Characterization of Maize Doubled Haploid and Varietal Hybrids under Low-nitrogen and Drought Stress Conditions

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DECLARATION

I declare that this is my original work and has not been presented for an award of a degree in any other university.

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To my mother Mary Njeri Mwangi, daughter Hellen Iroga and son Joshua Iroga whose prayers and encouragement in my life have been of immeasurable value.

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ABSTRACT

Drought and nitrogen (N) deficiency are important causes of low maize (*Zea mays* L.) yields in Eastern Africa. Breeders developing maize varieties use classical methods and little work has been done in sub-Sahara Africa using doubled haploid (DH) technology or the varietal hybrid (VH) methods which may confer enhanced efficiency in breeding for these stresses. This study was conducted in 24 locations across seven countries. The objectives of this study were to assess the heterosis for grain yield and secondary traits as well as yield stability in F_1 VHs *(Experiment 1)* and also to determine the combining abilities for grain yield and its associated secondary traits in DH lines *(Experiment 2)*. In *Experiment 1*, 10 F_1 VHs, their parents and 4 checks were evaluated at 17 locations: 5 drought stressed and 12 optimal. The trials under managed drought stress were grown under irrigation during rain-free months until two weeks to flowering when water was withdrawn to impose stress. An Alpha lattice design replicated twice was employed. Plot size was 5 m long, spaced 0.75 m and 0.25 m between and within rows respectively. Fields were kept free of weeds and pests. Each trial received 90.0 Kg ha^{-1} N and 98 Kg/ha P as Diammonium Phosphate fertilizer at planting and 100 Kg ha^{-1} N as Calcium Ammonium Nitrate fertilizer top-dressed at 6 weeks after emergence. In *Experiment 2*, 46 DH lines were crossed to Tester 1 (CML312/CML442) and to Tester 2 (CML395/CML444), belonging to heterotic groups (HG) A and B respectively. The 92 DH hybrids and 4 classical hybrid checks were evaluated across 7 locations: 1 under managed drought, 1 under low-N and 5 under optimal conditions. An Alpha lattice design was used replicated twice. The sizes of plots, weeds, fertilizers application and pest control measures were similar to those in *Experiment 1* but the plots under low N trial had been depleted of N until the yields were reduced to 30 % that of the estimated original optimal potential and no fertilizer was applied post-emergence. Results from *Experiment 1*, revealed that drought reduced broad heritability (H^2) from 90 % to 30 %. Similarly, whereas heterosis for grain yield was significant ($P \leq 0.05$) under optimal conditions, drought stress reduced the magnitude of this trait to insignificant levels. On the other hand, heterosis for plant height and anthesis silking-interval were significant (*$P \leq 0.05$*) under drought and not under optimal conditions. Amongst the VHs significant (*$P \leq 0.05$*) differences for grain yield occurred under optimal conditions but not under drought environments. Surprisingly, the highest heterosis values (of >40 %) were expressed under drought, where the widest ranges for grain yield were also realized. The VHs yielded 40 % higher than the OPV and as much as the 3-way cross hybrid used as commercial checks. Overall, three VHs (2, 8 and 10) were exceptionally good performers exhibiting both high yields and stability. It was recommended that these three varieties should be evaluated further for possible release to farmers. Results from *Experiment 2* revealed that highest H^2 for grain yield was present under drought (at 77 %), and lowest under low N conditions; H^2 under optimal conditions was in between these two extremes (at 60 %) amongst these DH materials. Variations amongst the DH lines were significant (*$P \leq 0.001$*) for grain yield and secondary traits under both stresses. Differences due to line x tester effects were significant (*$P \leq 0.05$*) for grain yield under drought stress and not significant (*$P \leq 0.05$*) under low N stress. Several DH lines (i.e. 29, 14 and 15) exhibited good GCAs for grain yield and secondary traits. The 46 DH lines were separated into 2 HGs: 24 fell into HG A and 22 into HG B; no lines were placed under HG AB. Although heterotic effects were important in the DH hybrids, GCA effects were more pronounced compared to SCA effects under all production environments. Whereas, across environments, yields under low N and drought stresses were respectively 45 % and 57 % lower than that under optimal conditions, yields of best line (DH Line 29) were consistently higher than those of the best classical-commercial hybrid checks. The findings of this study showed that both DH based hybrids and OPVs have great promise although DH-materials had much higher potential. They should therefore be assessed further for commercial exploitation in Eastern Africa.

CHAPTER ONE:

INTRODUCTION

1.1 General Introduction

Maize (*Zea mays* L.) is an important food crop in the world. It is grown in about 159 million hectares from where 817 million tonnes of grain is produced (FAOSTAT, 2011). Maize performs best in the sub-humid to semi-arid regions of the tropics. The cereal, however, is highly susceptible to stresses and produces highest in zones where water is abundant and soil fertility is high (Muchow and Davies, 1988). Irrespective of being susceptible to stress, progress in development of early maize and the fact that maize grain is well protected from birds, its yield is relatively more compared to the other cereals. Thus, in the semi-arid tropics, maize cropland has expanded over the past few years. In sub-Saharan Africa, the cereal covers about 25 million hectares and large areas suitable for the cereal are still available. In these countries, maize is a staple food. For instance, in eastern Africa, maize provides about 30 % of daily human calories (Smale et al., 2011). In Kenya, the cereal is equally important and accounts for about 40 % of daily calories (G.O.K., 2012). A critical analysis of usefulness of maize suggests that the cereal has a high potential and it is often a key indicator of food security.

1.2 Drought stress and low-nitrogen deficiency in maize

In the developing countries of eastern Africa, maize yields are relatively low. This is particularly so in lowland maize that suffers from effect of abiotic stresses. Maize requires about 400 mm to 600 mm of water to complete a full growth cycle (Singh, 1995). In most tropical maize growing areas, the annual rainfall received is adequate to supply these amounts. The rainfall is however, poorly distributed and usually interrupted by occurrence of unpredictable drought episodes (Campos et al., 2006; Lal, 2010). Maize fields are usually not irrigated, because water is scarce or is used for crops of greater economic importance. In addition, in eastern Africa, the main agricultural soils in the semi-arid zones are low in nitrogen (N) nutrients. Chemical fertilizer is unavailable or the cost is prohibitive. Hence at all stages of development, tropical maize grows in soils that are deficient of nitrogen and in areas exposed to drought stress. Hence, the most significant causes of yield loss on farmers' fields are nitrogen deficiency followed by drought (Bänziger and Diallo, 2004).

Stresses disrupt the normal nutritional equilibrium and alters occurrence of critical processes in plants (Morgan, 1984). At vegetative growth stage, water or low N stress lead to a reduced plant and leaf size. This reduces carbon capture and dry matter partitioning of foods to vital organs including the ears and anthers (Andrade et al., 2002). In addition stress alters allocation of carbohydrates to roots and stems affecting the biomass stored in these parts. At reproductive stage, water stress at one week before silking to two weeks after silking causes abortion of ovules, kernels, and ears. Nitrogen deficiency causes reduced radiation use efficiency, accelerated leaf senescence, increased mobilization of vegetative N to the grain, and a lower plant N concentration (Muchow and Davies, 1988).

The cumulated effect of stress is the commonly observed reduced maize yields at farm level. On average annual yields losses due to drought were about 20 % (Edmeades et al., 1992). Worse still, yield losses of 60 % per season were recorded in southern Africa (Rosen and Scott, 1992). Respectively, grain yield reductions of 45 % and 50 % were reported in maize grown under managed low nitrogen stress (Betrán et al., 2003a) and (Pswarayi and Vivek, 2008). In future, and partially due to global climate change, the intensity of drought stress and of nitrogen deficiency is expected to increase. Also maize is expected to be grown more in drier ecologies

(Bänziger et al., 2000). This could cause a further reduction in maize productivity and consequently threaten food security in eastern Africa (World Bank, 2007).

1.3 Breeding for abiotic stress tolerance in maize

Extensive characterization studies of landraces for morphological traits, drought and low nitrogen tolerance often identified tropical maize landraces with desirable traits (Alexander et al., 2013). Depending on genotype, the effect of stress on yield varies amongst maize cultivars. Thus, breeders have developed maize populations that yield highly under drought and low N. The high yields under stress were achieved through recurrent selection for grain yield and secondary traits at target environments and timing of application of stress (Monnneveux et al., 2006). Progenies were typically evaluated in replicated trials at one or two levels of stress. Drought stress was imposed during flowering and grain filling by withdrawing irrigation 2 week to flowering till end of season. Low N stress is applied by growing the crop in plots where nitrogen nutrient has been depleted and no nitrogen is added during the growing period. At the same time, progenies are tested under well-watered conditions (optimal-rainfed) for their potential yield and competitiveness in a wet year (Heisey and Edmeades, 1999).

Heritability (H^2) is the squared correlation between phenotypic value and actual genotypic value and is often used to quantify the precision of series of trials (Piepho and Mőhring, 2007). Plant breeders also use heritability to predict the response to selection R as $R = S\,H^2$ where S is the selection differential (Falconer and Mackay, 1996). While breeding for stress tolerance, stress could induce a genotype x environment interaction (GEI) and which causes low heritability (H^2). Low heritability renders it challenging to predict response to selection. Moderate stress is usually applied as it reflects better the yield potential of a genotype. Under moderate stress, the average grain yield were reduced to 30 % to 60 % of yields under optimal conditions at the same location (Bänziger et al., 1999b).

