2.38
TZEI 132	801	58.50	3.75	5.46	9.04	14.60	0.52	6.01	-2.55
TZEI 63	844	61.64	4.35	5.98	8.51	14.81	0.64	5.30	-2.56
ENT 8	926	57.76	4.20	5.69	17.58	23.85	0.63	5.59	-2.66
TZEI 17	843	58.46	3.54	5.36	21.58	34.51	0.62	5.00	-2.84
TZEI 200	851	62.54	3.30	4.80	25.74	41.70	0.49	5.20	-3.88
TZEI 80	714	57.31	4.14	5.50	13.73	21.44	0.57	5.98	-3.97
TZEI 19	1061	61.14	4.38	5.84	30.61	37.61	0.58	5.29	-4.01
TZEI 82	921	57.06	5.49	6.08	14.60	19.89	0.62	5.04	-4.08
TZEI 168	552	57.41	4.75	5.65	8.99	13.66	0.69	5.44	-4.38
TZEI 89	622	59.45	4.55	5.46	10.11	15.64	0.52	4.76	-4.79
TZEI 156	564	62.24	4.99	6.08	4.20	7.29	0.57	6.01	-5.11
TZEI 128	792	61.10	5.00	6.01	16.39	20.49	0.51	5.58	-5.37
TZEI 37	708	54.71	4.90	6.06	14.19	19.54	0.55	5.15	-5.42
TZEI 140	641	63.60	5.25	6.13	6.16	9.85	0.46	6.06	-5.87
TZEI 143	638	63.73	4.90	6.48	4.70	7.65	0.42	5.80	-5.95
TZEI 126	627	63.34	5.29	6.25	6.43	10.49	0.47	5.75	-6.13
TZEI 5	680	59.76	4.85	5.91	13.96	22.96	0.47	5.61	-6.17
TZEI 104	626	56.88	5.28	6.24	9.14	16.66	0.51	5.81	-6.40
TZEI 79	474	59.98	4.18	6.03	19.74	30.31	0.62	5.79	-6.91
TZEI 76	646	61.90	4.23	6.00	24.84	36.94	0.54	5.89	-6.93
ENT 15	572	62.74	4.91	6.35	12.59	15.51	0.43	6.03	-7.21
ENT 7	567	56.16	5.15	6.33	10.19	17.46	0.44	6.33	-7.34
TZEI 26	718	61.01	5.13	6.23	23.30	24.51	0.45	6.11	-7.36
TZEI 202	609	63.09	5.63	6.75	8.49	14.68	0.46	6.13	-7.55
ENT 4	742	62.01	4.69	6.51	27.20	31.34	0.45	6.16	-7.66
TZEI 142	526	63.84	5.44	6.45	4.14	6.05	0.34	5.85	-7.70
ENT 3	778	63.05	5.04	6.16	34.65	43.40	0.45	5.54	-8.58
TZEI 129	592	58.80	5.81	6.99	14.09	18.63	0.38	5.71	-9.29
TZEI 27	356	64.46	4.46	6.50	12.65	23.98	0.37	6.45	-9.37
TZEI 112	587	57.65	4.66	5.95	39.50	42.96	0.48	6.01	-9.45
Mean	993.42	58.87	3.61	4.91	14.27	20.26	0.68	5.02	
Min	355.72	53.73	1.7	3.13	3.71	6.05	0.34	3.33	
Max	1573.61	64.46	5.81	6.99	39.5	43.4	0.98	6.45	
Lsd	327.63	1.90	0.76	0.83	9.40	11.08	0.18	0.81	

Appendix 4.10. Grain yield and other agronomic traits of some selected hybrids (best 20 and worst 10) evaluated under *Striga*-infested environments at Abuja and Mokwa in 2011 and 2012

HYBRID	Grain yield kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	*Striga* damage score		*Striga* emergence		Ears per plant	Ear aspect	Base index
					8 WAP	10 WAP	8 WAP	10 WAP			
TZEI 175 x TZEI 177	3938	55.39	53.78	1.51	1.96	3.10	6.62	13.63	0.96	3.94	10.98
TZEI 173 x TZEI 24	4340	56.17	54.15	1.93	2.18	2.99	15.69	19.78	0.91	3.75	10.30
TZEI 146 x TZEI 175	4385	55.48	54.00	1.48	2.34	3.08	14.10	19.98	0.90	3.83	10.19
ENT 11 x ENT 12	4735	56.83	55.47	1.31	1.72	2.70	30.40	43.31	0.97	3.80	9.61
TZEI 10 x TZEI 175	3811	56.06	53.78	2.39	2.44	3.81	10.31	11.66	0.95	4.16	9.22
TZEI 10 x TZEI 24	2880	55.46	54.06	1.32	2.20	3.57	0.58	2.84	0.95	5.50	8.79
TZEI 184 x TZEI 173	3555	55.41	53.67	1.78	2.50	3.36	11.06	19.17	0.92	4.52	8.20
TZEI 17 x TZEI 24	3298	54.17	52.86	1.55	2.42	3.61	9.32	11.94	0.93	4.84	8.07
ChK 4 TZEI 23 x TZEI 13	3869	53.38	52.86	0.75	2.41	4.05	18.64	29.01	0.99	4.58	7.57
TZEI 175 x TZEI 23	3890	54.95	53.40	1.46	2.19	3.27	19.12	33.33	0.87	4.22	7.30
TZEI 23 x TZEI 173	3555	54.12	52.90	1.14	2.02	3.49	18.22	26.94	0.91	4.63	7.24
TZEI 9 x TZEI 23	3120	52.46	51.99	1.01	1.96	3.75	17.21	20.36	1.00	4.88	7.23
TZEI 173 x TZEI 149	3923	54.37	53.03	1.32	2.71	4.05	18.97	26.64	0.91	4.79	6.98
TZEI 135 x TZEI 175	3560	55.29	53.47	1.80	2.83	4.24	12.81	13.11	0.86	4.63	6.80
TZEI 65 x ENT 11	3960	55.83	54.91	0.81	2.33	3.61	23.23	36.14	0.90	3.78	6.73
TZEI 24 x TZEI 23	3253	51.72	51.24	1.27	1.89	3.21	24.07	25.67	0.94	4.55	6.73
Chk 3 TZEI 24 x TZEI 17	3741	55.53	53.70	1.84	3.13	3.97	13.58	23.84	0.88	4.08	6.62
TZEI 175 x TZEI 184	3932	55.58	53.20	2.29	2.85	4.03	19.76	25.14	0.84	4.52	6.34
TZEI 157 x TZEI 173	3413	55.02	53.64	1.38	2.19	3.60	17.08	36.74	0.92	4.09	6.19
ENT 11 x TZEI 4	4042	55.29	55.25	0.62	1.98	2.99	35.68	42.66	0.88	4.25	6.18
TZEI 56 x TZEI 39	4118	53.28	53.02	0.52	2.02	2.96	34.30	56.70	0.96	4.29	6.15
TZEI 149 x TZEI 184	3125	50.94	50.97	0.44	2.92	3.88	13.03	19.67	0.91	4.58	5.91
TZEI 175 x TZEI 157	3259	56.70	55.07	1.54	2.47	3.53	18.01	24.14	0.86	4.14	5.87
ENT 11 x TZEI 56	3948	55.60	54.73	1.07	2.35	3.28	25.29	43.46	0.84	3.74	5.84
TZEI 142 x TZEI 146	3710	55.49	53.74	1.79	2.63	3.64	23.49	33.04	0.88	4.60	5.81
TZEI 23 x TZEI 10	3151	52.19	51.92	0.72	2.11	3.93	16.79	32.22	0.93	5.08	5.66
TZEI 23 x TZEI 17	3092	54.11	52.60	1.45	2.58	4.18	17.32	26.90	0.99	4.83	5.60
TZEI 17 x TZEI 175	2949	58.11	55.79	2.39	3.31	3.91	6.58	17.17	0.87	4.42	5.45
TZEI 23 x TZEI 146	3378	51.41	51.86	1.22	2.43	4.27	24.95	30.96	0.98	4.94	5.32
TZEI 157 x TZEI 10	3201	53.39	52.61	1.17	2.54	3.67	21.36	22.74	0.86	4.66	5.32
Mean	2613	55.53	53.52	2.1	3.46	4.76	26.03	35.7	0.78	5.19	
Min	775	50.20	50.33	0.00	1.72	2.70	0.58	2.84	0.38	3.74	
Max	4735	61.15	57.11	5.59	6.61	7.47	68.91	100.47	1.08	6.79	
Lsd	978	2.14	0.91	1.90	0.98	1.04	18.90	22.14	0.17	0.85	

Appendix 4.10 continued. Grain yield and other agronomic traits of some selected hybrids (best 20 and worst 10) evaluated under *Striga*-infested environments at Abuja and Mokwa in 2011 and 2012

HYBRID	Grain yield kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	*Striga* damage score		*Striga* emergence		Ears per plant	Ear aspect	Base index
					8 WAP	10 WAP	8 WAP	10 WAP			
TZEI 24 x TZEI 177	2848	50.20	50.33	0.00	2.39	4.01	15.50	25.04	0.95	4.94	5.29
TZEI 24 x TZEI 184	1789	56.49	54.86	1.58	2.22	3.82	6.51	18.59	1.08	6.10	5.24
TZEI 22 x TZEI 65	3615	54.37	52.89	1.45	3.13	4.25	20.70	28.31	0.85	4.98	4.84
TZEI 157 x TZEI 146	3202	51.84	52.08	0.00	1.96	3.86	21.38	40.71	0.90	4.54	4.82
TZEI 146 x TZEI 24	3029	53.26	52.29	1.19	2.53	3.83	20.24	28.75	0.90	4.98	4.77
TZEI 177 x TZEI 17	3288	54.36	53.12	1.31	2.91	4.00	19.98	29.02	0.88	4.43	4.74
TZEI 54 x ENT 11	3844	55.75	54.39	1.33	2.75	3.62	26.70	42.06	0.82	3.98	4.72
TZEI 184 x TZEI 17	2820	54.45	53.13	1.33	2.35	4.00	16.59	24.22	0.88	4.77	4.68
ENT 16 x ENT 11	3915	56.45	54.55	1.93	2.38	3.18	41.64	50.71	0.93	3.91	4.61
TZEI 173 x TZEI 175	2251	60.95	57.11	3.99	2.88	4.62	1.77	9.47	0.86	5.54	4.35
TZEI 149 x TZEI 177	2434	52.50	51.76	0.79	3.47	4.56	9.10	8.91	0.92	5.47	4.11
TZEI 184 x TZEI 146	2806	54.44	53.23	1.36	2.82	4.47	10.99	28.07	0.84	5.25	3.71
TZEI 173 x ENT 13	3538	56.92	54.41	2.48	2.65	3.83	35.65	37.41	0.85	4.58	3.60
TZEI 142 x TZEI 10	3181	56.72	53.93	2.83	3.41	4.70	21.72	15.83	0.82	5.14	3.58
TZEI 184 x TZEI 10	2537	55.99	54.54	1.33	2.60	4.31	13.49	19.57	0.82	5.27	3.57
TZEI 24 x TZEI 157	2754	53.44	52.32	1.36	2.42	3.91	18.80	24.87	0.77	5.01	3.45
TZEI 157 x TZEI 17	3026	55.24	53.75	1.39	3.37	4.19	17.16	28.09	0.84	4.49	3.42
TZEI 39 x TZEI 108	2758	53.64	53.08	1.32	2.59	3.65	22.13	36.15	0.88	5.07	3.36
TZEI 9 x TZEI 177	2775	52.22	51.64	0.73	2.84	4.29	19.51	25.73	0.85	4.42	3.28
TZEI 177 x TZEI 173	2919	53.97	52.57	1.33	2.35	3.72	28.54	44.83	0.91	4.90	3.00
TZEI 24 x TZEI 142	2810	53.20	52.35	1.13	3.00	4.16	19.76	29.02	0.80	4.92	2.66
ENT 13 x TZEI 23	2792	53.78	52.48	1.30	2.46	4.13	29.07	43.50	0.96	5.29	2.66
ENT 12 x ENT 16	2930	56.25	54.23	2.12	2.67	3.82	29.77	37.62	0.85	5.06	2.55
TZEI 149 x TZEI 23	2336	52.28	51.84	1.15	2.49	4.40	22.81	27.22	0.90	5.05	2.40
TZEI 177 x TZEI 146	2977	52.64	52.04	0.66	2.03	4.03	28.00	45.80	0.81	4.81	2.34
TZEI 142 x TZEI 173	3255	58.37	56.08	2.27	2.78	3.78	33.59	41.62	0.78	4.52	2.18
TZEI 177 x TZEI 10	2900	52.56	51.43	1.22	2.72	4.40	28.99	35.73	0.86	5.04	2.13
TZEI 33 x TZEI 22	3348	55.92	53.96	1.90	3.31	4.06	26.26	42.55	0.75	4.74	1.96
TZEI 17 x TZEI 9	3054	55.74	54.06	1.56	3.24	4.52	25.29	34.14	0.80	4.39	1.91
ENT 16 x TZEI 32	2693	56.89	54.96	2.00	2.77	4.60	25.10	29.88	0.80	4.99	1.67
ENT 11 x TZEI 22	3872	57.08	56.05	1.14	2.12	3.72	42.75	84.22	0.90	4.32	1.62
ENT 12 x TZEI 39	2999	55.22	54.19	1.07	2.58	4.10	40.50	48.19	0.92	5.18	1.45
Mean	2613	55.53	53.52	2.1	3.46	4.76	26.03	35.7	0.78	5.19	
Min	775	50.20	50.33	0.00	1.72	2.70	0.58	2.84	0.38	3.74	
Max	4735	61.15	57.11	5.59	6.61	7.47	68.91	100.47	1.08	6.79	
Lsd	978	2.14	0.91	1.90	0.98	1.04	18.90	22.14	0.17	0.85	