Studies showed that, the overall correlation of between mean hybrid grain yield and the phenotypical yield stability of a given hybrid against the mean yield of all hybrids at the same location was 0.37 (Moser, 2004). Selection for high yield and stress tolerance was feasible. In CIMMYT, drought and low N tolerance was treated and selected as a trait using a selection index composed of secondary traits and grain yield. The index sought to reflect to what extent a genotype was able to maintain the time from sowing to anthesis, maintain or increase grain yield under stressed conditions, increase grain yield under drought, and decrease ASI, barrenness, the rate of leaf senescence, and leaf rolling. The selection gains realized were largely the result of reduced barrenness and an increase in the harvest index (Bänziger et al., 2000; Bolaños et al., 1993). In the current study, in agreement with Levitt (1980), the term 'tolerance' included both 'tolerance' and 'avoidance' mechanisms. An index similar to that used in CIMMYT was used to select desirable entries. The improved tropical populations are valuable genetic resources for enhancing maize productivity in eastern Africa. Extensive exploitation of these populations has been hampered by first, their genetic heterogeneity (Alexander et al., 2013). In addition, economic and agronomic limitations especially in the elite germplasm, that shows only one or few special traits (Edmeades et al., 2000).

Broadening the genetic base of elite maize germplasm is a major consideration in hybrid maize breeding. Maize testers of good general combining ability and that are adapted to tropical ecologies have been developed (Hede et al., 1999). Several evaluation studies on lines derived using the classical methods, while in combination with the locally adapted testers, under drought and under low N environments revealed, i) lines with good combining abilities, ii) heterosis was majorly due to effect of additive gene, iii) heterosis was expressed highest at stressed environments and, iv) yields in F_1 classical hybrids were more or as good as that in commercial hybrids (Derera et al., 2007), (Pswarayi and Vivek, 2008) and (Makumbi et al., 2010). Studies on OPVs formed using classical maize lines showed that, expression of heterosis increased with genetic improvement of the parental material (Carena, 2005). Studies under water stress also suggested that heterosis enabled plants to better adapt to stresses (Blum, 2005). At farmers' fields, in eastern Africa, yields in commercial hybrids were higher than in OPVs (Bänziger and Diallo, 2004). Thus adoption of hybrids could enhance maize yields in areas prone to drought and low nitrogen.

In the face of the adverse effect of climate change and soil nutrition, it is important that breeding of new varieties is conducted using methods that enhance efficiency. Traditionally, it requires about 6-8 generation of selfing and selection or about 7 years to obtain about 96.9 % of homozygosity from a heterozygous maize population. Due to selection, the number of lines could substantially reduce risking creation of ineffective population (Briggs and Knowles, 1967). Application of the doubled haploid technique could fast-track the process of hybrid development. Using the DH method, homozygous lines are obtained easily from heterozygous plants (Prigge, 2012). In the DH technique, heterozygous plants are crossed to a haploid inducer to produce haploid *(n=10)* plants. The tips of 3 to 4 days haploid coleoptiles are trimmed to 20 to 30 mm, immersed into a 0.06 % colchicine solution plus 0.5 % dimethyl sulfoxide and placed in the dark for 12 hours at 18°C (Eder and Chalyk, 2002; Gayen et al., 1994). The artificial photocopying of the single chromosome results in the formation of fertile and viable 100 % homozygous diploid *(n=20)* plants. This process is accomplished within two generations or 1.5 years (Prasanna et al., 2012). In the DH lines, the homologous chromosomes are identical and hence, assuming there is no epistasis effects, DH lines express high genetic purity and variance over environments and generations. Under drought stress, maize yields in hybrids derived from DH lines were more than that of hybrids derived from classical lines. Moreover, the DH hybrids showed as good agronomic traits as the classical hybrids (Beyene et al., 2012). Thus adoption of hybrids and especially those derived using the DH technology could enhance maize yields in ecologies prone to drought and nitrogen deficiency.

1.4 Statement of the problem

The high gap between potential and actual grain yields in farmers' maize fields associated with drought stress and N deficiency with both stresses occurring at the same time is worrying. In search of a solution, breeding programmes in eastern Africa began breeding against these stresses in the late 1960s and some measureable success has been achieved. Among the different types of germplasm developed are drought and low-N tolerant OPVs and hybrids; these have been developed by use of classically developed maize inbred lines. Starting in 2008, application of DH and varietal methods of hybrids development has been incorporated in the maize breeding programmes. However, information on performance of DH lines and classical OPVs while in combination with locally adapted testers and under abiotic stresses is limited.

Analysis of combining ability (CA) and heritability (H^2) are quick methods for investigating the genetic potential of new parents. CA analysis enables understanding the mode of gene action conditioning expression of a desired trait. Thus, CA analysis enables selection of parents with high amounts of favorable alleles and which shows heterosis. Heritability on the other hand is a good predictor of response to selection and a good measure of precision of data collected from field trials. Usually however, heterosis in maize is influenced by the environment of growth and therefore is expressed in varied amounts depending on the environment. This genetic instability can reduce progress in the breeding process or affect adoption of the selected hybrids by the farmers. Identification of genotypes which show stable and high heterosis under diverse stresses is required. The purpose of the current study was to guide breeders on how to utilize open pollinated varieties and DH lines in hybrid breeding in eastern Africa.

1.5 Objectives

The overall objective of the study was to evaluate the genetic potential of maize DH lines and open pollinated varieties under stressed and optimal conditions.

Specific objectives were to estimate:

i) mid-parent heterosis for grain yield and secondary traits as well as yield stability in early maturing maize varietal hybrids under drought stress and optimal conditions, and

ii) combining ability for grain yield and agronomic traits in DH lines under low-nitrogen stress, under managed drought and optimal conditions.

CHAPTER TWO:

REVIEW OF LITERATURE

2.1 Stress in maize plants

In a plant, drought stress occurs when water or nitrogen supply is insufficient to an extent that it negatively interferes with optimal growth and development (Seghatoleslami et al., 2008). Within a species, some plants tend to express less negative effects of stress or low nitrogen stress. Such genotypes are considered stress tolerant or resistant (Levitt, 1980). In the current study, stress tolerance was used to mean yield in relation to a limited supply of water and nitrogen.

2.2 Effect of abiotic stresses on maize plants

Stress disrupts the normal nutritional equilibrium and alters occurrence of critical processes in plants (Morgan, 1984). At vegetative growth stage, water or low N stress lead to a reduced plant and leaf size. This reduces carbon capture and dry matter partitioning to the ear during the critical period when weight and number of grains is determined (Andrade et al., 2002).

Stress has a negative effect on the process of storage of reserves in the stem and ear shank. The immediate impact of a water deficit on the effective leaf area or a smaller leaf area due to leaf rolling largely determines the extent of assimilation under drought (Blum, 1997). Prolonged drought stress during the vegetative stages affects the length of the internodes by influencing the cell size development. This may lead to plants with short height and a reduced capacity for storing assimilates (Denmead and Shaw, 1960). Under optimal conditions, reserves contribute little to reproductive success (Schussler and Westgate, 1995). However, when photosynthesis is limited during grain filling, the remobilization of stem reserves is considered to be a main source of carbohydrates for grain filling (Blum, 1997).

In presence of adequate water supply, the root system of maize formed during the first 60 days can sustain the plant until harvest (Araus et al., 2008). When soil moisture is limited, root growth may last throughout the growing season, even when N fertilization is inadequate. Hence a well established root system indicated by reduced root lodging could imply stress tolerance or susceptibility to stress. A well developed root system enables the plant to make better use of water and minerals and is an important component of stress tolerance at different growth stages (Blum, 1997). Vigorous root growth have also been reported to occurs at the expense of grain production (Bruce et al., 2002). Increases in grain yield under drought, resulting from selection for drought tolerance, are associated with a smaller root biomass in the upper 50 cm of the root profile in a tropical maize population (Bolaños et al., 1993).

Generally under drought and low N stresses, during reproduction, plant decreases the reproductive demand for carbon by reducing the number or size of the sinks (Blum, 2005). Nitrogen deficiency causes reduced radiation use efficiency, accelerated leaf senescence, increased mobilization of vegetative N to the grain, and a lower plant N concentration (Muchow and Davies, 1988). In maize, drought or low N stress, during the period between one week to and two weeks after silking causes abortion of ovules and kernels. Abortion of ovule and kernels occurs when ovules fail to extrude silks or grow because of slow growth rates associated with lack of adequate photosynthates (Edmeades et al., 1993; Westgate and Boyer, 1985). As a result of the reduced flow of photosynthates, silking is considerably delayed, while anthesis is hastened leading to an increase in the net anthesis silking-interval. Anthesis silking-interval is indicative of effectiveness of pollination and is highly correlated with kernel set and a prolonged interval maybe be an important reason for crop failure under drought stress (Byrne et al., 1995). Imperatively, results of trials with temperate hybrids suggested that direct effects of insufficient pollen supply (due to a prolonged ASI) on grain number per plant occur only when pollen production is reduced by 80 % and when ASI exceeds 8 days (Bassetti and Westgate, 1993). Conclusively, ASI is a good and easily ascertainable external indicator of partitioned assimilates to the ear, the growth rate of the female spikelet, grain number, and perhaps of the water potential of the plant. This seemed to also be true with regard to the partitioning of assimilates to the ear under low nitrogen (Edmeades et al., 2000). The cumulated effect of stress is an overall reduction in grain yield up to 30 % in the developing countries (Moser, 2004). On average annual yield loss due to drought is about 20 % (Edmeades et al., 1992). Yield losses of 60 % per season were also recorded in southern Africa (Rosen and Scott, 1992). Grain yield reductions of 50 % were reported in maize grown under managed low nitrogen stress (Pswarayi and Vivek, 2008). In future, and partially due to global climate change, the intensity of drought stress and of nitrogen deficiency is expected to increase. Also maize is expected to be grown more in drier ecologies (Bänziger et al., 2000). This could cause a further reduction in maize productivity and consequently threatens food security in eastern Africa (World Bank, 2007).

2.3 Breeding of stress tolerant maize

2.3.1 Creation of homozygous parents

Maize is both a monoecious and an allogamous plant. In a maize field therefore, outcrossing lead to genetic recombination of heterozygous chromosomes. Inheritance of grain yield in maize is polygenic and is influenced by environment. Hence, expression of the genetic potential for open pollinated varieties is poor. Unlike in OPVs, heterosis for grain yield in hybrids of homozygous and unrelated parents is distinctively high. Homozygosity affects the vigour and genetic variance of the parents as well as that of the progenies. Additionally, it affects management and maintenance of genetic purity and seed production (Smith, 2008). As such, lines with sufficient homozygosity are required in hybrid production (Hallauer et al., 2010). In a hybrid breeding, development of maize lines is therefore a major consideration.

Maize lines can be obtained from OPVs using various methods including; the doubled haploid (DH), the pedigree, markers assisted breeding and the backcross. The pedigree and the DH are the most common methods and they lead to formation of the classical lines (CLs) and DH lines respectively. In the pedigree method, lines are extracted by repeated selfing. It takes 6-8 generations of selfing to obtain CLs of an average level of homozygozity of 96.9 % (Briggs and Knowles, 1967). As such, the pedigree method might not be efficient especially under the current situation associated with climate change. As alternative, breeding programmes are increasingly adopting the DH technology. The technology utilizes cell biology processes to create haploid plants and thereafter pure lines within 1.5 years (Prasanna et al., 2012; Röber et al., 2005).

In maize, ovaries contain two polar nuclei and 1 mother cell. Normal fertilization in maize occurs twice. One sperm nuclei fuses with 2 polar nuclei and the second sperm nuclei fuse with the mother cell. The doubled fertilization results to formation of regular kernels with a triploid ($x=3n$) endosperm and a diploid ($x=2n$) embryo. Maize with haploid ($x=n$) embryos can be derived from diploids through genetic induction (*in vivo*) or anther culture (*in vitro*) techniques. The *in vitro* method is artificial, highly complex and the rate of plantlet regeneration is low (Beckert, 1994; Shatskaya et al., 1994). The *in vivo* method, on the other hand, is simple and only requires that the source populations are pollinated with pollen from a haploid inducer. Additionally, unlike the *in vitro* which is genotype dependent, haploids can be induced in female or male parents leading to maternal genotypes (Coe, 1959). The low rate of haploid induction is not a hindrance since the haploid-inducing capacity of the inducer can be increased by selection (Sarkar et al., 1972). Through selection, new inducers with haploid-induction rate of up to 10 %

have been formed. Thus the *in vivo* method is widely used by most breeders nowadays (Prigge, 2012; Röber et al., 2005).

The process behind the spontaneous haploid induction is not yet fully understood (Eder and Chalyk, 2002; Röber et al., 2005). Two hypotheses have been put forward to explain the irregularities leading to haploids formation: i) double fertilization and subsequent chromosome elimination or degeneration (Gernand et al., 2004; Wedzony et al., 2004). Two irregular occurrences have been suggested to cause chromosome elimination. In the first mechanism, the polar nucleus is fertilized, while the egg cell remains unfertilized. The unfertilized egg cell develops into embryos with the cell division of the fertilized polar nucleus. In the second mechanism, the egg cell is destroyed when the pollen tube is entering into embryo sacs. Then one of the sperms fertilizes the polar nucleus and the other develops into haploid embryos (Gernand et al., 2004; Wedzony et al., 2004), ii) Single fertilization theory; the velocity of transmission of two sperms in one microspore was found to vary (Hu, 1990). The sperm with high velocity fertilized normally, while the one with low velocity missed the fertilization. This broke the normal double fertilization leading to development of kernels with a haploid embryo (Chalyk et al., 2003).

Upon pollination with a haploid inducer, the kernels formed include numerous regular F_1 with a diploid embryo and about 10 % irregular haploids. To overcome the low rate of haploid induction, effective systems for distinguishing haploids from diploids have been developed. Haploid kernels are identified using colour markers, transgenic herbicide markers and inducible transgenic markers. The use of colour markers on embryo/ scutellum, cap, and stem is most common as it is considered simple and of low risk to flora and fauna (Eder and Chalyk, 2002; Röber, 1999). Most of the widely used inducers carry a dominantly inherited marker gene, *R1*-nj.

The *R1*-nj causes purple colouration of the scutellum and the aleurone of diploid kernels (Nanda and Chase, 1966). Since the purple *R1-nj* -encoded colouration is dominantly inherited; haploid kernels have a non-pigmented scutellum, while diploids have purple-coloured scutellum.

The haploid kernels display a normal germination rate and lead to viable haploid seedlings (Geiger and Gordillo, 2009). Majority of haploid plants are however sterile due to disrupted gamete formation (Tang et al., 2010). Spontaneous chromosome doubling occurs albeit at a rate of 0 % to 10 % (Deimling et al., 1997; Kato, 2002). In practical application of the DH technology, spontaneous occurrence of *in vivo* doubled haploid can be a major constraint. A breakthrough was accomplished by cutting off the tip of the haploid coleoptiles and immersed the seedlings into a 0.06 % colchicine solution plus 0.5 % dimethyl sulfoxide for 12 hours at 18°C (Gayen et al., 1994). The efficacy of this method can be increased by reducing the roots to 20 to 30 mm and placing the immersed seedlings in the dark (Deimling et al., 1997). After the colchicine treatment, the seedlings are carefully washed in water and subsequently grown in the greenhouse to the 5- to 6-leaf stage (during the first days under high humidity). Thereafter, the treated plants are transferred to pot filled with well nourished soil.

Naturally, after DNA replication, spindles fibers are formed and the microtubules pull the duplicated chromatids toward the two poles. This leads to division of the somatic cell into two daughter cells. Colchicine inhibits formation of the spindle fibers required for polar migration of chromosomes. Thus colchicines prevents division of nucleus in somatic cells leading to formation of single cells that contains two identical chromosomes (Wan et al., 1989). This method yielded an average doubling rate of 49 % from a broad range of donor genotypes 49 % (Eder and Chalyk, 2002). The first generation of haploid plants are 100 % homozygous and are commonly referred as to as DH 0 lines. In field conditions, about 50 to 60 % of the DH0 lines shed pollen and can be selfed. Upon selfing, about a third of DH0 produce < 5 to > 20 viable DH1 seeds per ear (Chalyk et al., 2003). Since, the homologous chromosomes in the DH lines are identical, genetic recombination during selfing does lead to a changed genetic constitution. As such, assuming there is no effect of epistasis or epigenetic, DH lines tend to maintain additive variance and which could lead to high gains from selection.

2.3.2 Evaluation for stress tolerance

2.3.2.1 Timings and environments for the evaluation process

The effect of stress on yield varies depending on the developmental stage at which it occurs. Hence it is important that the timing and the intensity of the induced stress in breeding programmes are similar to the typical target environmental conditions (Lorens et al., 1987). Breeding for drought tolerance requires well-managed water regimes in terms of timing, intensity, and uniformity because then will selection results be comparable and significant and ultimately lead to breeding progress. When selecting for drought tolerance, progenies are evaluated in replicated trials at one or two levels of drought stress by recurrent selection during a rain-free period. Severe drought induce a genotype x environment interaction for yield, the actual yield under moderate drought reflects better the yield potential of a genotype (Bänziger et al., 1999b). Drought is imposed during flowering and grain filling so that the average grain yield is reduced to 30 % to 60 % (moderate stress level, during grain-filling) or 15 % to 30 % (severe stress level, during flowering and grain-filling), respectively, of unstressed yields (Bänziger et al., 1999a). At the same time, progenies are tested under well-watered conditions (optimal-rainfed) for their potential yield and competitiveness in a wet year (Heisey and Edmeades, 1999).

2.3.2.2 Selection criteria and secondary traits

Drought stress at defined stages of development influences specific parameters. Stress before flowering influences stover biomass yield, plant height, number of leaves and leaf area. Stress at flowering reveals the genetic variation in the ASI, number of kernels, and ears through abortion, whereas post-flowering stress mainly shows the genetic variability in the kernel weight and leaf senescence (Bänziger et al., 2000). Although CIMMYT assumes that 50 % of yield losses worldwide are due to drought stress before flowering, stress during flowering is considered to be more important for two reasons: First, maize is particularly susceptible to drought at this stage. The grain yield can be reduced nearly to zero by severe stress during a relatively short period at flowering, when the final number of ears per plant and the number of kernels per plant are determined (Grant et al., 1989). The ability to produce an ear under stress is the most important characteristic associated with drought tolerance. Second, at the flowering stage, the season is too far advanced to consider replanting or adjustment of cropping patterns (Bolaños and Edmeades, 1996).