Appendix 4.10 continued. Grain yield and other agronomic traits of some selected hybrids (best 20 and worst 10) evaluated under *Striga*-infested environments at Abuja and Mokwa in 2011 and 2012

HYBRID	Grain yield kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	*Striga* damage score		*Striga* emergence		Ears per plant	Ear aspect	Base index
					8 WAP	10 WAP	8 WAP	10 WAP			
ENT 13 x TZEI 184	2673	55.92	54.15	1.87	2.71	4.39	31.94	37.01	0.86	5.11	1.27
TZEI 23 x TZEI 135	2368	53.14	51.82	1.28	3.50	4.61	16.09	21.28	0.77	5.57	1.26
TZEI 32 x ENT 12	2712	56.93	55.07	1.71	2.91	4.21	35.72	55.17	1.03	5.04	1.12
ENT 3 x ENT 12	3262	58.56	55.95	2.46	2.53	4.21	40.22	49.79	0.81	4.66	1.08
TZEI 22 x TZEI 39	3259	55.23	53.94	1.17	2.09	3.85	41.77	63.04	0.81	4.90	0.85
TZEI 9 x TZEI 157	2154	53.98	53.15	1.04	3.30	4.62	18.77	24.05	0.80	5.12	0.73
TZEI 65 x TZEI 108	2688	52.79	52.15	0.99	2.83	4.26	29.94	39.14	0.78	5.11	0.69
Chk 5 TZEI 2 x TZEI 87	2615	54.62	53.58	1.05	3.67	4.45	28.45	30.49	0.82	5.29	0.56
ENT 16 x TZEI 33	2707	55.96	53.22	2.67	3.57	5.02	24.14	31.72	0.81	5.23	0.52
ENT 12 x TZEI 89	2629	56.71	55.53	1.23	3.26	5.04	23.56	34.95	0.79	4.98	0.31
TZEI 146 x TZEI 149	2906	51.74	51.41	1.13	3.02	4.75	32.07	44.00	0.81	4.84	0.30
TZEI 168 x TZEI 39	3286	53.34	52.82	1.01	3.40	4.17	44.27	54.06	0.87	4.70	0.18
ENT 13 x TZEI 157	2888	54.93	53.43	1.73	3.28	4.44	40.88	41.03	0.84	5.02	0.00
ENT 12 x TZEI 65	2518	55.48	53.12	2.42	3.25	4.59	26.59	36.48	0.75	5.29	-0.23
TZEI 39 x ENT 11	3587	55.23	54.65	0.55	2.13	3.46	59.34	84.94	0.90	4.37	-0.32
TZEI 10 x TZEI 9	2526	55.35	53.21	2.07	2.99	5.18	28.69	36.69	0.77	5.11	-0.55
TZEI 56 x TZEI 54	2159	55.54	54.10	1.47	4.42	5.52	10.90	17.44	0.71	5.59	-0.73
ENT 11 x TZEI 168	3283	54.24	52.82	1.50	3.08	4.27	50.66	62.73	0.87	4.80	-0.75
ENT 13 x TZEI 142	2816	57.00	54.73	2.26	3.73	4.52	27.79	47.14	0.73	5.00	-0.81
TZEI 142 x TZEI 17	2323	57.08	54.09	2.92	3.94	5.02	22.02	29.84	0.76	5.35	-0.81
TZEI 33 x TZEI 56	2171	57.53	53.77	3.77	5.03	5.37	4.80	14.46	0.66	5.43	-0.82
TZEI 33 x ENT 12	2804	56.57	54.42	2.24	3.00	4.37	35.87	53.30	0.76	5.30	-0.92
TZEI 108 x TZEI 4	2470	55.93	53.28	2.70	3.77	5.06	24.97	31.76	0.73	5.48	-0.99
TZEI 32 x TZEI 4	2662	58.93	55.18	4.09	3.22	5.02	27.87	38.48	0.65	5.54	-1.26
TZEI 89 x ENT 11	3300	57.33	55.70	1.54	3.60	5.15	42.26	53.64	0.80	4.52	-1.29
TZEI 108 x ENT 12	2701	54.87	53.36	1.45	3.84	4.69	35.01	45.59	0.80	5.10	-1.38
Chk 6 TZEI 1 x TZEI 5	2452	58.04	55.07	2.89	4.21	5.57	22.50	28.46	0.74	5.53	-1.44
TZEI 56 x TZEI 89	2691	56.76	52.52	4.27	4.57	5.38	20.98	25.97	0.64	5.37	-1.44
TZEI 184 x TZEI 135	2505	57.32	52.09	5.34	4.05	5.58	20.23	29.49	0.68	5.81	-1.47
TZEI 10 x TZEI 149	2444	53.55	52.71	1.03	3.81	4.69	33.26	39.92	0.79	5.24	-1.55
TZEI 22 x TZEI 54	2498	56.36	54.17	2.17	3.42	5.38	29.36	42.50	0.77	5.29	-1.70
TZEI 4 x ENT 16	2631	56.08	54.30	1.89	3.50	4.72	32.50	42.47	0.68	5.20	-1.74
Mean	2613	55.53	53.52	2.1	3.46	4.76	26.03	35.7	0.78	5.19	
Min	775	50.20	50.33	0.00	1.72	2.70	0.58	2.84	0.38	3.74	
Max	4735	61.15	57.11	5.59	6.61	7.47	68.91	100.47	1.08	6.79	
Lsd	978	2.14	0.91	1.90	0.98	1.04	18.90	22.14	0.17	0.85	

Appendix 4.10 continued. Grain yield and other agronomic traits of some selected hybrids (best 20 and worst 10) evaluated under *Striga*-infested environments at Abuja and Mokwa in 2011 and 2012

HYBRID	Grain yield kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	*Striga* damage score		*Striga* emergence		Ears per plant	Ear aspect	Base index
					8 WAP	10 WAP	8 WAP	10 WAP			
TZEI 39 x ENT 3	2803	56.08	54.07	1.85	2.67	4.20	37.91	82.16	0.86	5.22	-1.79
TZEI 157 x TZEI 135	2149	54.09	52.49	1.60	3.87	4.97	19.85	35.66	0.70	5.28	-1.86
TZEI 17 x ENT 13	1827	56.46	52.98	3.55	3.32	4.51	28.27	34.31	0.75	5.40	-1.90
TZEI 89 x TZEI 33	1680	55.33	53.98	1.49	4.63	5.99	14.15	22.97	0.88	5.29	-1.99
TZEI 149 x TZEI 142	2242	54.70	53.43	1.23	3.84	5.02	25.93	39.24	0.74	5.33	-2.06
TZEI 175 x TZEI 142	2055	58.41	56.24	2.10	4.05	5.40	20.20	29.71	0.71	5.19	-2.21
TZEI 173 x TZEI 9	2347	55.39	53.69	1.77	3.82	4.72	36.29	37.74	0.75	5.24	-2.22
TZEI 56 x ENT 16	2064	57.54	54.09	3.54	4.41	5.26	17.66	24.68	0.63	5.46	-2.44
TZEI 22 x ENT 16	2226	57.83	54.03	3.84	4.10	5.30	24.69	35.47	0.71	5.76	-2.54
TZEI 108 x TZEI 56	1946	55.83	53.68	2.49	4.96	5.85	13.63	19.36	0.70	5.86	-2.57
TZEI 32 x TZEI 56	2118	58.76	53.69	5.03	4.00	5.49	24.34	34.78	0.73	5.70	-2.63
TZEI 32 x TZEI 22	2950	57.53	54.13	3.39	3.30	5.09	49.67	52.24	0.76	5.70	-2.64
TZEI 108 x TZEI 22	1922	54.48	53.17	1.29	4.04	5.63	22.23	34.50	0.79	5.42	-2.66
TZEI 89 x TZEI 32	2319	57.87	53.78	4.07	4.19	5.61	22.49	33.57	0.67	5.43	-2.69
TZEI 65 x TZEI 32	2249	53.90	52.53	1.30	3.46	4.98	30.53	41.87	0.67	5.73	-2.79
TZEI 135 x TZEI 9	2395	53.66	52.52	1.15	4.02	5.71	31.30	35.70	0.71	5.16	-3.02
TZEI 10 x ENT 13	2347	55.12	53.65	1.34	3.39	4.75	38.00	59.46	0.79	5.58	-3.15
TZEI 56 x TZEI 65	2043	57.92	53.40	4.62	4.83	5.39	20.31	30.39	0.69	5.61	-3.15
TZEI 146 x ENT 13	2207	57.09	53.62	3.48	3.74	5.35	34.47	41.04	0.73	5.66	-3.32
TZEI 65 x TZEI 33	1962	56.57	52.67	4.26	4.03	5.49	19.99	32.91	0.62	5.52	-3.43
TZEI 17 x TZEI 149	2140	55.30	52.92	2.33	3.66	5.06	37.01	45.66	0.75	5.08	-3.51
TZEI 4 x TZEI 89	1915	54.71	53.99	1.26	4.58	5.62	23.83	27.61	0.69	5.38	-3.64
ENT 16 x ENT 3	2136	58.54	54.21	4.29	3.40	4.89	34.83	45.58	0.66	5.33	-3.64
TZEI 39 x TZEI 33	2308	54.68	52.67	2.01	2.34	4.38	55.86	61.76	0.78	5.25	-3.70
Chk 2 TZEI 5 x TZEI 98	1938	59.33	55.40	3.85	5.29	5.88	15.90	24.23	0.65	5.61	-3.89
TZEI 33 x TZEI 4	2016	55.76	54.52	1.66	3.92	5.29	28.81	41.48	0.67	5.38	-3.92
ENT 3 x TZEI 56	2420	57.06	54.19	2.87	4.14	5.47	36.38	46.26	0.71	5.21	-3.99
TZEI 54 x TZEI 32	1673	55.45	53.43	1.97	4.82	5.78	20.67	29.91	0.69	6.13	-4.48
ENT 13 x TZEI 177	2119	54.14	52.73	1.28	3.42	4.66	51.95	58.15	0.83	5.68	-4.49
TZEI 22 x TZEI 89	1979	58.67	54.12	4.50	4.87	6.02	18.23	22.81	0.53	5.70	-4.58
TZEI 4 x TZEI 54	1453	54.84	53.47	1.51	4.78	6.72	14.40	23.04	0.71	5.92	-4.74
TZEI 142 x TZEI 135	1583	58.64	54.87	3.78	4.81	6.03	18.94	29.94	0.68	6.03	-4.85
Mean	2613	55.53	53.52	2.1	3.46	4.76	26.03	35.7	0.78	5.19	
Min	775	50.20	50.33	0	1.72	2.70	0.58	2.84	0.38	3.74	
Max	4735	61.15	57.11	5.59	6.61	7.47	68.91	100.47	1.08	6.79	
Lsd	978	2.14	0.91	1.90	0.98	1.04	18.90	22.14	0.17	0.85	

Appendix 4.10 continued. Grain yield and other agronomic traits of some selected hybrids (best 20 and worst 10) evaluated under *Striga*-infested environments at Abuja and Mokwa in 2011 and 2012

HYBRID	Grain yield kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	*Striga* damage score		*Striga* emergence		Ears per plant	Ear aspect	Base index
					8 WAP	10 WAP	8 WAP	10 WAP			
ENT 3 x TZEI 4	1958	59.93	55.22	4.70	3.06	4.88	41.06	49.64	0.61	6.04	-4.98
ENT 12 x TZEI 54	1766	55.51	53.67	1.94	4.54	5.98	25.27	32.28	0.66	5.84	-5.01
TZEI 108 x TZEI 168	1605	56.51	52.60	4.15	5.21	6.54	19.93	26.36	0.72	6.07	-5.20
TZEI 39 x TZEI 32	2414	54.77	53.21	1.63	3.39	4.98	52.85	63.13	0.73	5.36	-5.22
TZEI 9 x TZEI 142	1974	54.05	53.38	0.61	4.36	5.92	31.42	38.40	0.65	4.98	-5.23
ENT 3 x TZEI 22	2116	57.58	54.90	2.71	3.10	4.93	38.69	64.97	0.64	5.26	-5.25
TZEI 9 x TZEI 184	1699	53.70	52.47	1.25	4.30	5.91	29.01	39.14	0.69	5.79	-5.37
TZEI 177 x TZEI 135	1429	52.53	51.85	0.75	4.39	5.69	29.94	32.78	0.72	6.37	-5.40
ENT 3 x TZEI 168	2206	56.57	53.54	3.14	4.15	5.86	35.87	48.91	0.66	5.52	-5.45
TZEI 149 x TZEI 157	1232	54.52	53.41	1.41	4.03	5.41	24.37	33.17	0.63	5.81	-5.51
TZEI 54 x ENT 3	1100	55.18	53.47	1.70	5.31	6.63	13.06	11.64	0.66	6.79	-5.53
TZEI 168 x TZEI 89	1789	57.63	52.85	4.87	5.17	6.45	18.27	23.37	0.55	6.31	-5.58
TZEI 54 x TZEI 108	1600	53.66	53.07	0.84	5.26	6.47	21.71	24.47	0.68	6.21	-5.58
TZEI 135 x TZEI 149	1596	55.03	52.71	2.80	4.61	6.26	26.81	28.67	0.66	6.20	-5.67
TZEI 32 x TZEI 168	2332	55.44	53.11	2.46	4.54	5.48	40.12	45.22	0.60	5.66	-5.75
TZEI 146 x TZEI 9	2063	55.46	53.05	2.74	3.96	5.48	45.38	49.61	0.69	5.86	-5.87
TZEI 4 x TZEI 65	1491	54.27	53.28	1.18	4.46	5.60	32.15	43.37	0.64	5.98	-6.74
TZEI 4 x TZEI 39	2683	54.75	53.12	1.75	3.03	4.35	68.91	100.47	0.75	5.17	-7.36
TZEI 135 x TZEI 24	1762	56.43	52.66	3.82	4.52	6.06	35.09	50.76	0.62	6.11	-7.47
TZEI 65 x ENT 3	1598	57.20	53.31	3.91	5.03	6.55	27.51	39.22	0.61	5.78	-7.50
TZEI 135 x ENT 13	1643	55.54	52.85	2.72	4.67	6.02	42.65	47.81	0.72	5.84	-7.54
TZEI 168 x ENT 16	1110	58.60	53.17	5.45	5.87	6.51	13.03	13.46	0.43	6.47	-7.84
TZEI 168 x TZEI 65	1168	54.24	52.41	1.65	5.54	6.86	20.64	32.21	0.64	6.22	-8.04
TZEI 54 x TZEI 33	1382	57.85	53.06	5.07	5.08	6.23	30.50	40.56	0.57	6.43	-8.39
ENT 16 x TZEI 108	1566	57.19	53.54	3.99	5.50	6.62	27.25	35.67	0.50	6.05	-8.70
TZEI 33 x TZEI 168	1212	55.92	52.89	2.87	6.00	6.92	26.47	36.05	0.61	5.95	-9.37
TZEI 89 x ENT 3	1286	61.15	55.48	5.59	5.39	6.89	26.20	38.84	0.48	6.45	-9.82
TZEI 89 x TZEI 108	1437	57.34	52.99	4.40	5.64	6.84	29.95	39.79	0.50	6.30	-9.83
Chk 1 TZEI 26 x TZEI 5	988	58.74	53.64	5.19	5.95	7.05	32.04	42.87	0.45	6.69	-12.28
TZEI 168 x TZEI 54	775	57.39	53.05	4.24	6.61	7.47	26.42	38.12	0.38	6.74	-13.54
Mean	2613	55.53	53.52	2.1	3.46	4.76	26.03	35.7	0.78	5.19	
Min	775	50.20	50.33	0	1.72	2.70	0.58	2.84	0.38	3.74	
Max	4735	61.15	57.11	5.59	6.61	7.47	68.91	100.47	1.08	6.79	
Lsd	978	2.14	0.91	1.90	0.98	1.04	18.90	22.14	0.17	0.85	