In a large-scale experiment, the overall correlation between mean grain yields in the hybrids and the phenotypical yield stability of a given hybrid against the mean yield of all hybrids at the same location was 0.37 (Denic et al., 2001). This demonstrated that selection for high yield and drought tolerance may be feasible. Thus, in CIMMYT, drought tolerance is treated and selected as a trait. Heritability for grain yield declines especially under severe drought stress is low. Selection is based on an index that seeks to reflect to what extent a parent is able to maintain the time from sowing to anthesis, maintain or increase grain yield under well-watered conditions, increase grain yield under drought, and decrease ASI, barrenness, the rate of leaf senescence, and leaf rolling under drought.

It is recommended that a several simple secondary traits be used in selecting for drought tolerance (Edmeades et al., 2000). These traits may increase selection efficiency especially when the yields fall below 50 to 60 % of the potential yield (Bruce et al., 2002). Traits that are most likely to improve yield under drought should meet several criteria: (i) The duration the trait influence yield (Lorens et al., 1987), ('ii)the trait should be inherited and expressed together with the grain yield, iii) the target environment for a specific trait and specific stage of growth such as seasonal rainfall pattern, soil-nutrition (iv) lastly, the markets since the desirable traits may differ substantially depending on market demand (Heisey and Edmeades, 1999)

Selection gains were largely the result of reduced barrenness and an increase in the harvest index (Bänziger et al., 2000; Bolaños et al., 1993). Selection under various water regimes generally reduces the genetic variation in the potential grain yield (Bolaños and Edmeades, 1996). Likewise, other constitutive (i.e. non-adaptive) traits such as plant phenology, early plant vigour, root size and depth, and utilization of stem reserves for grain filling, may serve as selection criteria under moderate stress only (Blum, 1997).

2.3.3 Hybrid versus open-pollinated varieties

Drought-tolerant populations of CIMMYT composites from numerous landraces and cultivars with one or several drought-adaptive traits were competitive over the full range of water availability. However, they showed some inherited agronomic defects, which limits the scope of such approaches, mainly from an economic perspective and for national breeding programmes (Edmeades et al., 2000). It is, therefore, recommended that recurrent selection with elite germplasm be implemented to achieve the most rapid improvement in tolerance to drought.

A considerable amount of CIMMYT's research into drought tolerance has focused on OPVs. Evidence however suggests traits conditioning drought tolerance are carried over to lines and hybrids and that they are consistent across various drought scenarios (Bänziger et al., 2000). Extensive trials conducted by CIMMYT evaluated the performance of the most prominent drought-tolerant OPVs and the best stress-tolerant classical hybrids. Stress-tolerant hybrids generally out-yielded OPVs under a wide range of conditions. As such heterosis must be considered an important source of stress tolerance (Blum, 1997). Heterosis is pronounced most at stressed environments and it seemed to help maize to better adapt to stress (Betrán et al., 2003b).

Commercial hybrids, which are not especially stress-tolerant, compared with hybrids developed from stress-tolerant inbred lines often failed when cultivated under conditions of severe drought at flowering (Edmeades et al., 2000). There is no evidence that hybrids are inherently more susceptible to low soil fertility than OPVs (Akintoye et al., 1999). But, owing to the narrow genetic base, classical hybrids may be more susceptible to stress than varietal hybrids (Jaradat et al., 2010). Breeding for genotypes with a medium yielding potential might be a more promising approach, provided that these genotypes will be used in environments where drought is predictable in terms of time, duration, and intensity (Ceccarelli and Grando, 2007).

2.3.4 Analysis of ggenetic parameters

2.3.4.1 Analysis of variance

Usually, analysis and interpretation of genetic effects derived from selfed populations is challenging (Hallauer and Miranda, 1981). Imposing of random mating is conducted to produce progenies or different kind of relatives. The mating methods most commonly used are the diallel, design II and the line by tester. During the early stages of a breeding cycle, the number of parents are numerous and this should be put into consideration; the line x tester (lxt) is found effective. In the l x t method, the lines and the testers are planted in a paired nursery in adjacent but alternating rows on a single date or staggered date. In lxt both full-sib (*FS*) and/or half-sib (*HS*) relatives are produced simultaneously through hand pollination. Genetic analysis of the testcrosses enables breeders to rapidly establish the value of lines while in hybrid combination. The line x tester and the top cross methods were used in the current study.

Depending on the objective of the breeder, during the evaluation, data or the values of qualitative and quantative variables are recorded. Using the data variance is partitioned as follows (Sharma, 1988):

i) Individual trial/location

$$\mathbf{Y_{ijk} = \mu + l_i + t_j + (l \times t)_{ij} + e_{ijkth}}$$

Where:

Y_{ijk} is the k^{th} observation on i^{th} x j^{th} hybrid

μ is trial mean,

l_i is the effects of the i^{th} lines,

t_j is the effects j^{th} tester (single cross hybrid),

$(l \times t)_{ij}$ is the interaction effect of the cross between the i^{th} line and j^{th} tester,

ei_{jk} is the error term associated with each observation,

ii) Across locations or environments

$$\mathbf{Y_{ijkm} = \mu + l_i + t_j + (l \times t)_{ij} + (lxs)_{im} + (lxs)_{jm} + (lxtxs)_{ijm} + e_{ijkm}}$$

Where:

Y_{ijkm} is the k^{th} replication at the m^{th} site of the i^{th} x j^{th} progeny,

μ is trial mean,

$(l \times s)_{im}$ is the interaction effect of the **i^{th}** line and the **m^{th}** site,

$(t \times s)_{jm}$ is the interaction effect of the **j^{th}** tester and the mth site,

$(l \times t \times s)_{ijm}$ is the interaction effect of the **i^{th}** line and the **j^{th}** tester at the **m^{th}** site,

e_{ijkm} is the error effect associated with the **ikm^{th}** observation.

2.3.4.2 Analysis of yields stability

Through various parameters, numerous models for genotype x environment interaction (GEI) or instability analysis have been developed. For a large data set, the commonly used stability parameters includes the following; the linear regression Eberhart and Russel, (1966), additive main effects and multiplicative interaction (AMMI) Gauch and Zobel, (1996) and, genotype-genotype x environment (GGE) Yan, (2002). While breeding for stress tolerance hybrids, entries with consistently high grain yield across environments are desirable. It is imperative therefore, that methods adopted enable simultaneous identification of stable and high yielding hybrids. In the current study, selection for desirable hybrids was based on Eberhart and Russel, (1966)and the GGE Yan, (2002) methods of analysis.

2.3.4.2.1 Regression model of Eberhart-Russel

Using regression model, yield stability can be estimated in terms of performance of entries across different environments using three statistics (Eberhart and Russel, 1966). The 3 statistics includes, entry means, regression coefficient or slope and, deviation from the mean regression of an entry. The three measures can be generated using the following formulas:

iii) Environmental Index, that is, the effect of environment j across all genotypes,

$$I_j = \bar{e}_j - \bar{X},$$

iv) Regression coefficient or the slope or the predicable response in an entry,

$$b_i = \sum_j Y_{ij} \div \sum_j I^2 j$$

v) Deviation of Y_{ij} from the linear regression value for a given Ij,

$$S^2 di = \{\sum j\ \delta^2 ij \div (n-2)\} - s^2_e/r,$$

vi) Mean of entry ***i*** in location ***j***

$$\mathbf{Y_{ij} = u + \bar{X}_i + \beta_i I_j + \delta_{ij}}$$

Where,

$\bar{e}_j$ is the average performance of all entries at a given location,

$\mathbf{Y_{ij}}$ is the entry mean of the **i**th entry at the **j**th location,

$\bar{X}i$ is the mean of the **i**th entry over all locations (the grand mean),

$\mathbf{\delta^2_{ij}}$ is the deviation from regression of the **i**th entry at the **j**th location,

$\mathbf{\beta_i}$ is the regression coefficient that measures the response of **i**th entry to varying sites,

$\mathbf{I_j}$ is obtained as the mean of all entries at the **j**th location minus the trial mean,

$\mathbf{s^2e/r}$ is the estimate of the pooled error or the variance of a entry mean in that **j**th location.

Assuming a mean regression coefficient of 1 in a population, then an entry response to environment is interpreted as follows; if b=0, the entry yield is same at all the environments (no response) to change, if b=1, it yield changes over environments but in a magnitude which is the same as the average response of all genotypes in the experiment, if b>1 the entry is highly responsive to change. Such an entry yield under favorable and unfavorable condition is above and below average respectively and if b<1 the entry is lowly responsive to change in environments and such entry is of higher adaptability to low-yielding environments.

Plotting the line of goodness for each entry alongside the line of goodness of the environmental index enabled viewing of entries that deviated from the mean regression. The deviation from regression ($\boldsymbol{\delta^2_{ij}}$), is an indicator of the goodness of fit of an entry. Entries with small deviations are desirable as they are considered stable whereas large values of $\boldsymbol{\delta^2_{ij}}$ indicate poor fitness. In a large study of tropical maize germplasm the model was effective in identifying desirable entries (Bänziger et al., 2004).

2.3.4.2.2 Genotype - genotype - environment (GGE) Biplots

In the GGE method, G and GE effects are analyzed as a single mixture. First, genotype and the environment means are decomposed into a single value (SV) or a GGE matrix. Further, the GGE matrix is decomposed into environment eigenvector matrix, the genotype eigenvector matrix, and the SV matrix (array). The genotype and environment eigenvectors indicates the principal component (PC) one and PC two respectively (Yan, 2002). The general pattern of the data are then presented in form of GGE biplots similar to those initially developed by (Gabriel, 1971). In the GGE model, biplots generated using the values of PC1 and PC2 are viewed as: (i) the which-won-where pattern or the genotype x environment relations (Gauch and Zobel, 1996); ii) the interrelationships among test environments; which help in identification of the most effective environments (Yan and Rajcan, 2002), and iii) yield and stability analysis, as displayed in the average environment coordination (AEC) view of the biplot. In hybrid breeding, AEC biplots are amongst the most important tools as they enable breeders to compare and identify entries based on both yield and stability (Yan, 2002). In AEC biplot (Figure 1), PC1 is a measure of performance and it approximates the G effects associated with each genotype. The PC2 approximates the GEI effects associated with each genotype, which is a measure of instability (Yan, 2002). In the AEC biplot, an average environment is defined by the average PC1 and PC2 scores of all locations. It is represented in the biplot by a small circle.

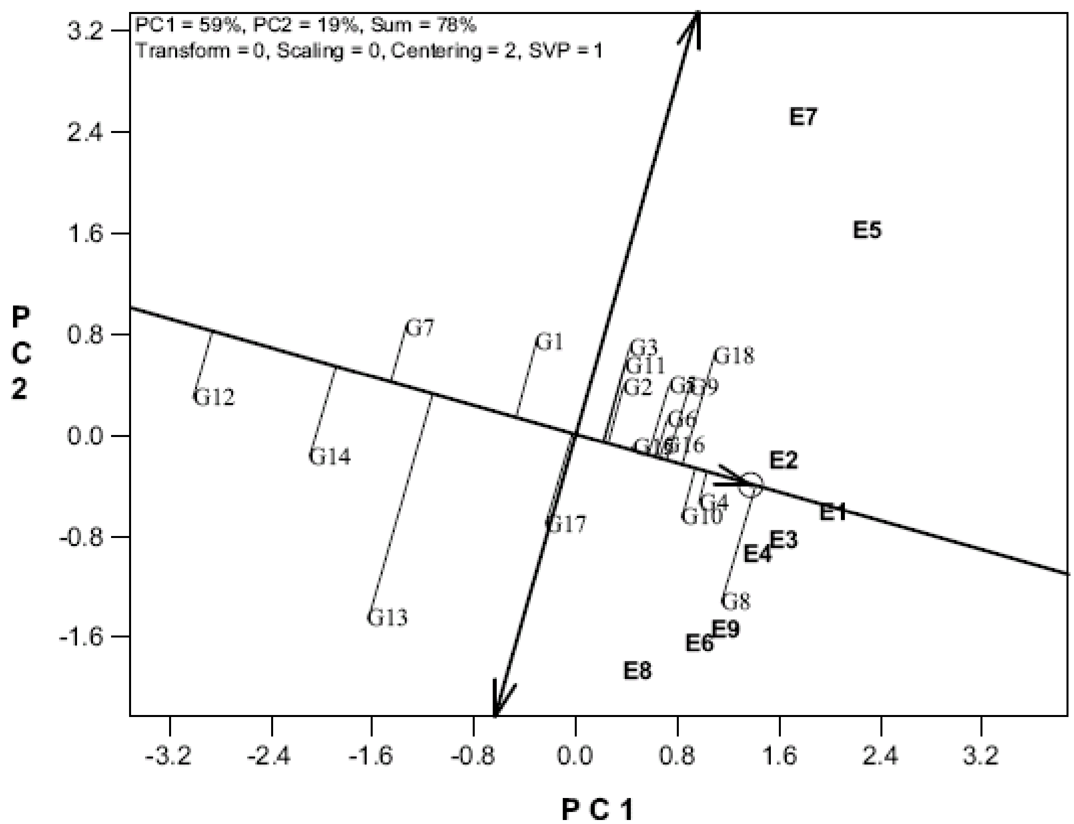

Figure 1. 1: **Average environment coordination biplot showing ranking of genotypes based on yields and stability**

Source: (Yan et al., 2000)

The single arrowed line that passes through the small circle and the biplot origin is known as the average environment axis. This line serves as the abscissa of the AEC and it estimates the genotype main effects (performance). Hence the further a genotype is from the biplot origin the higher the performance. The doubled arrowed line passes through the biplot origin, is perpendicular to the AEC abscissa. This line is known as the ordinate of the AEC. AEC ordinate points towards either direction from the origin and indicates increasing GEI effect or a reduced stability. Ideal genotypes should therefore have the highest mean yield and least distance from the origin of the biplot. GGE biplots were found useful in mega-environment analysis (Yan and Tinker, 2006). In addition GGE biplots proved useful in genotype evaluation (Kang et al., 2004).

2.3.4.3 Analysis of combining ability effects

The concept of combining ability is defined as the relative measure of ability of a biotype to transmit its traits to its progenies. The measure is partitioned into general combining (GCA) and into specific combining (SCA) abilities. GCA is the mean performance of a line while in hybrid combination(s), relative to average performance of all lines while in hybrid combinations. SCA is the deviation of a specific cross from the mean performance of a line while in hybrid combinations (Sprague and Tatum, 1942). Significant variance amongst the two parameters indicates that while in hybrid combinations, the lines performance is different. Thus the two parameters enable selection for suitable lines from a pool of new lines. Usually, selection is based on GCA. Lines with large, positive and significant GCAs estimates for grain yield are considered good for forming hybrids. Lines with good GCAs for secondary traits could be useful source of genetic diversity (Pswarayi and Vivek, 2008). Lines with large, significant but negative GCA estimates should be tested using a different tester. Predominance of low GCA indicates that the lines could form hybrids of high stability. Good GCAs is however not sufficient to select a good line. Rather lines with potential use in a hybrid programme should have the highest GCA, heterosis and the best general adaptability at all test-sites (Hohls et al., 1995).

GCA is primarily due to additive genetic effects (Griffing, 1956). SCA effects is due to effect of dominant genes and GEI (Rojas and Sprague, 1952). As such, the variance due to GCA is usually considered to be an indicator of the extent of additive type of gene action, whereas SCA is taken as the measure of non- additive type of gene actions in breeding for heterosis.

Combining ability analysis therefore is the quickest method of investigating genetic potential in new parents. It helps in understanding the genetic nature of quantitatively inherited traits by giving essential information about the potential parents which are suitable for hybrid production.

In the lxt method, the mean squares of lines and tester are equivalent to their respective GCAs while the line x tester source is equivalent to SCA (Hallauer and Miranda, 1981). Estimates of GCAs and SCAs are generated using the following formulas:-

vii) GCA of lines = $g_i = y_{i.} - Y_{..}$

viii) GCA of tester = $g_j = y_{j.} - Y_{..}$

ix) SCA effects = $S_{ij} = y_{ij} - Y_{..} - g_i - g_j$

Where:

$Y_{..}$ is overall mean of trial, g_i is GCA of line; $y_{i.}$ is mean performance of female x across tester(s); g_i is GCA of tester, $y_{j.}$ is mean performance of tester y in combination with all lines; S_{ij} is SCA of hybrid between line x and tester y and Y_{ij} is hybrid of l x and t y.

In biometric analysis of testcrosses, GCA effect is the main effect of a particular parent while the SCA effect is the effect due to the parents' interaction. Thus the ratio of GCA: SCA variance offers additional analysis parameter. A ratio of above one indicates that parents have not been selected or are in the early stages of selection. In addition, it indicates that the additive genetic effect is more preponderance than the non-additive effect. A ratio of less than one indicate the preponderance of the dominant genetic effect or heterosis (Gardner and Eberhart, 1966).

In addition to strength of the dominant genes, expression of heterosis in hybrids usually depends on genetic divergence of the parents. The divergence can be inferred from the heterotic patterns manifested in the series of variety crosses. If heterosis in the cross is large, then it shows that the two parents used are genetically diverse (Hallauer and Miranda, 1988). Hence establishment of heterotic patterns among varieties is important in selection for parents suitable for hybrid production. In hybrid breeding, to fully exploit heterosis, the concept of heterotic groups and patterns is an important consideration. A heterotic group (HG) is "is a group of related or unrelated genotypes from the same or different populations. Genotypes in a HG show similar pattern of specific combining ability or heterotic response when crossed with genotypes from other genetically distinct groups''. Then, a heterotic pattern refers to a specific pair of two heterotic groups which express high heterosis or performance upon crossing (Melchinger, 1999). Classification of germplasm into HG is an important aspect in hybrid breeding. Based on combining ability analysis two methods are used. The ratio of SCA: GCA variance; a lower ratio indicates predominance of dominant genetic effect. In breeding a lower ratio implies that the two set of parents that formed the cross are not genetically divergent or are of the same heterotic group. Hybrids of such parents may not express heterosis (Reif et al., 2005). A higher ratio indicates predominance of additive genetic effect and early testing may be effective. Based on the prediction from GCA effects promising hybrids can be identified and selected. Crossing of the parents with the highest GCA could lead to development of the best hybrid (Baker, 1978). In the second method, the magnitude of SCA effect is used to estimate heterosis and assign germplasm into heterotic groups. In this model, expression of negative SCA effect indicates reduced heterotic effects. Hence the parents involved could be of the same heterotic group (Vasal et al., 1992). Some lines showed positive SCA effects with both testers and were classified into a new group. Other lines showed negative SCA with both testers and were assigned to both heterotic groups (Warburton et al., 2002). In the tropics, lines belonging to more than one heterotic group are considered superior to those of one group. This is because they could permit development of genetically broad hybrids and possibly more stress tolerant hybrids (Pswarayi and Vivek, 2008). The SCA method is easy and was found effective in assigning maize line to a heterotic group (Li et al., 2007; Pswarayi and Vivek, 2008; Vasal et al., 1992).