Appendix 4.12. Grain yield and other agronomic traits of early maturing maize hybrids (best 20 and worst 10) evaluated under low N environments in Ile-Ife and Mokwa in 2011 and 2012.

Hybrids	Grain yield Kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	SG* (1-9)	Ears per plant	Ear aspect (1-9)	Base index
ENT 16 x TZEI 32	5541	56.95	55.33	1.49	4.10	2.23	0.98	3.38	15.11
Chk 2 TZEI 5 x TZEI 98	5095	56.16	55.73	0.47	3.96	3.83	1.01	3.85	11.63
TZEI 33 x ENT 12	4304	55.91	55.18	0.72	4.08	2.89	0.93	3.95	8.98
ENT 11 x TZEI 22	4146	58.21	58.01	0.46	4.06	4.02	0.99	4.02	7.26
ENT 11 x TZEI 4	4287	57.00	56.12	0.82	4.43	3.39	0.95	4.03	7.12
ENT 12 x TZEI 39	4073	55.71	55.16	0.56	4.26	3.41	0.96	4.27	6.88
TZEI 33 x TZEI 168	3873	54.05	53.30	1.06	4.42	2.81	1.01	4.56	6.76
TZEI 32 x ENT 12	4855	57.10	55.92	1.20	4.70	3.38	0.90	4.20	6.59
TZEI 32 x TZEI 168	4519	54.50	53.13	1.44	4.75	3.21	0.99	4.48	6.36
TZEI 4 x ENT 16	4237	56.28	54.74	1.48	4.39	3.02	0.95	4.38	6.06
TZEI 32 x TZEI 56	4041	55.89	54.67	1.14	4.05	3.16	0.96	4.58	5.99
TZEI 24 x TZEI 142	4093	55.52	54.44	1.33	3.98	3.54	0.96	4.19	5.84
ENT 12 x ENT 16	3858	57.38	55.70	1.67	4.29	2.72	0.96	4.28	5.80
TZEI 32 x TZEI 4	4298	56.79	55.31	1.41	4.51	3.14	0.95	4.40	5.71
ENT 13 x TZEI 184	3787	55.12	54.20	0.83	4.26	3.74	1.00	4.19	5.69
ENT 16 x ENT 11	4168	57.06	56.43	0.63	4.66	3.79	0.94	4.07	5.56
TZEI 65 x ENT 11	4153	55.99	55.35	0.89	4.58	3.57	0.97	4.44	5.40
TZEI 168 x ENT 16	3897	55.73	54.32	1.44	4.24	3.30	0.99	4.33	5.40
TZEI 56 x ENT 16	3990	56.48	55.19	1.42	4.35	3.32	1.00	4.54	5.18
TZEI 168 x TZEI 54	4022	54.48	52.85	1.71	4.71	2.92	1.02	4.72	5.08
TZEI 175 x TZEI 184	4012	56.20	54.76	1.40	4.58	3.20	0.93	4.03	4.98
TZEI 10 x ENT 13	3678	55.43	54.30	1.16	3.81	3.28	0.96	4.60	4.86
ENT 11 x TZEI 168	4190	54.92	54.00	0.92	4.78	3.97	0.99	4.33	4.72
TZEI 54 x TZEI 32	3513	56.16	54.67	1.53	4.43	2.57	0.96	4.43	4.63
ENT 11 x TZEI 56	3967	57.11	55.96	1.08	4.41	3.45	0.94	4.46	4.49
TZEI 10 x TZEI 149	3761	52.61	52.26	0.43	5.03	3.42	1.00	4.74	4.48
Chk 6 TZEI 1 x TZEI 5	4408	56.36	54.84	1.38	4.41	3.91	0.93	4.30	4.48
TZEI 142 x TZEI 146	3669	56.48	55.23	1.26	3.83	3.79	0.94	3.96	4.43
TZEI 4 x TZEI 39	3619	55.19	54.50	1.03	4.12	2.75	0.88	4.70	3.98
TZEI 39 x ENT 3	3813	56.09	55.05	1.04	4.43	2.94	0.90	4.67	3.96
TZEI 157 x TZEI 10	3360	53.95	53.05	0.87	4.63	3.05	0.96	4.51	3.83
ENT 16 x TZEI 108	3990	56.19	55.06	1.21	4.11	4.18	0.97	4.54	3.56
ENT 12 x TZEI 54	3830	56.18	54.44	1.85	4.49	3.35	1.00	4.56	3.56
ENT 12 x TZEI 89	3871	58.23	57.16	1.07	4.47	3.71	0.94	4.38	3.54
TZEI 17 x TZEI 149	3584	56.02	55.04	1.24	3.83	3.43	0.94	4.83	3.24
TZEI 17 x TZEI 9	4019	56.12	54.47	1.78	4.38	3.99	0.92	3.81	3.20
TZEI 54 x ENT 11	3558	57.61	56.40	1.27	4.47	3.45	0.99	4.73	3.14
TZEI 157 x TZEI 17	3581	55.55	54.58	1.04	4.84	3.52	0.98	4.55	2.88
TZEI 89 x ENT 3	3935	58.42	56.59	1.92	4.41	3.56	0.94	4.32	2.85
TZEI 173 x ENT 13	3853	57.30	55.14	2.23	4.30	3.60	0.98	4.33	2.83
TZEI 146 x TZEI 149	3821	53.41	52.42	1.24	4.90	3.56	0.96	4.53	2.79
ENT 3 x TZEI 56	3674	57.47	55.43	2.02	4.97	3.20	1.04	4.72	2.79
TZEI 89 x TZEI 33	3417	55.78	55.02	0.80	4.52	3.68	0.98	4.68	2.72
TZEI 173 x TZEI 9	3840	56.50	54.95	1.66	4.06	4.07	0.95	4.28	2.68
TZEI 184 x TZEI 173	3825	56.62	55.17	1.95	4.40	3.51	0.94	4.31	2.65
TZEI 149 x TZEI 184	3488	53.98	52.92	1.31	4.92	3.29	1.00	4.69	2.60
ENT 16 x TZEI 33	3469	56.80	55.09	1.73	4.41	2.78	0.95	4.85	2.60
TZEI 89 x ENT 11	4089	56.72	56.60	0.89	4.74	4.27	0.94	4.50	2.54
TZEI 146 x TZEI 175	3728	57.00	55.65	1.40	4.76	3.37	0.91	4.37	2.27
TZEI 24 x TZEI 157	3168	54.66	53.58	1.29	4.79	3.03	0.98	4.63	2.27
TZEI 184 x TZEI 135	3568	55.04	53.73	1.34	4.70	3.48	1.00	4.94	2.25
ENT 12 x TZEI 65	3878	55.85	54.30	1.48	4.89	3.80	0.95	4.36	2.22
Mean	3375	56.1	54.73	1.43	4.93	3.52	0.93	4.78	
Min	1254	52.2	51.92	0.41	3.81	2.23	0.75	3.38	
Max	5541	62	58.11	4.21	6.98	5.02	1.05	6.47	
Lsd	803	1.48	1.28	0.95	0.80	0.67	0.09	0.60	
SE	578	1.06	0.92	0.68	0.57	0.48	0.07	0.43	

Appendix 4.12 continued. Grain yield and other agronomic traits of early maturing maize hybrids (best 20 and worst 10) evaluated under low N environments in Ile-Ife and Mokwa in 2011 and 2012.

Hybrids	Grain yield Kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	SG* (1-9)	Ears per plant	Ear aspect (1-9)	Base index
ENT 3 x ENT 12	3653	58.18	56.76	1.45	4.57	3.72	0.95	4.40	2.14
ENT 13 x TZEI 23	3403	54.25	52.87	1.45	5.06	3.55	1.05	4.70	2.12
ENT 13 x TZEI 142	4129	56.88	55.24	1.73	4.73	4.19	0.95	4.31	1.99
TZEI 142 x TZEI 10	3757	56.11	55.54	0.64	4.24	4.24	0.90	4.65	1.96
TZEI 9 x TZEI 184	3452	55.14	53.51	1.55	4.19	3.79	0.95	4.41	1.92
TZEI 54 x TZEI 108	3418	54.97	53.67	1.34	4.76	3.19	0.97	4.95	1.85
TZEI 177 x TZEI 17	3316	54.81	53.74	1.06	5.31	3.22	0.96	4.42	1.84
TZEI 108 x TZEI 168	3425	54.32	53.04	1.06	4.66	3.51	0.95	4.73	1.80
TZEI 135 x TZEI 9	3478	54.11	53.63	0.48	4.92	4.12	0.98	4.72	1.72
TZEI 4 x TZEI 65	3497	56.01	54.89	1.07	4.97	3.13	0.94	4.92	1.70
ENT 11 x ENT 12	3689	57.73	57.26	0.96	4.72	3.65	0.88	4.51	1.58
TZEI 39 x TZEI 32	3577	55.98	54.52	1.45	5.37	2.95	0.94	4.72	1.52
TZEI 146 x ENT 13	3570	55.93	55.00	0.87	5.15	3.75	0.95	4.55	1.49
TZEI 177 x TZEI 10	3072	54.55	53.42	1.04	4.90	2.96	0.95	4.76	1.46
TZEI 17 x ENT 13	3420	57.01	54.59	2.38	4.79	3.13	0.97	4.31	1.35
TZEI 56 x TZEI 65	3692	55.45	54.31	1.11	4.76	3.44	0.90	4.86	1.29
TZEI 17 x TZEI 24	3349	56.39	54.65	1.71	5.30	3.27	1.00	4.53	1.19
TZEI 146 x TZEI 9	3615	54.93	54.59	0.61	5.11	4.59	0.99	4.45	1.16
TZEI 10 x TZEI 9	3581	55.53	54.46	1.22	4.89	4.14	0.99	4.66	0.97
TZEI 184 x TZEI 17	3437	56.06	54.49	1.54	4.84	3.39	0.97	4.88	0.93
TZEI 149 x TZEI 142	3747	55.51	54.17	1.42	4.81	4.17	0.96	4.56	0.92
TZEI 56 x TZEI 89	3334	56.36	55.18	1.12	4.69	3.86	0.94	4.59	0.67
TZEI 65 x ENT 3	3242	56.07	54.76	1.74	4.49	3.17	0.94	4.91	0.60
ENT 3 x TZEI 168	3507	57.19	55.11	1.97	5.09	3.48	1.00	4.74	0.58
TZEI 4 x TZEI 89	3552	55.71	55.38	1.26	4.95	3.60	0.92	4.78	0.54
TZEI 168 x TZEI 65	3383	54.88	53.66	1.19	5.03	3.47	0.91	4.56	0.52
TZEI 65 x TZEI 33	2860	55.61	54.17	1.40	4.56	2.84	0.94	4.94	0.50
TZEI 135 x TZEI 24	3471	53.34	52.09	1.18	4.95	3.33	0.89	4.84	0.27
ENT 3 x TZEI 4	2892	57.91	56.65	1.34	4.58	3.18	0.99	5.21	0.26
TZEI 89 x TZEI 32	3752	57.43	55.80	1.67	4.64	3.72	0.90	4.80	0.25
Chk 3 TZEI 24 x TZEI 17	3475	56.13	54.92	1.36	4.86	3.51	0.90	4.71	0.23
TZEI 168 x TZEI 89	3508	55.65	54.18	1.53	4.96	3.30	0.91	4.83	0.20
TZEI 65 x TZEI 32	3056	56.67	55.50	1.32	5.17	2.72	0.96	5.28	0.19
TZEI 32 x TZEI 22	3906	57.32	55.35	1.84	5.01	3.35	0.87	4.75	0.15
TZEI 24 x TZEI 23	2879	52.20	51.92	0.41	5.25	3.41	0.96	4.97	0.09
TZEI 142 x TZEI 17	3913	56.17	54.83	1.55	5.02	4.15	0.84	3.93	0.03
TZEI 173 x TZEI 24	3042	58.07	56.48	1.63	4.68	3.50	1.00	4.93	-0.01
TZEI 23 x TZEI 146	3240	53.70	53.24	1.01	5.34	3.66	0.95	4.82	-0.46
TZEI 168 x TZEI 39	3371	55.60	54.02	1.57	5.41	3.54	0.96	4.73	-0.49
TZEI 177 x TZEI 146	3458	53.86	53.26	0.67	5.21	3.75	0.88	4.89	-0.62
TZEI 175 x TZEI 23	3230	55.71	54.05	1.56	5.41	3.32	0.97	4.92	-0.63
TZEI 135 x ENT 13	3448	54.88	53.54	1.40	4.83	4.04	0.92	4.64	-0.66
TZEI 54 x TZEI 33	2820	54.86	53.29	1.49	4.71	2.62	0.92	5.30	-0.69
ENT 13 x TZEI 177	3484	53.64	52.59	1.13	5.39	4.12	0.97	4.85	-0.76
ENT 3 x TZEI 22	3354	57.58	55.86	1.73	5.00	3.54	0.92	4.73	-0.77
TZEI 146 x TZEI 24	3145	55.76	54.64	1.26	4.94	3.82	0.96	4.89	-0.77
Chk 5 TZEI 2 x TZEI 87	3450	55.86	54.86	1.02	5.35	3.86	0.94	4.99	-0.78
TZEI 33 x TZEI 4	2830	57.18	56.48	0.82	5.43	2.84	0.88	4.83	-0.88
TZEI 22 x TZEI 65	3568	56.59	54.92	1.67	5.11	3.52	0.91	5.02	-1.02
TZEI 56 x TZEI 39	3129	55.43	54.26	1.24	4.92	3.82	0.97	5.13	-1.13
TZEI 23 x TZEI 17	3015	54.11	53.21	1.34	5.54	3.09	0.97	5.20	-1.26
TZEI 39 x ENT 11	3607	56.49	55.46	1.14	5.07	3.47	0.75	4.37	-1.27
Mean	3375	56.1	54.73	1.43	4.93	3.52	0.93	4.78	
Min	1254	52.2	51.92	0.41	3.81	2.23	0.75	3.38	
Max	5541	62	58.11	4.21	6.98	5.02	1.05	6.47	
Lsd	803	1.48	1.28	0.95	0.80	0.67	0.09	0.60	
SE	578	1.06	0.92	0.68	0.57	0.48	0.07	0.43	