2.3.4.4 Heritability in the broad sense

Heritability in the broad sense (H^2) is defined as the proportion of phenotypic variance that is attributable to an effect of the whole genotype, comprising the sum of additive, dominance, and epistatic effects (Falconer and Mackay, 1996; Nyquist, 1991). Several authors also term H^2 as "repeatability". Additionally heritability is measured in two ways; on plot basis or on entry mean basis. For a balanced m trial laid out in randomized complete blocks with **r** replicates, $\boldsymbol{H^2}$ on an entry mean basis is defined the following model of Falconer and Mackay (1996):-

$$\boldsymbol{H^2 = \sigma^2_G / \sigma^2_P}$$

Where $\boldsymbol{\sigma^2_G}$ is the genotypic variance and $\boldsymbol{\sigma^2_P}$ is the phenotypic variance. The phenotype is the means of a genotype across m trials (environments) and **r** replicates per trial. This has variance

$$\boldsymbol{\sigma^2_P = \sigma^2_G + \sigma^2_{GE}/m + \sigma^2/rm}$$

where $\boldsymbol{\sigma^2_{GE}}$ is the genotype-environment interaction variance and $\boldsymbol{\sigma^2}$ is the residual error variance.

Heritability guides plant breeders to select traits from a population based on their measured phenotypic values or to quantify the precision of series of trials (Piepho and Mőhring, 2007). A H^2 of 0 value implies that the variance realized is all due to environmental factors and if $H^2 = 1$ it implies that all the variance realized is due to genetic factors (Nyquist, 1991). Magnitude of heritability is used to predict the response to selection R as $R = S\,H^2$ where S is the selection differential (Falconer and Mackay, 1996). In practice, magnitude of heritability helps breeders in devising the appropriate selection criteria and assessing the level of genetic improvement. Traits of low heritability are considered for recurrent selection while those expressing higher heritability are considered for varieties development (Bouchez and Gallais, 2000). Moreover, higher estimates of heritability confirm the scope of selection in developing new genotypes with desirable characteristics.

In maize evaluated under low nitrogen stress, average H^2 of 0.46 for grain yield, 0.52 for ASI, 0.44 for ears per plant, 0.35 for leaf chlorophyll concentration, and 0.60 for leaf senescence have been reported (Bänziger et al., 1997). Notably, under optimal conditions, the H^2 values for the same traits were much higher. Broad-sense heritability for grain yield under low N were on average 29 % and smaller than under high N maybe because of lower genotypic variances under low N. In another study on maize under drought stress, H^2 for grain yield averaged between 0.40 to 0.60 (Bolaños and Edmeades, 1996). Although values of H^2 were smaller under stress, the two studies recommended that maize breeding programs targeting areas prone to drought and to low-N stresses should include trials under these stresses in order to maximize on selection gains.

CHAPTER THREE:

HETEROSIS AND YIELD STABILITY IN EARLY MATURING MAIZE VARIETAL HYBRIDS UNDER DROUGHT AND OPTIMAL CONDITIONS

Summary

Drought is an important stress that limits maize (*Zea mays* L.) production in eastern Africa. Heterosis in varietal hybrids (VHs) derived from CIMMYT maize lines purported to be tolerant to drought could enhance yield in drought prone ecologies. In this study, 10 F_1 VHs were evaluated in Kenya, Tanzania, Rwanda, Burundi, South Sudan and India in the year 2008. The objectives were to, i) estimate mid-parent heterosis for secondary traits and grain yields of the F_1 VHs, ii) estimate grain yields and stability of the F_1 VHs compared to commercial checks; a 3-way cross hybrid and an open pollinated variety. The 10 F_1 VHs and checks were evaluated across 17 locations; 12 under optimal, 2 under managed drought stress (MDS) and 3 under random drought stress. Trials under MDS were grown under irrigation during rain free months till 2 weeks to flowering when water was withdrawn to impose stress. An Alpha lattice design was used with 3 replications. Plot size was 5 m long, spaced 0.75 m and 0.25 m between and within rows respectively. Fields were kept out of weeds and pests. Applied as diammonium phosphate fertilizer, each trial received 90.0 Kg ha^{-1} N and 98 Kg/ha P at planting and 100 Kg ha^{-1} N as a top-dress at 6 weeks after emergence. In trials under managed drought, the plants were grown under irrigation during the rain free period and drought stress was imposed by withdrawing water 2 weeks before flowering till end of the season. Data for grain yield, male and female flowering, ears per plant, plant height, ear aspect, ear rot, leaf blight caused by *Exerohilium turcicum* and moisture content recorded from all plots were analyzed in MSExcel, SAS and GenStat softwares and the means were separated using the least square deviation method. Results under drought stress revealed; significance (*P≤0.05*) of heterosis in grain yield, plant height and anthesis silking-interval, and non-significance (*P≤0.05*) of heterosis in ears per plant. Under drought stress, H^2 values for grain yield, ears per plant, ASI and plant height were 0.30, 0.33, 0.40 and 0.01 respectively. Values of H^2 for the traits recorded were higher under optimal conditions. Whereas the variations for traits amongst the VHs were non-significant (*P≤0.05*), surprisingly, highest heterosis values (≥40 %) and ranges for grain yield were realized under drought. Heterosis was important for drought tolerance and grain yields in best VHs were as good as that in the 3-WC hybrid and 40 % higher than the OPV; the commercial checks. Whereas, on average the yields of the VHs under drought were 36 % that under optimal conditions, VHs 2, 8 and 10 showed relatively good yield stability across environments. In conclusion, varietal hybrids derived from imporved CIMMYT maize lines, could be beneficial to hybrid breeding programmes targeted to drought prone ecologies. The potential of OPVs as was revealed in this study should be further investigated.

3.1 Introduction

Drought stress is a major constraint to maize production in sub-Sahara Africa. In tropical maize, it is estimated that about 20 % of annual optimal yield reduction is due to drought stress (Edmeades et al., 1993). During some seasons, reductions of as much as 60 % have been reported in southern Africa (Rosen and Scott, 1992). Partly, due to effect of climate change, more maize is expected to be grown in drought prone environments in future and this may cause more negative and devastating effects in maize production in eastern Africa (World Bank, 2007). The effect of drought is particularly felt by the small-scale farmers who lack the economic power to grow maize using high-input systems. In eastern Africa, a large percentage of farmers rely on maize for supply of about 30 % of the required daily calories (Hassan et al., 2001). Thus reduced yields raise concern on food security and economic welfare of the communities in marginalized ecologies. In eastern Africa region, breeding for drought tolerant maize is often suggested as a sustainable approach to increasing maize yields (Bänziger et al., 1999b).

Open pollinated varieties and landraces are valuable genetic resources (Alexander et al., 2013). Characterization of landraces for desirable morphological traits, adaptation to low nitrogen and drought, and pest resistance has been conducted leading to identification of OPVs with desirable traits. Over a long time, extensive exploitation of OPVs however, was hampered by the general assumption that due to their genetic heterogeneity, their heterosis is low. This challenge might no longer be a hindrance. Tropical breeding programmes have developed several maize populations with enhanced drought tolerance (Monnneveux et al., 2006). In the early to intermediate populations, the high grain yield was attributed to additive and non-additive genetic effects (Hede et al., 1999; Ortiz et al., 2010). Under drought, the higher yield was as a result of presence of useful genetic diversity including; more number of ears per plant, increase in kernel number and reduction in time to 50 % of pollen shed (Bolaños and Edmeades, 1993; Bolaños et al., 1993). The other traits highly correlated to high yields under stress are a reduced anthesis silking interval (Edmeades et al., 2000). In addition, a delay in leaf senescence was highly correlated with kernel set (Bolaños et al., 1993). As such, tropical OPVs could be useful genetic resources for hybrid breeding programmes targeting drought prone areas.

Heterosis, the increased productivity expressed in a F_1 generation, and not in its corresponding parents, is an important phenomenon in hybrid breeding. The higher yield is dependent on genetic divergence in the presence of dominant genetic effect (Falconer and Mackay, 1996; Moll et al., 1965). In OPVs, heterotic response was improved by continuous selection for specific combining ability (Carena and Wick, 2006). Additive genetic effects also accounted for the most successful crosses tested in tropical regions of the USA (Melani and Carena, 2005). Heterosis for the whole plant was particularly important for enhanced grain yield under drought (Blum, 1988).

Research showed that grain yield performance of varietal hybrids could be enhanced through reciprocal recurrent selection programmes. In these programmes, mid parent heterosis values ranged from 25.4 % to 76.0 % and high parent heterosis values ranged from 22.5 % to 72.4 % after an average of 8.33 cycles of selection. Improved populations were five-fold higher in heterosis than their respective unimproved versions (Carena and Wick, 2006). In addition, magnitudes of heterosis increased significantly in crosses between OPVs assembled from geographically isolated regions (Carena, 2005). Heterosis was particularly important in increasing maize yields under drought stress. On average, heterosis under drought stress was more than 50 % higher than under optimal-rainfed conditions. In addition, the variation on heterosis was clear and significant (Makumbi et al., 2010). This implied that it could be effective to select for useful heterosis under drought stress. Adoption of improved OPVs, could facilitate tapping of heterosis in varietal hybrids in a manner similar to that in classical hybrids (Carena, 2005; Hallauer and Miranda, 1988). Breeding programmes rarely make full use of the additive and non-additive genetic variation existing in elite OPVs (Lonnquist and Gardener, 1963).