Appendix 4.12 continued.

Hybrids	Grain yield Kg ha^{-1}	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	SG* (1-9)	Ears per plant	Ear aspect (1-9)	Base index
TZEI 108 x TZEI 56	3171	54.81	53.58	1.21	4.88	4.06	0.93	4.84	-1.51
TZEI 175 x TZEI 177	3333	56.14	54.59	1.56	4.93	3.89	0.91	4.76	-1.58
TZEI 54 x ENT 3	3149	56.79	54.76	1.96	5.32	3.12	0.92	4.82	-1.69
ENT 13 x TZEI 157	3120	55.40	54.26	1.15	5.28	3.60	0.94	5.16	-1.76
TZEI 184 x TZEI 146	2886	55.96	54.70	1.12	5.68	3.37	0.95	4.83	-1.77
TZEI 23 x TZEI 10	3220	54.10	52.64	1.76	5.22	3.51	0.97	5.20	-1.78
TZEI 22 x ENT 16	3435	58.43	55.88	2.61	5.10	3.43	0.94	4.81	-1.97
TZEI 173 x TZEI 149	3257	57.16	54.61	2.46	4.86	3.68	0.97	4.88	-2.00
TZEI 4 x TZEI 54	3074	56.75	55.42	1.43	5.62	3.33	0.95	5.13	-2.04
TZEI 9 x TZEI 157	2671	54.77	54.51	0.92	4.63	4.07	0.92	4.80	-2.25
TZEI 89 x TZEI 108	3341	55.98	54.61	1.40	5.20	3.96	0.87	4.69	-2.52
TZEI 135 x TZEI 149	2772	53.78	52.69	1.01	5.73	3.32	0.92	4.92	-2.63
Chk 1 TZEI 26 x TZEI 5	3145	56.92	55.27	1.71	4.98	4.44	1.00	5.03	-2.69
TZEI 157 x TZEI 146	2784	55.85	54.37	1.36	5.36	3.21	0.90	5.04	-2.80
TZEI 108 x ENT 12	2859	57.48	56.10	1.37	4.68	3.45	0.87	5.20	-2.81
TZEI 135 x TZEI 175	3217	56.92	54.70	2.03	5.32	3.50	0.92	5.01	-2.88
TZEI 22 x TZEI 54	3140	57.73	56.17	1.64	5.03	3.37	0.87	5.17	-2.93
Chk 4 TZEI 23 x TZEI 13	3021	56.27	54.41	1.99	5.21	3.43	0.91	4.95	-3.08
TZEI 142 x TZEI 135	3321	56.90	55.34	1.57	4.95	3.77	0.80	4.75	-3.41
TZEI 39 x TZEI 108	3043	54.80	53.98	1.14	5.50	3.81	0.89	5.03	-3.45
TZEI 175 x TZEI 142	3295	59.71	58.11	2.01	4.26	4.30	0.80	4.38	-3.53
TZEI 108 x TZEI 4	3108	55.33	54.09	1.33	5.02	3.88	0.83	4.95	-3.79
TZEI 157 x TZEI 135	2719	55.55	53.62	1.93	5.24	3.48	0.97	5.39	-4.08
TZEI 22 x TZEI 39	2938	57.55	56.02	1.62	5.07	3.69	0.87	5.18	-4.35
ENT 16 x ENT 3	3156	59.27	56.35	2.88	5.37	3.39	0.90	4.80	-4.35
TZEI 24 x TZEI 177	2718	53.48	52.58	0.93	6.02	3.35	0.88	5.21	-4.59
TZEI 33 x TZEI 22	2863	57.63	55.51	2.03	5.05	3.15	0.82	5.07	-4.63
TZEI 142 x TZEI 173	3440	60.29	56.92	3.24	4.46	4.05	0.82	4.39	-4.69
TZEI 9 x TZEI 177	2470	54.50	53.56	1.06	5.06	4.37	0.97	5.28	-4.76
TZEI 149 x TZEI 177	2323	54.52	53.43	0.97	5.89	3.17	0.92	5.40	-4.91
TZEI 33 x TZEI 56	2811	56.53	54.01	2.35	5.13	3.23	0.89	5.27	-4.93
TZEI 22 x TZEI 89	2889	57.06	55.71	1.36	5.77	3.86	0.93	5.39	-4.95
TZEI 23 x TZEI 135	2786	54.11	52.75	1.39	5.48	3.42	0.86	5.37	-5.09
TZEI 9 x TZEI 23	2551	54.51	53.60	1.03	5.75	3.83	0.93	5.49	-5.52
TZEI 149 x TZEI 23	2206	53.20	52.51	0.67	6.05	3.34	0.96	5.85	-5.67
TZEI 10 x TZEI 24	2339	56.06	54.50	1.98	5.25	3.04	0.91	5.54	-5.67
TZEI 177 x TZEI 135	2424	53.92	52.98	1.23	5.68	3.63	0.86	4.97	-5.99
TZEI 65 x TZEI 108	2422	54.81	53.77	1.09	5.24	3.96	0.88	5.43	-6.17
TZEI 9 x TZEI 142	3176	57.46	55.79	1.68	5.00	5.02	0.84	4.67	-6.18
TZEI 157 x TZEI 173	2928	57.37	55.62	1.70	5.51	3.82	0.83	5.16	-6.22
TZEI 10 x TZEI 175	2605	58.07	55.94	2.15	5.61	3.75	0.90	5.03	-6.62
TZEI 177 x TZEI 173	2611	56.27	54.32	1.84	5.61	3.54	0.86	5.18	-6.63
TZEI 23 x TZEI 173	2628	56.33	53.93	2.42	5.24	3.50	0.88	5.34	-6.74
TZEI 17 x TZEI 175	2477	59.30	57.13	2.24	5.91	3.62	0.94	5.35	-7.39
TZEI 39 x TZEI 33	2307	55.82	53.92	1.91	5.68	3.22	0.86	5.53	-7.71
TZEI 108 x TZEI 22	2724	56.28	54.59	1.78	5.44	3.89	0.80	5.46	-8.27
TZEI 175 x TZEI 157	2525	58.96	56.36	2.55	5.44	3.69	0.82	5.25	-9.09
TZEI 149 x TZEI 157	2212	54.99	54.33	0.92	6.41	3.54	0.85	5.84	-9.23
TZEI 56 x TZEI 54	1866	57.64	54.96	2.52	6.09	3.07	0.88	5.90	-11.12
TZEI 24 x TZEI 184	1657	58.57	56.31	2.28	6.46	2.89	0.90	6.18	-11.79
TZEI 184 x TZEI 10	1340	59.15	56.76	2.34	6.49	3.60	0.81	6.40	-16.75
TZEI 173 x TZEI 175	1254	62.00	57.73	4.21	6.98	4.01	0.76	6.47	-23.22
Mean	3375	56.1	54.73	1.43	4.93	3.52	0.93	4.78	
Min	1254	52.2	51.92	0.41	3.81	2.23	0.75	3.38	
Max	5541	62	58.11	4.21	6.98	5.02	1.05	6.47	
Lsd	803	1.48	1.28	0.95	0.80	0.67	0.09	0.60	
SE	578	1.06	0.92	0.68	0.57	0.48	0.07	0.43	

Appendix 4.14. Grain yield and other agronomic traits of the best 20 and worst 10 hybrids evaluated under optimum environments at Ile-Ife and Mokwa in 2011 and 2012

HYBRID	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	Root lodging (%)	Stalk lodging (%)	Husk cover (1-5)	Ears per plant	Ear aspect (1-9)	Ear rot (%)
ENT 12 x TZEI 89	6426	56.43	56.07	0.57	4.11	0.00	11.77	2.08	1.00	2.88	4.27
TZEI 32 x ENT 12	6386	54.61	54.10	0.86	3.76	0.56	2.89	2.38	0.95	3.49	3.79
ENT 11 x TZEI 4	6082	55.08	54.91	0.11	3.39	0.76	7.33	1.80	0.98	3.60	1.33
Chk 2 TZEI 5 x TZEI 98	6023	54.02	53.67	0.58	3.31	2.63	6.59	1.56	1.00	3.90	3.07
TZEI 32 x TZEI 22	5949	54.86	53.71	1.06	3.90	2.00	4.87	2.16	0.95	4.26	6.25
TZEI 175 x TZEI 142	5946	56.22	54.61	1.59	2.82	2.13	2.70	1.49	0.91	3.86	4.31
TZEI 32 x TZEI 168	5941	53.11	52.25	0.80	4.01	0.31	3.65	2.21	1.03	3.77	0.60
TZEI 33 x ENT 12	5908	55.09	54.84	0.30	3.89	0.00	16.07	1.79	0.98	4.33	3.50
TZEI 4 x ENT 16	5760	54.15	52.77	1.34	3.22	1.69	4.26	1.83	0.98	3.20	5.95
TZEI 142 x TZEI 173	5698	56.05	55.05	1.49	3.19	0.00	4.77	1.56	0.98	3.42	2.94
TZEI 4 x TZEI 89	5682	53.49	52.18	1.54	3.99	0.00	2.77	1.91	1.00	4.03	4.11
ENT 16 x ENT 11	5621	55.44	54.65	0.78	3.51	2.46	5.36	1.86	0.97	4.34	0.00
TZEI 184 x TZEI 173	5620	53.72	52.63	1.10	3.09	1.86	4.09	1.47	0.99	3.75	7.00
TZEI 142 x TZEI 146	5588	53.62	53.21	0.42	3.27	0.00	0.00	1.70	0.97	2.99	2.34
TZEI 17 x TZEI 9	5548	53.60	52.83	0.80	3.56	0.65	14.43	2.19	1.00	3.29	4.95
ENT 16 x TZEI 108	5546	52.67	51.98	0.56	2.92	0.12	7.30	1.45	0.97	4.00	3.17
ENT 3 x ENT 12	5545	55.87	55.09	0.96	3.42	0.00	18.28	1.86	0.96	4.03	1.76
ENT 11 x TZEI 168	5523	53.29	53.31	0.49	3.37	0.54	6.08	1.92	0.95	3.37	1.30
ENT 12 x TZEI 39	5509	53.42	53.07	0.28	3.67	0.91	8.68	1.76	0.96	4.00	7.16
TZEI 168 x ENT 16	5499	53.03	52.36	0.69	3.31	0.00	3.27	1.62	1.00	3.72	3.94
TZEI 10 x ENT 13	5486	54.12	52.98	1.09	3.16	0.00	9.85	1.88	1.00	3.57	2.29
ENT 3 x TZEI 4	5479	56.52	55.38	1.12	3.35	0.74	3.60	1.64	0.94	4.17	4.06
TZEI 89 x ENT 3	5450	57.52	55.52	2.09	3.90	1.80	4.26	1.94	0.97	4.17	2.79
TZEI 65 x ENT 11	5430	54.19	54.23	0.79	3.29	1.81	9.90	1.88	0.97	4.35	1.05
TZEI 22 x TZEI 39	5399	53.61	53.06	0.59	3.59	0.15	3.20	1.99	0.96	4.22	3.19
TZEI 39 x TZEI 32	5390	52.91	52.40	0.53	3.89	0.00	0.69	1.98	0.96	3.70	5.15
TZEI 89 x ENT 11	5388	55.01	54.06	0.75	3.79	4.71	17.38	1.71	0.96	4.43	0.16
TZEI 32 x TZEI 56	5386	54.01	52.88	1.14	3.31	0.00	4.22	1.91	0.99	4.20	7.12
TZEI 146 x TZEI 175	5383	54.07	53.51	0.57	4.16	0.17	4.07	1.94	0.99	4.07	2.50
TZEI 56 x ENT 16	5361	54.43	53.21	1.28	3.18	1.90	2.54	1.49	1.00	4.12	2.79
Mean	4640	54.01	53.11	0.99	4.19	1.35	9.03	1.99	0.97	4.36	5.28
Min	1915	51.44	51.15	0.11	2.82	0	0	1.45	0.81	2.88	0
Max	6426	59.58	56.54	3.69	6.25	12.81	38.33	2.53	1.03	6.22	17.89
Lsd	719	1.28	1.16	0.82	0.74	3.03	9.66	0.35	0.06	0.73	5.25
SE	517	0.92	0.84	0.59	0.54	4.22	6.96	0.25	0.04	0.52	3.78

Appendix 4.14 continued. Grain yield and other agronomic traits of the best 20 and worst 10 hybrids evaluated under optimum environments at Ile-Ife and Mokwa in 2011 and 2012

HYBRID	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	Root lodging (%)	Stalk lodging (%)	Husk cover (1-5)	Ears per plant	Ear aspect (1-9)	Ear rot (%)
TZEI 142 x TZEI 10	5345	53.71	52.96	0.98	3.64	2.60	9.23	1.98	0.97	3.35	2.80
ENT 3 x TZEI 168	5337	54.54	53.28	1.22	4.30	0.00	6.84	2.06	0.97	4.18	0.69
ENT 3 x TZEI 22	5315	55.05	53.84	1.19	3.69	0.00	15.65	1.80	0.95	3.89	3.91
TZEI 32 x TZEI 4	5313	54.40	53.75	0.62	3.91	0.00	0.15	1.90	0.96	4.09	9.88
TZEI 54 x ENT 11	5310	54.61	53.90	0.67	3.76	4.14	6.29	1.96	0.96	4.51	0.67
TZEI 142 x TZEI 135	5305	55.26	53.72	1.47	3.42	0.03	10.72	1.81	0.94	3.61	5.25
TZEI 175 x TZEI 184	5297	55.05	53.76	1.27	3.92	0.00	0.57	1.75	0.98	4.65	6.01
Chk 6 TZEI 1 x TZEI 5	5293	55.39	54.27	1.08	4.03	0.00	7.93	2.08	0.99	4.00	3.28
ENT 11 x ENT 12	5285	56.23	55.45	0.77	3.82	3.70	9.91	1.89	0.94	3.59	1.22
ENT 16 x TZEI 32	5259	56.30	54.60	1.72	4.26	0.00	0.27	1.96	0.97	4.08	4.62
TZEI 22 x ENT 16	5250	54.63	53.55	1.07	3.99	0.00	12.12	2.09	0.97	4.26	2.83
TZEI 89 x TZEI 32	5243	55.28	54.34	1.06	4.37	2.67	2.63	2.24	1.00	4.33	3.09
TZEI 54 x ENT 3	5224	54.00	52.96	1.05	4.19	1.68	4.41	2.08	0.95	4.35	6.18
TZEI 22 x TZEI 89	5210	54.85	53.94	0.94	4.10	1.72	9.41	2.16	1.02	4.03	1.25
TZEI 22 x TZEI 65	5201	53.59	52.64	1.39	3.85	0.00	3.60	2.03	0.96	4.93	9.51
TZEI 10 x TZEI 9	5176	53.79	52.99	1.45	3.64	2.34	9.60	2.06	0.96	3.71	3.36
TZEI 39 x ENT 3	5167	53.74	53.08	0.59	4.15	0.00	6.66	1.96	0.95	4.22	1.66
TZEI 56 x TZEI 89	5150	53.71	53.05	0.76	3.92	0.66	8.76	2.05	0.99	4.19	1.09
TZEI 173 x ENT 13	5149	56.28	54.63	1.65	4.28	0.00	4.03	1.76	0.99	4.05	7.16
TZEI 89 x TZEI 108	5148	52.87	52.59	0.32	3.70	3.04	4.40	1.79	0.99	4.05	3.10
ENT 12 x TZEI 65	5129	54.51	53.41	0.95	4.13	0.72	13.08	2.10	0.99	4.35	7.16
TZEI 4 x TZEI 54	5127	53.54	52.76	0.86	3.82	1.22	0.26	1.76	0.98	4.70	6.91
ENT 11 x TZEI 22	5116	56.54	56.54	0.34	4.06	2.78	15.07	2.23	0.97	3.67	6.06
TZEI 22 x TZEI 54	5104	54.29	53.38	0.98	3.83	1.72	12.86	2.05	0.97	3.97	9.37
TZEI 24 x TZEI 142	5089	53.32	52.49	0.98	3.50	2.47	5.42	1.59	0.98	4.18	0.95
TZEI 149 x TZEI 184	5079	51.45	51.28	0.61	3.96	3.01	10.16	2.05	0.97	4.58	5.55
TZEI 56 x TZEI 65	5069	53.43	52.25	1.16	3.78	0.00	5.81	1.85	0.99	4.37	2.79
TZEI 108 x ENT 12	5056	54.08	53.51	0.67	3.97	0.00	16.38	1.94	0.97	4.46	5.87
TZEI 157 x TZEI 17	5028	53.37	53.32	0.64	4.23	0.33	13.85	1.83	0.99	4.50	6.62
TZEI 184 x TZEI 135	5003	52.96	51.67	1.33	3.43	0.00	6.08	1.81	0.96	4.35	7.87
ENT 12 x TZEI 54	4993	53.40	52.48	0.96	4.10	1.75	1.77	1.94	0.95	4.58	0.74
TZEI 10 x TZEI 149	4983	52.48	52.01	0.39	3.70	0.24	7.76	2.08	1.00	4.51	4.17
Mean	4640	54.01	53.11	0.99	4.19	1.35	9.03	1.99	0.97	4.36	5.28
Min	1915	51.44	51.15	0.11	2.82	0	0	1.45	0.81	2.88	0
Max	6426	59.58	56.54	3.69	6.25	12.81	38.33	2.53	1.03	6.22	17.89
Lsd	719	1.28	1.16	0.82	0.74	3.03	9.66	0.35	0.06	0.73	5.25
SE	517	0.92	0.84	0.59	0.54	4.22	6.96	0.25	0.04	0.52	3.78

Appendix 4.14 continued. Grain yield and other agronomic traits of the best 20 and worst 10 hybrids evaluated under optimum environments at Ile-Ife and Mokwa in 2011 and 2012

HYBRID	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	Root lodging (%)	Stalk lodging (%)	Husk cover (1-5)	Ears per plant	Ear aspect (1-9)	Ear rot (%)
ENT 13 x TZEI 184	4975	53.73	53.18	0.67	3.24	6.75	13.29	1.78	1.03	3.79	5.31
TZEI 168 x TZEI 54	4972	52.73	52.05	0.74	4.13	1.49	1.66	1.95	0.98	4.01	0.74
ENT 11 x TZEI 56	4970	54.84	54.08	0.99	3.71	0.00	18.09	1.87	0.97	4.03	1.34
TZEI 9 x TZEI 142	4969	54.46	53.54	0.95	3.25	8.38	23.57	1.73	0.99	3.34	3.19
TZEI 168 x TZEI 39	4964	52.54	52.00	0.49	4.31	0.26	5.80	2.03	0.98	4.46	3.22
ENT 3 x TZEI 56	4904	55.38	54.12	1.26	3.85	0.00	8.78	2.00	1.01	4.22	1.22
TZEI 56 x TZEI 39	4903	52.70	52.53	0.32	4.11	1.89	4.34	2.09	1.00	4.60	0.90
TZEI 54 x TZEI 32	4893	54.70	53.32	1.52	3.79	0.28	0.63	1.98	0.98	4.72	7.86
TZEI 173 x TZEI 9	4890	54.33	53.13	1.22	3.64	0.00	5.88	1.89	1.02	3.37	9.11
TZEI 168 x TZEI 89	4850	53.75	52.54	1.21	4.10	1.17	8.42	2.04	0.96	4.39	4.52
TZEI 108 x TZEI 168	4850	52.49	51.92	0.51	4.62	0.00	7.97	2.05	0.98	4.57	5.69
TZEI 54 x TZEI 108	4801	52.82	52.09	0.99	4.02	0.49	4.72	1.88	0.98	4.69	3.05
TZEI 149 x TZEI 142	4801	53.26	52.48	0.58	3.90	3.67	14.52	1.83	0.97	4.35	4.51
TZEI 17 x ENT 13	4793	53.76	53.09	0.93	4.10	0.47	11.18	2.24	0.97	4.10	7.52
ENT 16 x TZEI 33	4784	54.84	53.46	1.32	3.49	0.00	10.75	1.84	0.96	4.59	3.58
ENT 13 x TZEI 142	4782	55.20	53.81	1.48	3.90	2.59	19.93	1.73	0.99	3.68	3.20
TZEI 142 x TZEI 17	4778	54.36	53.60	0.83	3.70	1.23	8.40	1.59	0.96	3.55	4.28
TZEI 146 x ENT 13	4776	53.70	53.08	0.65	4.14	0.90	7.28	1.98	1.01	4.33	4.95
TZEI 4 x TZEI 39	4714	52.99	52.46	0.56	3.62	0.49	0.00	1.75	0.98	4.32	7.16
TZEI 168 x TZEI 65	4711	52.37	51.61	0.87	4.22	0.00	9.23	2.11	0.97	4.22	3.84
TZEI 33 x TZEI 22	4692	54.60	53.64	0.97	4.20	0.13	9.83	2.11	0.98	4.31	3.53
TZEI 184 x TZEI 17	4678	53.90	52.71	1.29	4.39	0.47	11.29	1.98	1.03	4.77	5.36
ENT 16 x ENT 3	4664	56.36	54.32	2.01	4.55	0.08	9.80	1.94	0.98	4.27	2.10
TZEI 33 x TZEI 168	4656	53.57	52.66	0.94	4.05	0.22	10.51	1.88	0.96	4.61	1.75
Chk 4 TZEI 23 x TZEI 13	4650	54.39	52.88	1.55	4.50	2.17	0.00	2.00	0.95	4.63	5.84
TZEI 4 x TZEI 65	4627	54.46	53.92	0.48	3.88	0.15	7.92	2.02	1.00	4.54	5.38
TZEI 65 x TZEI 32	4624	53.97	53.17	0.74	4.47	0.00	3.97	1.94	0.98	4.65	9.39
Chk 1 TZEI 26 x TZEI 5	4601	54.66	53.66	1.08	4.10	0.83	6.71	2.00	1.00	3.94	3.76
TZEI 173 x TZEI 24	4579	55.78	54.29	1.49	4.33	2.11	3.89	1.75	0.96	4.73	4.41
TZEI 146 x TZEI 9	4578	53.13	52.47	0.67	3.82	10.30	18.63	1.76	0.99	4.11	5.56
Chk 5 TZEI 2 x TZEI 87	4516	54.12	53.57	0.51	4.35	5.53	10.88	1.94	0.98	4.36	2.79
TZEI 10 x TZEI 175	4479	56.11	54.29	1.89	4.76	0.83	2.31	1.81	0.96	4.93	4.97
Mean	4640	54.01	53.11	0.99	4.19	1.35	9.03	1.99	0.97	4.36	5.28
Min	1915	51.44	51.15	0.11	2.82	0	0	1.45	0.81	2.88	0
Max	6426	59.58	56.54	3.69	6.25	12.81	38.33	2.53	1.03	6.22	17.89
Lsd	719	1.28	1.16	0.82	0.74	3.03	9.66	0.35	0.06	0.73	5.25
SE	517	0.92	0.84	0.59	0.54	4.22	6.96	0.25	0.04	0.52	3.78

Appendix 4.14 continued. Grain yield and other agronomic traits of the best 20 and worst 10 hybrids evaluated under optimum environments at Ile-Ife and Mokwa in 2011 and 2012