A large percentage of farmers in marginalized environments grow maize OPVs. About 50 % of maize land in East Africa is under classical hybrids while the rest grow OPV or recycled F_1 hybrids (Bellon, 2001). In a recent study, elite OPVs from CIMMYT, with one or several drought-adaptive traits, were competitive over the full range of water availability. However, they showed some inherited agronomic defects, which mainly from an economic perspective and for national breeding programmes limits use of this germplasm (Edmeades et al., 2000). It is, therefore, recommended that recurrent selection with elite germplasm be implemented to achieve the most rapid improvement in tolerance to drought.

In a varietal hybrid recurrent selection programme, 10 elite OPVs were obtained from intercrosses of drought and low-nitrogen tolerant maize lines. To enhance on earliness and adaptation, the elite OPVs were backcrossed to locally adapted and commercial early open pollinated varieties (W. Mwasya, personal communication). To optimally utilize the new OPVs, it was necessary that those with desirable heterotic response were identified from the initial pool. Studies show that heterosis was influenced by environment. Hence evaluation for drought tolerance is conducted under moderate drought stress (Bänziger et al., 1999a). In addition, inorder to asses yield potential, at the same time evaluation is conducted under optimal conditions (Heisey and Edmeades, 1999). Entries that consistently showed high heterotic response across environments were desirable. Such hybrids might be highly adapted to unfavorable conditions and could be beneficial to maize farmers in marginalized areas. The objectives of this study were to, i) estimate mid-parent heterosis (MPH) for grain yield and secondary traits in varietal hybrids, and ii) evaluate performance and stability for grain yield in 10 F_1 varietal hybrids compared to commercial checks; an OPV and a classical hybrid.

3.2 Materials and Methods

3.2.1 Experimental materials

Eleven parental open pollinated varieties (OPVs), their 10 varietal hybrids and 4 checks (Table 3.1) were used in this study. Out of the 11 OPVs, ten were the females and 1 was the common male parent. The female parents were intercrosses of up to 200 drought and low N tolerant classical maize lines acquired from CIMMYT Africa and from Kenya and Tanzania national breeding programmes. The common male parent (SYN2006) is known for good GCA and desirable adaptation to drought prone conditions. The OPVs were maintained by sib-mating at KARI-Kiboko ($2^0$25'' S, $37^0$75'' E, and 975 masl) research station in Kenya.

Table 3.1: **Parents, hybrids and checks evaluated in the study**

Entry no.	Genotype name	Type of entry	Geographical origin	Potential special traits
1	ZIMLINE/KAT BCI - 8/SYNTH2006	Varietal hybrid	Kenya	.
2	ZIMLINE/KAT BCI - 10/SYNTH2006	Varietal hybrid	Kenya	.
3	ZIMLINE/KAT BCI - 13/SYNTH2006	Varietal hybrid	Kenya	.
4	ZIMLINE/KAT BCI - 15/SYNTH2006	Varietal hybrid	Kenya	.
5	ZIMLINE/KAT BCI - 25/SYNTH2006	Varietal hybrid	Kenya	.
6	ZIMLINE/MORO BCI - 1/SYNTH2006	Varietal hybrid	Kenya	.
7	ZIMLINE/MORO BCI - 24/SYNTH2006	Varietal hybrid	Kenya	.
8	M37/MORO BCI - 1/SYNTH2006	Varietal hybrid	Kenya	.
9	M37/MORO BCI - 5/SYNTH2006	Varietal hybrid	Kenya	.
10	ECA-EE-55	Standard OPV check	CIMMYT	Extra early maturing
11	Katumani	Commercial Opv check	KARI-Kenya	Extra early maturing
12	DUMA43	Commercial 3WC hybrid check	Kenya	Early maturing
13	AMSECA/KAT BCI - 2/SYNTH2006	Female parent	CIMMYT/NARS-Kenya	Drought & Low-N tolerance
14	ZIMLINE/KAT BCI - 8-#	Female parent	CIMMYT/NARS-Kenya	Drought & Low-N tolerance
15	ZIMLINE/KAT BCI - 10-#	Female parent	CIMMYT/NARS-Kenya	Drought & Low-N tolerance
16	ZIMLINE/KAT BCI - 13-#	Female parent	CIMMYT/NARS-Kenya	Drought & Low-N tolerance
17	ZIMLINE/KAT BCI - 15-#	Female parent	CIMMYT/NARS-Kenya	Drought & Low-N tolerance
18	ZIMLINE/KAT BCI - 25-#	Female parent	CIMMYT/NARS Tanzania	Drought & Low-N tolerance
19	ZIMLINE/MORO BCI – 1	Female parent	CIMMYT/NARS Tanzania	Drought & Low-N tolerance
20	ZIMLINE/MORO BCI – 24	Female parent	CIMMYT/NARS Tanzania	Drought tolerant
21	M37/MORO BCI -1	Female parent	CIMMYT/NARS Tanzania	Drought tolerant
22	M37/MORO BCI – 5	Female parent	CIMMYT/NARS Tanzania	Drought tolerant
23	AMSECA/KAT BCI – 2	Female parent	CIMMYT /NARS Kenya	Drought tolerant
24	SYNTH2006	Common male parent	CIMMYT	Good GCA for grain yield

The four checks used in this study included; one standard OPV, one commercial OPV, a commercial classical 3-WC hybrid, and a local check. The local checks depended on the location and were excluded in the analysis and presentation.

3.2.2 Pollination and formation of hybrids

The varietal hybrids were formed in a nursery at KARI-Kiboko research station. In the nursery male and females were sowed in blocks of 10 rows, each of 4 metres, laid adjacent to each other.

All standard agronomic practices were applied to both male and females. In females, at emergence of male and female flowers, tassels were removed and the ear shoots were covered with a shoot-bag. At emergence of male flowers, tassels of the male plants were covered with a pollen bag to enable pollen harvesting. From male plants, pollen was harvested, bulked and used to hand-pollinate the females. To increase on pollination effectiveness, pollen harvesting and pollination took place every day between 10 a.m. and 12 noon local time. After pollination the female flowers remained covered to avoid contamination. At maturity, seeds of the 10 F_1 varietal hybrids were formed by separately harvesting, bulking, shelling and packaging kernels from each female.

3.2.3 Experimental design and environments

The trials were conducted in 17 locations (Table 3.2) and laid out as a 5x5 Alpha-lattice design (Paterson and Williams, 1976). The entries were grown in 3 replications. Plot size was two rows, each of 5 metres length. The spacing between and within rows was 0.75 metres by 0.25metres respectively. Evaluation was conducted under moderate drought stress and under optimal conditions. In this write up, the artificially induced drought is referred to as managed drought (MDS); the natural drought is referred to as the random drought (RD) and the optimal rainfed conditions are referred as optimal. In two MDS locations, drought stress was managed by planting the trials during the rain free months under irrigation and withdrawing water two weeks to flowering till end of the season. In 3 RD locations; the trials the rainfall was below the usual amount at the respective locations and hence the trial experienced natural drought. Fertilizer was applied as 60 kg P ha^{-1} at planting as Diammonium phosphate to facilitate development of essential structures of the seedlings. Another dose of 60 kg N ha^{-1} was side dressed 30 days after emergence as Calcium Ammonium Nitrate. All the other required agronomic practices were undertaken at the rates recommended at each location.

Table 3. 2: **Agro-climatic characteristics and management at the 17 locations used for evaluation of the varietal hybrids**

Location No.	Location	Country	Longitude	Latitude	Altitude (masl)	Management
1	Kiboko	Kenya	$37^0$75'E	$02^0$15' S	975	Managed Drought
2	Wad Medani	Sudan	$30^0$41" E	$04^0$04' N	807	Managed Drought
3	Selian	Tanzania	$00^0$30'E	$36^0$37' S	1287	Random drought
4	Kakamega	Kenya	$34^0$45' E	00^0 16' N	1585	Random drought
5	Rahad Res	Sudan	$31^0$25' E	$12^0$44' N	449	Random drought
6	Yei	Sudan	$33^0$31' E	$08^0$22' N	406	Optimum
7	Kimaeti	Kenya	$00^0$36' E	$34^0$24' S	1300	Optimum
8	Kakamega	Kenya	$34^0$76'E	$00^0$27' N	1526	Optimum
9	Maseno	Kenya	$34^0$36' E	00^0 00' N	1531	Optimum
10	Kitale	Kenya	01^0 01' E	$39^0$59' N	1849	Optimum
11	Mparambo	Burundi	30^0 23'E	02^0 43' S	1644	Optimum
12	WeruWeru	Tanzania	00^0 37' E	$03^0$19' S	992	Optimum
13	Mosso	Burundi	04^0 00' E	$30^0$04' S	382	Optimum
14	Patancheru	India	$17^0$53' E	$78^0$27' N	545	Optimum
15	Elgon Downs	Kenya	$00^0$30' E	$35^0$16' S	2080	Optimum
16	Wad Medani	Sudan	$33^0$31' E	$14^0$23' N	406	Optimum
17	Kiboko	Kenya	37^0 75' E	$02^0$09' S	975	Optimum

masl = metres above sea level

3.2.4 Data collection

The following data were collected in each plot: Days to pollen shed (DTP) were the number of days after planting when 50 % of the plants shed pollen. Days to silking (DTS) were the number of days after planting when silks emerged in 50 % of the plants. Ears per plant (EPP) were the number of ears with at least one fully developed kernel divided by the number of plants with a harvestable ear. Anthesis silking interval was calculated as DTS minus DTP. Plant height was measured as the height in centimetre between the base of a plant to the insertion of the first tassel branch of the same plant. *Exserohilum turcicum* (ET) was recorded as a visual score on severity of diseases symptoms on a scale from 1 (= clean, no infection) to 5 (= severely diseased). Ear aspect (EA) was recorded as a score from 1-5 where 1=good and desirable ears and 5 undesirable ears. Ear rot (ER) was calculated as the percent of the ears with 50 % rotten kernels. Unshelled ears of each entry were weighed in kilograms and moisture content in grain was measured as a percent of field weight. Grain yields were derived from field weight (FW) as follows; GY = FW in t ha $^{-1}$ x [(100-field MC/100-12.5)] x 10/plot size in metres squared.