HYBRID	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	Root lodging (%)	Stalk lodging (%)	Husk cover (1-5)	Ears per plant	Ear aspect (1-9)	Ear rot (%)
TZEI 135 x TZEI 175	4473	54.10	52.76	1.32	4.19	0.00	5.86	2.14	0.90	4.58	14.42
TZEI 135 x TZEI 9	4459	53.14	52.08	1.04	3.79	5.65	19.76	2.05	0.95	4.33	12.53
TZEI 108 x TZEI 4	4442	53.64	53.24	0.96	4.28	1.89	5.61	2.11	0.98	4.43	4.77
TZEI 89 x TZEI 33	4438	53.83	53.30	0.86	3.90	0.46	5.56	1.97	0.97	4.22	1.69
Check 3 - TZEI 24 x TZEI	4398	53.76	52.76	1.01	4.07	2.22	6.42	2.06	0.95	4.75	8.44
TZEI 39 x TZEI 108	4393	52.56	52.31	0.86	4.77	0.75	6.48	2.23	0.97	4.17	3.88
TZEI 184 x TZEI 146	4387	53.68	52.81	0.79	4.86	3.69	11.49	2.09	0.92	4.80	4.20
TZEI 17 x TZEI 149	4324	53.14	52.38	0.80	4.00	0.41	4.59	1.75	0.96	4.13	5.56
ENT 12 x ENT 16	4322	56.39	54.50	1.89	4.26	0.00	11.93	1.95	0.95	4.05	9.03
TZEI 23 x TZEI 10	4321	51.90	51.25	0.76	4.92	3.90	6.19	2.24	1.00	4.47	6.62
TZEI 157 x TZEI 10	4316	53.52	52.66	0.84	4.59	1.19	11.16	2.24	0.98	4.54	4.58
TZEI 177 x TZEI 17	4297	53.78	52.23	1.57	4.64	0.59	13.99	2.06	0.98	4.96	9.93
TZEI 33 x TZEI 4	4272	55.07	54.48	0.56	3.92	1.15	7.73	1.82	0.93	4.63	1.38
TZEI 135 x TZEI 149	4253	52.79	51.54	1.16	4.54	0.15	5.34	2.02	0.96	5.03	8.24
TZEI 33 x TZEI 56	4236	54.17	52.39	1.74	4.63	1.06	7.57	1.92	0.99	4.58	4.80
TZEI 108 x TZEI 56	4234	53.04	52.13	0.94	3.82	2.86	11.08	2.01	1.00	4.43	7.34
TZEI 175 x TZEI 157	4232	54.83	54.16	0.67	4.40	0.00	3.25	2.09	0.92	4.66	6.57
TZEI 65 x ENT 3	4232	54.86	53.06	1.76	4.06	2.48	8.24	2.04	0.93	4.52	9.66
TZEI 175 x TZEI 23	4230	54.03	53.20	0.83	5.17	0.91	10.61	2.23	0.97	4.81	4.36
TZEI 39 x ENT 11	4215	54.86	54.74	0.35	4.28	4.47	11.05	1.80	0.96	4.17	4.27
TZEI 108 x TZEI 22	4151	54.26	53.40	0.93	4.34	0.98	5.85	2.25	0.95	4.54	7.73
TZEI 177 x TZEI 10	4133	52.36	51.15	1.14	4.62	3.50	10.93	2.02	1.00	4.19	7.25
TZEI 135 x ENT 13	4130	53.35	52.20	1.15	4.20	0.89	7.71	2.17	1.01	3.61	2.62
TZEI 65 xTZEI 33	4114	53.05	52.16	0.94	4.08	0.06	6.56	1.84	0.92	4.68	4.45
TZEI 17 x TZEI 24	4106	53.21	52.42	1.06	4.98	0.67	7.29	2.05	0.98	4.71	5.18
TZEI 173 x TZEI 149	4099	53.74	53.32	1.46	4.66	0.56	7.06	2.00	0.96	4.54	10.23
TZEI 135 x TZEI 24	4097	53.07	52.51	0.57	4.72	0.00	8.89	1.89	0.95	4.47	6.28
TZEI 9 x TZEI 184	4093	52.67	52.34	0.61	3.58	5.00	19.78	2.01	0.96	4.63	2.89
ENT 13 x TZEI 23	4084	52.09	51.55	0.47	4.46	0.00	19.28	2.16	0.96	4.35	6.89
TZEI 177 x TZEI 146	4071	51.87	51.38	0.62	5.01	2.92	11.54	2.04	1.01	4.67	4.99
ENT 13 x TZEI 157	4046	53.24	53.04	0.44	4.24	3.51	15.17	2.02	1.01	4.08	6.07
TZEI 146 x TZEI 24	4041	52.75	52.56	1.08	4.45	0.60	12.12	2.19	0.99	4.75	2.83
Mean	4640	54.01	53.11	0.99	4.19	1.35	9.03	1.99	0.97	4.36	5.28
Min	1915	51.44	51.15	0.11	2.82	0	0	1.45	0.81	2.88	0
Max	6426	59.58	56.54	3.69	6.25	12.81	38.33	2.53	1.03	6.22	17.89
Lsd	719	1.28	1.16	0.82	0.74	3.03	9.66	0.35	0.06	0.73	5.25
SE	517	0.92	0.84	0.59	0.54	4.22	6.96	0.25	0.04	0.52	3.78

Appendix 4.14 continued. Grain yield and other agronomic traits of the best 20 and worst 10 hybrids evaluated under optimum environments at Ile-Ife and Mokwa in 2011 and 2012

HYBRID	Grain yield (Kg ha^{-1})	Days to silking	Days to anthesis	Anthesis-silking interval	Plant aspect (1-9)	Root lodging (%)	Stalk lodging (%)	Husk cover (1-5)	Ears per plant	Ear aspect (1-9)	Ear rot (%)
ENT 13 x TZEI 177	3996	52.62	51.56	0.93	4.22	0.79	9.36	2.05	1.00	4.19	3.32
TZEI 23 x TZEI 146	3970	51.44	51.27	0.31	4.69	0.56	12.49	2.18	0.97	4.54	4.99
TZEI 146 x TZEI 149	3966	51.89	51.72	0.59	4.96	2.74	11.63	1.96	1.02	4.47	5.15
TZEI 157 x TZEI 173	3944	55.42	54.04	1.44	4.42	0.62	6.94	1.96	0.93	4.81	7.06
TZEI 23 x TZEI 173	3889	53.92	52.36	1.64	4.31	0.20	6.27	2.16	0.99	4.77	9.31
TZEI 9 x TZEI 157	3816	52.20	51.71	0.43	4.60	11.60	38.33	2.11	0.99	4.49	7.00
TZEI 175 x TZEI 177	3806	54.75	53.47	1.42	4.42	1.29	14.06	2.11	0.94	4.84	7.81
TZEI 39 x TZEI 33	3805	53.70	52.78	0.80	4.70	0.51	12.73	2.11	0.97	4.95	5.19
TZEI 54 x TZEI 33	3730	53.36	52.12	1.15	4.39	0.00	9.35	1.91	0.97	4.94	2.02
TZEI 17 x TZEI 175	3728	58.04	56.10	1.96	4.92	0.86	7.12	2.04	0.97	4.60	5.28
TZEI 157 x TZEI 135	3726	54.07	52.78	1.29	5.06	1.14	8.23	2.24	0.98	4.68	5.56
TZEI 24 x TZEI 157	3716	52.81	52.05	0.98	4.38	1.26	9.08	2.00	0.97	4.31	5.11
TZEI 23 x TZEI 135	3699	53.28	52.13	1.20	5.60	0.12	10.58	2.53	1.00	5.53	9.88
TZEI 149 x TZEI 177	3683	51.74	51.66	0.33	5.14	0.16	14.74	2.27	0.97	5.20	11.64
TZEI 177 x TZEI 135	3666	52.90	51.29	1.62	4.99	1.85	9.82	2.06	0.93	4.90	8.08
TZEI 157 x TZEI 146	3618	52.96	52.95	0.29	5.10	5.50	9.18	2.15	0.95	4.81	5.87
TZEI 177 x TZEI 173	3616	54.66	53.14	1.55	4.62	0.00	7.16	1.90	0.95	4.80	6.09
TZEI 23 x TZEI 17	3427	53.02	52.13	0.91	5.54	0.13	9.47	2.11	0.98	4.57	9.55
TZEI 24 x TZEI 23	3157	51.48	51.16	0.56	5.36	2.61	16.10	2.20	1.00	5.34	6.92
TZEI 65 x TZEI 108	3077	52.68	51.89	0.65	5.26	2.34	22.48	2.31	0.97	4.98	4.94
TZEI 10 x TZEI 24	3076	54.66	53.63	1.15	5.33	0.97	4.72	2.28	0.95	5.04	7.75
TZEI 9 x TZEI 177	3050	52.31	51.83	0.82	4.87	12.81	27.24	2.25	0.96	4.87	9.17
TZEI 56 x TZEI 54	2998	55.29	53.81	1.56	5.55	0.29	3.33	2.34	1.00	5.56	11.26
TZEI 24 x TZEI 177	2862	51.67	51.30	0.61	5.53	1.67	14.63	2.38	0.95	5.19	6.78
TZEI 9 x TZEI 23	2812	52.08	51.44	0.60	5.01	5.86	31.31	2.31	0.92	5.20	10.40
TZEI 173 x TZEI 175	2736	59.58	55.88	3.69	6.13	0.00	0.77	2.31	0.89	5.59	11.85
TZEI 184 x TZEI 10	2511	56.39	54.64	1.81	6.15	0.00	7.14	2.27	0.96	5.71	14.87
TZEI 24 x TZEI 184	2134	56.60	54.34	2.18	6.09	1.19	10.39	2.08	0.81	6.22	17.89
TZEI 149 x TZEI 23	2134	52.79	52.09	0.62	6.15	0.00	19.42	2.40	0.90	5.95	10.18
TZEI 149 x TZEI 157	1915	53.20	53.05	0.73	6.25	7.66	22.24	2.33	0.96	5.46	9.04
Mean	4640	54.01	53.11	0.99	4.19	1.35	9.03	1.99	0.97	4.36	5.28
Min	1915	51.44	51.15	0.11	2.82	0	0	1.45	0.81	2.88	0
Max	6426	59.58	56.54	3.69	6.25	12.81	38.33	2.53	1.03	6.22	17.89
Lsd	719	1.28	1.16	0.82	0.74	3.03	9.66	0.35	0.06	0.73	5.25
SE	517	0.92	0.84	0.59	0.54	4.22	6.96	0.25	0.04	0.52	3.78

Appendix 4.16. Estimates of heterosis for grain yield and other traits under low N environments.

Hybrids	Grain yield		Plant aspect		Stay-green		Ears per plants		Ear aspect	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
ENT 13 x TZEI 142	404	205	14	55	-7	29	29	9	-2	7
ENT 13 x TZEI 157	117	130	30	42	18	20	8	8	9	9
ENT 13 x TZEI 177	171	157	53	65	26	33	3	1	17	22
ENT 13 x TZEI 184	251	179	9	28	19	27	-1	-8	-9	-3
ENT 13 x TZEI 23	253	151	16	41	12	13	11	8	-8	0
TZEI 10 x ENT 13	155	140	-1	13	-1	1	13	11	2	16
TZEI 10 x TZEI 149	166	146	15	16	-15	-13	3	1	13	16
TZEI 10 x TZEI 175	90	70	24	29	-16	-12	13	12	31	34
TZEI 10 x TZEI 24	106	53	13	24	-11	-10	26	19	0	13
TZEI 10 x TZEI 9	231	134	1	14	-14	-12	14	9	4	11
TZEI 135 x ENT 13	158	154	-1	14	-13	-10	12	12	10	34
TZEI 135 x TZEI 149	112	111	14	14	-3	-2	13	8	-1	2
TZEI 135 x TZEI 175	155	144	25	30	2	6	13	10	14	25
TZEI 135 x TZEI 24	238	164	1	11	14	14	22	12	-12	-8
TZEI 135 x TZEI 9	256	164	-13	-3	-2	2	26	17	-16	-15
TZEI 142 x TZEI 10	314	146	2	20	-16	5	23	8	12	25
TZEI 142 x TZEI 135	315	152	-13	3	-21	0	33	14	-9	-5
TZEI 142 x TZEI 146	270	116	1	20	-16	7	13	-5	-3	8
TZEI 142 x TZEI 17	842	617	-18	-9	-41	-29	40	23	-14	-14
TZEI 142 x TZEI 173	216	82	7	28	-38	-20	17	-2	-3	5
TZEI 146 x ENT 13	134	110	27	44	10	13	12	8	20	36
TZEI 146 x TZEI 149	155	125	13	15	-9	-8	7	-1	8	12
TZEI 146 x TZEI 175	157	119	21	25	0	4	22	15	11	14
TZEI 146 x TZEI 24	158	85	24	37	-1	-1	14	3	9	24
TZEI 146 x TZEI 9	210	113	15	30	-2	2	9	-2	8	16
TZEI 149 x TZEI 142	374	189	-10	6	-10	16	36	22	-14	-7
TZEI 149 x TZEI 157	57	45	15	19	18	23	18	10	4	5
TZEI 149 x TZEI 177	85	79	33	39	8	22	1	-7	9	12
TZEI 149 x TZEI 184	233	169	26	29	-9	-8	19	18	1	6
TZEI 149 x TZEI 23	136	70	13	20	3	10	14	10	0	8
TZEI 157 x TZEI 10	120	120	17	21	-4	2	2	-3	17	19
TZEI 157 x TZEI 135	91	78	2	5	-4	1	14	12	-4	1
TZEI 157 x TZEI 146	73	64	27	30	-16	-12	5	3	7	9
TZEI 157 x TZEI 17	246	135	26	37	-9	0	11	6	-1	8
TZEI 157 x TZEI 173	71	55	5	6	-5	-2	5	5	-5	-4
TZEI 17 x ENT 13	260	152	38	68	-8	-7	3	1	14	45
TZEI 17 x TZEI 149	289	177	11	17	-29	-26	20	17	6	14
TZEI 17 x TZEI 175	183	105	8	19	-5	3	21	19	-3	10
TZEI 17 x TZEI 24	421	513	-6	-3	-24	-20	32	24	-12	-11
TZEI 17 x TZEI 9	580	636	6	12	-8	-8	5	0	2	6
TZEI 173 x ENT 13	138	104	29	45	-21	-18	8	5	19	39
TZEI 173 x TZEI 149	105	72	4	6	-11	-10	13	5	7	7
TZEI 173 x TZEI 175	-19	-34	29	26	-10	-7	6	1	16	22
TZEI 173 x TZEI 24	132	61	15	28	-3	-2	19	7	-6	3
TZEI 173 x TZEI 9	204	103	-12	1	13	20	-3	-11	-8	-5
TZEI 175 x TZEI 142	342	173	-7	14	-17	10	33	18	-14	-1
TZEI 175 x TZEI 157	85	109	16	17	-22	-21	9	3	23	28
TZEI 175 x TZEI 177	175	176	15	14	19	30	5	-2	6	16
TZEI 175 x TZEI 184	300	233	28	38	-6	-3	22	19	11	24
TZEI 175 x TZEI 23	263	168	17	31	-5	-1	12	10	2	17

Appendix 4.16 continued. Estimates of heterosis for grain yield and other traits under low N environments.

Hybrids	Grain yield		Plant aspect		Stay-green		Ears per plants		Ear aspect	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
TZEI 177 x TZEI 10	124	101	8	13	-4	11	7	0	-13	-7
TZEI 177 x TZEI 135	92	84	6	11	-15	-3	7	3	-1	-1
TZEI 177 x TZEI 146	137	103	11	15	25	42	0	0	4	11
TZEI 177 x TZEI 17	276	173	-5	5	25	49	3	-2	-9	-5
TZEI 177 x TZEI 173	68	38	21	24	17	31	-12	-14	0	3
TZEI 184 x TZEI 10	15	-12	4	8	-9	-7	15	11	-11	-3
TZEI 184 x TZEI 135	237	171	5	8	-6	-5	11	5	-3	-1
TZEI 184 x TZEI 146	131	70	10	15	-14	-14	12	3	4	14
TZEI 184 x TZEI 17	410	329	10	12	-10	-6	21	17	-4	-3
TZEI 184 x TZEI 173	184	102	12	18	28	29	1	-7	-4	2
TZEI 23 x TZEI 10	206	110	9	17	2	12	10	9	3	15
TZEI 23 x TZEI 135	195	112	30	39	-10	-2	3	2	14	19
TZEI 23 x TZEI 146	185	91	-6	2	-12	-4	9	5	-10	1
TZEI 23 x TZEI 17	438	424	8	7	3	17	14	13	-10	-9
TZEI 23 x TZEI 173	113	39	14	24	4	11	1	-2	7	16
TZEI 24 x TZEI 142	852	611	-8	-1	-20	2	41	31	-16	-15
TZEI 24 x TZEI 157	201	108	-13	-2	14	20	23	11	-19	-10
TZEI 24 x TZEI 177	203	124	-11	2	-16	-4	7	-5	-9	-4
TZEI 24 x TZEI 184	141	107	-3	2	-18	-17	32	29	-12	-9
TZEI 24 x TZEI 23	400	400	-18	-19	11	21	22	14	-18	-18
TZEI 9 x TZEI 142	591	400	-4	0	-29	-15	27	16	4	8
TZEI 9 x TZEI 157	147	75	6	23	-6	3	-8	-15	-8	-3
TZEI 9 x TZEI 177	167	103	0	18	24	49	13	2	-9	-8
TZEI 9 x TZEI 184	381	331	-5	2	-16	-11	32	30	-11	-10
TZEI 9 x TZEI 23	321	302	-22	-19	-19	-8	18	11	-24	-21
ENT 11 x ENT 12	258	170	33	50	-8	-4	18	17	4	38
ENT 11 x TZEI 168	290	207	4	40	-25	-18	18	15	12	44
ENT 11 x TZEI 22	211	204	25	33	-19	-19	7	3	11	29
ENT 11 x TZEI 56	196	191	29	35	-22	-15	8	6	39	44
ENT 11 x TZEI 4	257	214	7	39	-1	3	8	4	13	32
ENT 12 x ENT 16	329	251	-13	-5	-34	-30	20	15	-36	-31
ENT 12 x TZEI 39	293	483	3	15	12	14	14	9	-16	-15
ENT 12 x TZEI 54	431	448	-1	4	-19	-17	19	5	-15	-11
ENT 12 x TZEI 65	323	455	3	17	-12	-6	1	1	-11	-4
ENT 12 x TZEI 89	395	347	-14	-7	-5	-1	16	12	-22	-17
ENT 16 x ENT 11	238	206	24	54	-1	10	19	14	25	52
ENT 16 x ENT 3	121	79	22	46	-3	1	21	20	0	12
ENT 16 x TZEI 108	193	146	8	18	-14	7	12	9	-11	-7
ENT 16 x TZEI 32	255	174	-3	9	1	5	11	3	-12	-5
ENT 16 x TZEI 33	319	216	-4	-3	24	29	27	22	-15	-11
ENT 3 x ENT 12	197	107	26	37	-9	-7	26	22	-2	20
ENT 3 x TZEI 168	176	99	6	36	-6	11	20	20	9	30
ENT 3 x TZEI 22	119	90	38	41	-12	-6	3	-3	25	34
ENT 3 x TZEI 4	107	64	-1	23	-5	-3	26	24	7	16
ENT 3 x TZEI 56	139	109	20	21	5	6	11	6	13	17
TZEI 108 x ENT 12	146	76	63	64	-4	13	-10	-11	18	22
TZEI 108 x TZEI 168	185	111	0	18	-18	-17	1	0	-8	-6
TZEI 108 x TZEI 22	86	68	11	18	-15	-5	7	2	-11	-3
TZEI 108 x TZEI 4	134	92	-4	9	-27	-15	19	15	-8	-1
TZEI 108 x TZEI 56	116	95	12	20	-15	3	15	12	5	28

Appendix 4.16 continued. Estimates of heterosis for grain yield and other traits under low N environments.

Hybrids	Grain yield		Plant aspect		Stay-green		Ears per plants		Ear aspect	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
TZEI 168 x ENT 16	314	255	-3	4	-11	9	21	19	4	10
TZEI 168 x TZEI 39	213	145	-26	-23	-2	11	19	17	-24	-21
TZEI 168 x TZEI 54	427	414	-8	2	-4	7	35	22	-19	-18
TZEI 168 x TZEI 65	253	198	15	19	-33	-28	8	4	19	25
TZEI 168 x TZEI 89	325	305	-11	-3	-21	-13	13	12	-17	-13
TZEI 22 x ENT 16	186	163	11	29	9	21	7	-1	1	5
TZEI 22 x TZEI 39	119	125	22	45	-12	-9	3	-5	1	15
TZEI 22 x TZEI 54	206	140	10	22	-8	-6	21	3	-3	5
TZEI 22 x TZEI 65	192	173	-1	20	-7	-5	7	3	-7	-3
TZEI 22 x TZEI 89	166	121	10	25	-20	-20	13	6	-10	-4
TZEI 32 x ENT 12	257	140	3	5	-23	-22	8	4	-14	1
TZEI 32 x TZEI 168	223	124	16	40	-21	-7	0	-7	14	30
TZEI 32 x TZEI 22	135	93	29	33	1	7	-6	-6	18	22
TZEI 32 x TZEI 4	181	113	-2	15	-1	0	17	8	12	16
TZEI 32 x TZEI 56	142	100	18	23	5	7	7	5	12	20
TZEI 33 x ENT 12	585	516	-6	3	6	17	20	10	-19	-16
TZEI 33 x TZEI 168	478	595	1	7	1	30	17	10	-6	-5
TZEI 33 x TZEI 22	207	119	14	34	0	17	14	2	-2	7
TZEI 33 x TZEI 4	255	173	-2	1	15	28	16	12	-1	7
TZEI 33 x TZEI 56	200	114	6	26	23	31	17	6	2	24
TZEI 39 x ENT 11	164	163	8	38	-7	-5	23	18	7	44
TZEI 39 x ENT 3	143	116	9	34	3	6	23	21	0	24
TZEI 39 x TZEI 108	103	88	-4	7	-24	-13	23	19	-6	-1
TZEI 39 x TZEI 32	111	77	39	60	0	4	-5	-13	27	51
TZEI 39 x TZEI 33	139	68	-7	-8	2	15	29	24	-12	-8
TZEI 4 x ENT 16	297	309	-19	-16	-3	3	26	26	-8	-5
TZEI 4 x TZEI 39	200	249	8	6	6	8	20	19	4	18
TZEI 4 x TZEI 54	246	197	-13	-6	-30	-28	34	22	-10	-3
TZEI 4 x TZEI 65	222	238	-9	-9	-6	1	12	7	0	5
TZEI 4 x TZEI 89	273	243	-21	-17	12	17	23	22	-5	-1
TZEI 54 x ENT 11	238	161	59	89	-8	-6	13	0	34	70
TZEI 54 x ENT 3	151	79	23	41	28	33	36	23	-3	13
TZEI 54 x TZEI 108	189	111	24	30	-27	-17	30	16	-2	-2
TZEI 54 x TZEI 32	154	74	25	35	5	9	6	-10	8	21
TZEI 54 x TZEI 33	334	279	8	13	-3	10	46	39	-14	-14
TZEI 56 x ENT 16	231	204	11	30	23	26	10	3	8	25
TZEI 56 x TZEI 39	133	138	11	34	18	24	1	-5	-17	6
TZEI 56 x TZEI 54	81	42	18	34	-3	3	22	6	8	30
TZEI 56 x TZEI 65	201	181	33	64	-10	0	9	8	35	58
TZEI 56 x TZEI 89	206	154	17	37	-4	3	18	13	9	28
TZEI 65 x ENT 11	232	204	11	45	-17	-15	17	16	12	37
TZEI 65 x ENT 3	124	84	30	62	-16	-8	10	7	21	37
TZEI 65 x TZEI 108	76	49	4	19	-1	8	14	13	3	6
TZEI 65 x TZEI 32	94	51	-8	8	7	16	3	0	-17	-10
TZEI 65 x TZEI 33	238	152	-19	-16	3	23	24	14	-16	-13
TZEI 89 x ENT 11	267	200	29	59	-13	-13	9	6	14	40
TZEI 89 x ENT 3	199	123	0	17	-13	-8	20	20	-5	8
TZEI 89 x TZEI 108	168	106	-12	-5	-28	-20	17	14	-11	-9
TZEI 89 x TZEI 32	160	86	4	15	-6	-1	1	-6	12	22
TZEI 89 x TZEI 33	380	294	8	11	15	34	5	0	6	9

Appendix 4.16. Estimates of heterosis for grain yield and other traits under *Striga*-infested environments.

Hybrids	Grain yield		SDR1		SDR2		SEC1		SEC2		EPP		EASP	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
ENT 13 x TZEI 142	232	141	-17	5	-16	4	54	572	119	680	16	7	-5	7
ENT 13 x TZEI 157	159	147	1	11	2	2	65	136	35	74	27	12	12	16
ENT 13 x TZEI 177	72	63	11	32	15	26	128	284	116	248	35	16	30	40
ENT 13 x TZEI 184	135	129	-10	11	3	6	56	257	39	131	12	5	4	10
ENT 13 x TZEI 23	126	115	-7	45	7	22	51	354	90	404	33	19	20	28
TZEI 10 x ENT 13	119	101	9	27	10	10	76	241	138	358	-12	-19	16	20
TZEI 10 x TZEI 149	156	151	24	42	1	9	81	198	71	208	2	2	7	8
TZEI 10 x TZEI 175	214	163	-5	0	-5	2	25	92	12	50	19	11	0	22
TZEI 10 x TZEI 24	181	168	-14	-11	-7	6	-94	-92	-77	-75	19	11	27	47
TZEI 10 x TZEI 9	179	159	-7	11	3	20	80	150	91	177	-4	-10	5	6
TZEI 135 x ENT 13	32	25	10	31	23	38	72	141	64	125	12	7	20	26
TZEI 135 x TZEI 149	41	20	9	32	20	26	20	47	1	31	30	-3	24	27
TZEI 135 x TZEI 175	156	145	-24	15	-8	14	4	123	-15	59	1	1	8	35
TZEI 135 x TZEI 24	47	34	22	84	37	80	178	364	211	346	11	3	38	63
TZEI 135 x TZEI 9	123	82	-6	9	2	5	72	81	59	71	-8	-8	4	7
TZEI 142 x TZEI 10	324	227	-16	28	-13	9	183	424	66	161	33	14	-5	4
TZEI 142 x TZEI 135	71	20	-7	-3	1	10	74	359	119	396	-26	-30	10	18
TZEI 142 x TZEI 146	356	237	-41	-25	-32	-14	94	469	90	447	11	3	-4	23
TZEI 142 x TZEI 17	239	175	-12	11	-15	-6	71	430	47	392	-4	-11	-1	7
TZEI 142 x TZEI 173	258	152	-32	1	-25	3	572	713	493	589	4	2	-11	4
TZEI 146 x ENT 13	94	89	6	6	25	27	32	71	24	42	-8	-14	35	51
TZEI 146 x TZEI 149	185	164	-14	-13	4	12	39	58	40	52	15	5	12	29
TZEI 146 x TZEI 175	243	202	-22	-4	-23	-17	10	161	9	157	5	5	7	12
TZEI 146 x TZEI 24	178	175	-15	3	1	14	46	166	43	152	78	34	33	33
TZEI 146 x TZEI 9	113	87	9	12	10	30	128	130	86	101	2	1	36	56
TZEI 149 x TZEI 142	207	140	-14	11	-12	1	75	529	98	550	32	23	-1	10
TZEI 149 x TZEI 157	23	16	26	37	16	23	13	40	16	41	17	1	26	34
TZEI 149 x TZEI 177	118	88	15	34	5	23	-53	-32	-65	-47	22	19	23	35
TZEI 149 x TZEI 184	207	183	0	21	-14	-6	-20	54	-18	27	47	27	-9	-6
TZEI 149 x TZEI 23	109	80	-3	47	6	30	43	256	29	216	-1	-8	12	22
TZEI 157 x TZEI 10	214	201	-11	-6	-16	-15	44	84	20	69	53	42	0	7
TZEI 157 x TZEI 135	80	63	-2	31	1	13	13	14	59	67	-8	-14	12	22
TZEI 157 x TZEI 146	197	191	-39	-33	-10	-8	18	28	58	76	47	1	12	21
TZEI 157 x TZEI 17	218	185	4	14	-14	-5	-12	-1	-3	20	49	39	-4	4
TZEI 157 x TZEI 173	190	164	-23	-21	-11	-2	48	192	133	360	16	9	-6	-6
TZEI 17 x ENT 13	82	56	-6	-6	-7	3	5	31	-4	-1	22	5	12	16
TZEI 17 x TZEI 149	141	129	5	6	-2	2	57	72	34	36	-12	-12	3	4
TZEI 17 x TZEI 175	158	104	12	37	-14	5	-45	38	-15	131	37	27	5	29
TZEI 17 x TZEI 24	244	207	-19	-2	-17	7	-36	23	-48	5	34	33	11	29
TZEI 17 x TZEI 9	265	262	-11	-8	-19	-16	22	28	15	38	0	-6	-11	-9
TZEI 173 x ENT 13	187	174	-16	-4	-5	4	88	507	66	367	32	27	2	5
TZEI 173 x TZEI 149	252	203	-13	-2	-6	11	20	222	27	232	45	34	4	10
TZEI 173 x TZEI 175	64	55	11	18	25	26	-69	-67	20	22	62	40	42	62
TZEI 173 x TZEI 24	267	236	-17	-12	-15	-11	131	165	102	145	80	35	-8	0
TZEI 173 x TZEI 9	121	82	18	39	1	29	184	519	131	372	14	0	14	20
TZEI 175 x TZEI 142	108	42	3	66	6	45	325	389	330	391	13	4	12	51
TZEI 175 x TZEI 157	159	124	-9	0	-13	-6	50	218	49	200	24	11	7	21
TZEI 175 x TZEI 177	187	171	-22	-20	-17	-17	-30	23	12	76	19	12	5	15
TZEI 175 x TZEI 184	207	170	15	15	2	8	163	250	104	213	10	-6	5	32
TZEI 175 x TZEI 23	183	168	6	29	-8	-3	224	255	306	329	27	26	12	23

Appendix 4.16 continued. Estimates of heterosis for grain yield and other traits under *Striga*-infested environments.

Hybrids	Grain yield		SDR1		SDR2		SEC1		SEC2		EPP		EASP	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
TZEI 177 x TZEI 10	155	123	3	5	10	19	135	160	141	175	37	34	12	25
TZEI 177 x TZEI 135	9	8	17	70	24	53	92	122	73	96	-22	-27	39	57
TZEI 177 x TZEI 146	148	129	-34	-22	2	9	66	107	101	174	16	4	23	28
TZEI 177 x TZEI 17	207	153	-5	13	-12	8	14	48	13	74	21	3	-2	9
TZEI 177 x TZEI 173	125	125	-12	-9	1	2	195	386	263	460	40	35	17	21
TZEI 184 x TZEI 10	144	130	1	6	2	5	33	49	34	50	21	20	4	7
TZEI 184 x TZEI 135	107	90	11	68	17	35	58	135	62	88	-9	-11	13	14
TZEI 184 x TZEI 146	154	154	-5	16	7	8	-25	22	25	75	-6	-14	18	40
TZEI 184 x TZEI 17	190	155	-22	-4	-16	-3	8	85	-4	51	36	30	-6	-5
TZEI 184 x TZEI 173	197	175	-4	3	-14	-8	50	89	60	140	8	8	-5	4
TZEI 23 x TZEI 10	177	143	-4	24	2	16	91	162	198	273	33	21	12	23
TZEI 23 x TZEI 135	81	79	6	106	4	37	33	151	42	146	2	0	20	35
TZEI 23 x TZEI 146	181	160	-7	43	12	27	88	289	66	259	27	26	25	32
TZEI 23 x TZEI 17	189	138	-1	52	-4	24	24	171	25	212	57	45	6	17
TZEI 23 x TZEI 173	175	174	-9	19	-1	3	198	212	224	237	34	32	9	12
TZEI 24 x TZEI 142	251	162	-24	22	-15	23	237	379	233	380	5	-11	2	31
TZEI 24 x TZEI 157	158	157	-11	-2	1	16	51	147	42	118	10	0	24	34
TZEI 24 x TZEI 177	141	120	-4	-2	13	19	55	115	84	126	19	11	27	32
TZEI 24 x TZEI 184	64	62	-9	-9	2	13	-20	-13	36	64	44	41	37	63
TZEI 24 x TZEI 23	174	151	-9	11	-5	-5	245	277	157	198	25	16	15	21
TZEI 9 x TZEI 142	191	138	-5	17	-3	3	164	661	150	536	-19	-24	-7	3
TZEI 9 x TZEI 157	128	103	-1	12	-9	5	1	8	0	2	12	-7	12	18
TZEI 9 x TZEI 177	161	114	-9	11	-9	16	22	50	28	58	18	6	0	9
TZEI 9 x TZEI 184	76	54	40	77	20	43	103	225	92	144	-3	-19	16	20
TZEI 9 x TZEI 23	193	140	-28	15	-18	11	31	168	22	135	17	17	9	18
ENT 11 x ENT 12	252	205	-30	-14	-30	-14	51	72	62	76	74	45	-12	14
ENT 11 x TZEI 168	212	111	-9	53	-3	37	280	464	228	360	32	16	10	44
ENT 11 x TZEI 22	187	149	-23	5	-8	19	77	141	152	241	16	9	1	30
ENT 11 x TZEI 56	179	154	-20	16	-16	5	70	110	99	129	4	-2	0	12
ENT 11 x TZEI 4	217	161	-25	0	-28	-4	67	106	42	76	57	30	-2	28
ENT 12 x ENT 16	177	157	-16	-7	-20	-16	64	107	68	125	36	33	-6	-5
ENT 12 x TZEI 39	126	99	-26	-10	-15	-10	87	95	76	85	22	14	3	11
ENT 12 x TZEI 54	52	49	77	102	41	52	43	98	31	58	-29	-33	19	31
ENT 12 x TZEI 65	130	121	17	23	7	15	49	104	50	82	-2	-17	4	9
ENT 12 x TZEI 89	198	130	-13	13	1	11	43	132	57	123	3	-4	-1	4
ENT 16 x ENT 11	210	152	-15	18	-22	2	156	181	143	197	23	15	-11	18
ENT 16 x ENT 3	143	118	-22	-5	-13	-3	38	130	48	163	-14	-20	-3	-2
ENT 16 x TZEI 108	63	60	42	54	32	32	106	134	101	109	-29	-36	15	20
ENT 16 x TZEI 32	221	176	-13	-1	-6	-3	56	69	39	74	15	4	-12	-9
ENT 16 x TZEI 33	223	177	2	4	3	6	95	145	126	189	25	20	-2	0
ENT 3 x ENT 12	240	186	-36	-12	-21	-8	40	78	38	73	-10	-17	-14	-
ENT 3 x TZEI 168	232	183	-15	-13	-1	4	64	298	71	257	-14	-15	1	1
ENT 3 x TZEI 22	120	85	-27	-11	-12	-1	19	27	52	54	-20	-25	-3	0
ENT 3 x TZEI 4	120	96	-27	-8	-14	-6	36	59	24	36	-1	-32	11	13
ENT 3 x TZEI 56	135	89	-7	7	0	16	56	203	48	144	-1	-17	8	26
TZEI 108 x ENT 12	159	137	9	33	-2	3	105	201	94	148	6	4	-2	1
TZEI 108 x TZEI 168	114	69	16	25	22	30	85	113	60	88	-6	-7	16	20
TZEI 108 x TZEI 22	84	68	6	16	13	13	6	91	14	87	-14	-19	5	8
TZEI 108 x TZEI 4	154	147	1	14	-1	1	34	116	16	73	-3	-5	6	9
TZEI 108 x TZEI 56	75	52	24	28	20	24	15	17	4	5	-3	-13	28	41

Appendix 4.16 continued. Estimates of heterosis for grain yield and other traits under *Striga*-infested environments.

Hybrids	GY		SDR1		SDR2		SEC1		SEC2		EPP		EASP	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
TZEI 168 x ENT 16	45	14	41	65	22	29	10	45	-12	-1	-40	-50	19	19
TZEI 168 x TZEI 39	219	118	-23	-17	-22	-17	196	391	171	295	41	-3	-7	0
TZEI 168 x TZEI 54	-11	-35	89	194	56	90	143	194	124	179	-58	-61	36	51
TZEI 168 x TZEI 65	46	11	50	109	43	73	87	130	91	136	-8	-9	21	29
TZEI 168 x TZEI 89	206	189	12	14	16	18	100	113	65	77	4	-10	24	32
TZEI 22 x ENT 16	110	94	16	18	6	6	9	67	20	108	40	5	7	9
TZEI 22 x TZEI 39	146	116	-44	-39	-23	-23	66	104	87	144	9	7	-2	5
TZEI 22 x TZEI 54	114	111	19	52	21	37	36	130	36	108	-15	-21	9	19
TZEI 22 x TZEI 65	229	216	2	18	-5	7	-4	59	-8	42	51	26	-1	3
TZEI 22 x TZEI 89	124	73	21	40	15	21	-10	80	-21	45	-6	-13	13	20
TZEI 32 x ENT 12	195	138	2	4	-9	-8	80	108	102	114	64	51	-10	-6
TZEI 32 x TZEI 168	273	233	20	62	6	16	207	346	129	231	-5	-7	0	4
TZEI 32 x TZEI 22	211	151	-7	4	2	5	67	131	27	67	42	22	2	8
TZEI 32 x TZEI 4	213	166	5	15	2	6	29	63	23	49	3	-5	-1	4
TZEI 32 x TZEI 56	114	66	20	43	16	16	67	103	55	84	6	5	14	37
TZEI 33 x ENT 12	205	146	-5	4	-6	-4	121	265	168	386	10	9	0	2
TZEI 33 x TZEI 168	94	73	46	74	33	46	181	194	193	229	-12	-20	12	14
TZEI 33 x TZEI 22	263	192	-4	-4	-16	-14	31	168	61	288	-6	-12	-10	-9
TZEI 33 x TZEI 4	137	102	16	18	7	12	61	193	74	278	-3	-4	2	3
TZEI 33 x TZEI 56	119	69	37	45	13	13	-63	-59	-8	25	-8	-23	16	31
TZEI 39 x ENT 11	134	131	-30	6	-15	11	208	235	235	245	20	17	9	32
TZEI 39 x ENT 3	144	85	-42	-35	-25	-17	34	78	134	212	12	-4	2	12
TZEI 39 x TZEI 108	125	83	-37	-37	-27	-27	36	90	62	96	20	3	4	8
TZEI 39 x TZEI 32	118	60	-1	21	2	5	178	208	143	144	31	9	2	15
TZEI 39 x TZEI 33	109	53	-38	-32	-10	-7	264	468	233	463	7	-9	6	12
TZEI 4 x ENT 16	166	163	1	5	-8	-7	59	119	58	148	9	6	-4	-2
TZEI 4 x TZEI 39	114	78	-18	-9	-15	-14	195	231	221	285	19	10	3	10
TZEI 4 x TZEI 54	33	22	71	112	47	71	-26	12	-19	13	-2	-13	21	33
TZEI 4 x TZEI 65	45	42	49	68	22	41	65	146	53	117	3	-29	18	24
TZEI 4 x TZEI 89	136	92	16	38	6	9	32	135	6	76	4	-8	7	13
TZEI 54 x ENT 11	181	148	29	37	3	16	76	110	87	107	33	-8	2	20
TZEI 54 x ENT 3	12	-7	46	136	31	68	-45	2	-63	-43	-13	-26	36	52
TZEI 54 x TZEI 108	50	35	64	134	45	64	78	87	26	33	-12	-18	31	39
TZEI 54 x TZEI 32	77	41	91	114	33	47	38	62	29	47	36	2	19	37
TZEI 54 x TZEI 33	47	16	79	126	44	58	170	211	159	271	-17	-26	33	44
TZEI 56 x ENT 16	83	61	19	24	8	11	32	47	37	44	-7	-8	14	32
TZEI 56 x TZEI 39	196	173	-48	-47	-39	-37	114	193	155	203	52	40	-3	3
TZEI 56 x TZEI 54	75	69	45	96	28	40	-11	-8	-11	-7	-2	-17	30	35
TZEI 56 x TZEI 65	75	60	48	82	24	36	62	69	56	61	0	-10	25	35
TZEI 56 x TZEI 89	183	110	9	18	6	14	90	108	50	66	-3	-14	21	29
TZEI 65 x ENT 11	204	155	0	16	2	15	51	78	62	81	19	11	-7	14
TZEI 65 x ENT 3	75	52	31	90	29	65	15	111	24	96	-3	-5	12	20
TZEI 65 x TZEI 108	169	155	-17	7	-5	7	142	157	104	113	24	14	3	6
TZEI 65 x TZEI 32	157	114	27	31	14	25	102	134	83	109	19	-1	7	18
TZEI 65 x TZEI 33	124	86	32	52	26	38	74	103	112	199	-15	-28	10	14
TZEI 89 x ENT 11	203	112	9	77	20	64	197	309	162	238	6	4	12	36
TZEI 89 x ENT 3	84	65	12	18	19	26	17	159	32	148	-40	-44	25	35
TZEI 89 x TZEI 108	83	52	30	36	31	36	176	197	134	155	-6	-19	29	32
TZEI 89 x TZEI 32	251	231	14	50	10	19	65	122	62	114	-8	-18	2	14
TZEI 89 x TZEI 33	154	140	16	35	17	26	42	44	73	109	42	22	6	11