3.2.4 Data Analysis

3.2.4.1 Performance and analysis of variance

Mean and mean squares were generated using Statistical analysis software (SAS, 2008). Yields stability were analyzed using GENStat software (Genstat 12.2, 2012). At each location and each environment, least square means and means squares of the main and the interactive effects were generated using the general linear model (Blouin and Saxton, 1990). The *F*-test for significance was calculated at 5 %, 1 % and 0.1 % levels of probability as follows: effect of environment and heterosis was tested against error term while effects of entries, checks, parents and hybrids was tested against their respective interactions with environments. Least square means were separated using least square deviation (LSD) (Cochran and Cox, 1957). The LSD method enables identification of minute differences amongst means. MS Office packages were used for further numerical synthesis and presentation of the results.

3.2.4.2 Estimation of heterosis in 10 varietal hybrids under different environments

Average heterosis was estimated in the ANOVA using the single degree of freedom comparison of parents vs. hybrids (p *vs.* h) as stipulated in (Hallauer and Miranda, 1981). In this model, effect of parents vs. hybrids (p *vs.* h), was generated using the orthogonal partitioning variance for all the entries by the least squares method. Significant mean squares for (p *vs.* h) indicated presence of heterosis. Using the least square means, in parents and in corresponding hybrids, at every environment mid-parent heterosis was calculated as percent increase (+) or decrease (-) exhibited by the F_1 hybrids over mid parent value (Fehr, 1987);

Percent Mid parent heterosis = [(F_1- Midparent)/Midparent)]*100

Where F_1 = performance of the hybrid and,

Mid Parent = average performance of 2 parents involved in making the VH.

3.2.4.3 Yields stability aanalysis across environments using Eberhart and Russel model

Yields of the varietal hybrids, recorded at the 17 locations were used to analyze stability. Yields stability in terms of performance of entries across different environments was assessed using three statistics (Eberhart and Russel, 1966). The 3 stability measures includes, entry means, regression coefficient or slope and deviation from the mean regression of an entry. The 3 measures were generated using the following formulas:

i) Environmental Index, that is, the effect of environment j across all genotypes,

$$I_j = \bar{e}_j - \bar{X},$$

ii) Regression coefficient or the slope or the predicable response in an entry,

$$b_i = \sum_j Y_{ij} \div \sum_j I^2 j$$

iii) Deviation of Y_{ij} from the linear regression value for a given I*j*,

$$S^2 di = \{\sum j\ \delta^2 ij \div (n-2)\} - s^2_e/r,$$

iv) Mean of entry ***i*** in location ***j***

$$Y_{ij} = u + \bar{X}_i + \beta_i I_j + \delta_{ij}$$

Where,

$\bar{e}_j$ is the average performance of all entries at a given location,

$\mathbf{Y_{ij}}$ is the entry mean of the $\mathbf{i^{th}}$ entry at the $\mathbf{j^{th}}$ location,

$\bar{X}\boldsymbol{i}$ is the mean of the $\mathbf{i^{th}}$ entry over all locations (the grand mean),

$\boldsymbol{\delta^2_{ij}}$ is the deviation from regression of the $\mathbf{i^{th}}$ entry at the $\mathbf{j^{th}}$ location,

$\boldsymbol{\beta_i}$ is the regression coefficient that measures the response of $\mathbf{i^{th}}$ entry to varying sites,

$\mathbf{I_j}$ is obtained as the mean of all entries at the $\mathbf{j^{th}}$ location minus the trial mean,

$\mathbf{s^2e/r}$ is the estimate of the pooled error or the variance of a entry mean in that $\mathbf{j^{th}}$ location.

Assuming a mean regression coefficient of 1 in a population, then an entry response to environment is interpreted as follows; if b=0, the entry yield is same at all the environments (no response) to change, if b=1, it yield changes over environments but in a magnitude which is the same as the average response of all genotypes in the experiment, if b>1 the entry is highly responsive to change. Such an entry yield under favorable and unfavorable condition is above and below average respectively and if b<1 the entry is lowly responsive to change in environments and such entry is of higher adaptability to low-yielding environments.

Plotting the line of goodness for each entry alongside the line of goodness of the environmental index (mean regression) enabled analysis of deviation of an entry from the mean regression. The deviation from regression ($\boldsymbol{\delta^2_{ij}}$), is an indicator of the goodness of fit of an entry. Entries with small deviations are desirable as they are considered stable whereas large values of $\boldsymbol{\delta^2_{ij}}$ indicate poor fitness. In a several studies in tropical maize germplasm the model was found effective in identifying desirable entries (Bänziger et al., 2004).

3.2.4.4 Yield stability across environment using GGE model

Mean for grain yield of the varietal hybrids, recorded at the 17 locations were used to analyze stability using the GGE biplot method (Yan et al., 2000) in GenStat. Following this method, hybrids and environment means were decomposed into a single value (SV) or a GGE matrix. Further, the GGE matrix was decomposed into environment eigenvector matrix, the genotype eigenvector matrix, and the SV matrix (array). The genotype and environment eigenvectors indicated the principal component (PC) 1 and PC 2 respectively. The biplots generated using the values of PC1 and PC2 were viewed as average environment coordination (AEC). In AEC biplot (Figure 3.1), PC1 is a measure of performance and the PC2 approximates stability (Yan, 2002).

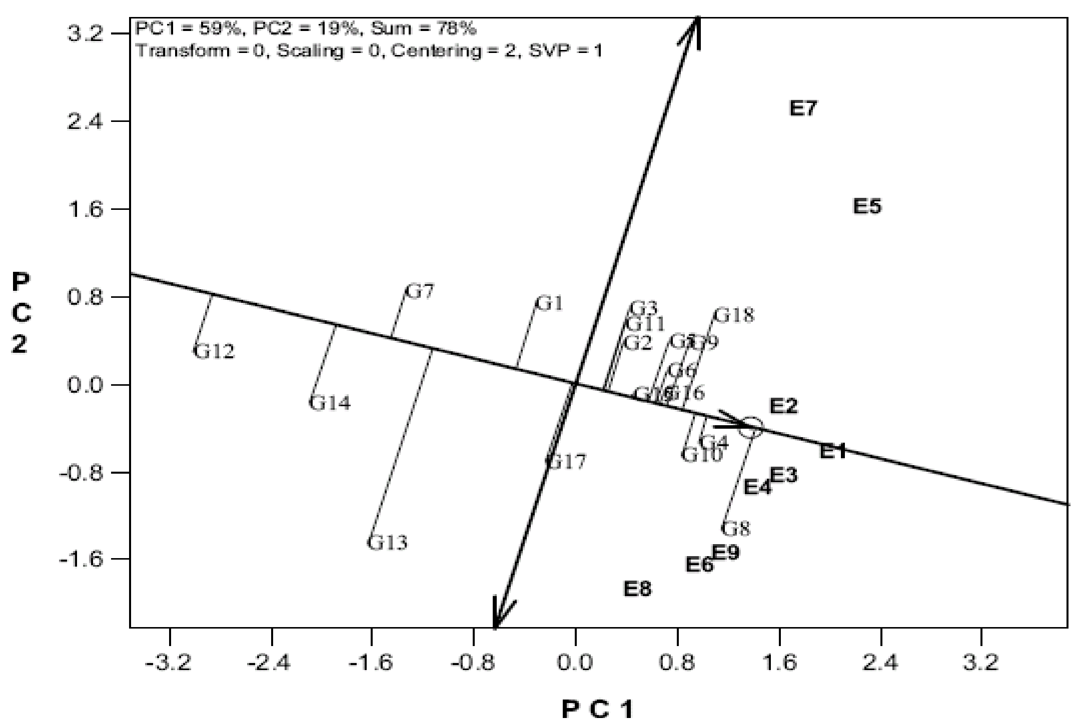

Figure 3. 1: **GGE - average environment coordination biplot displaying the genotypes yield and stability.**

Source: (Yan et al., 2000)

In the biplot, the average PC1 and PC2 scores of all locations is represented in the biplot by a small circle. A single arrowed line passes through the small circle and the biplot origin serves as the abscissa of the AEC and it estimates performance. Hence the further a genotype is from the biplot origin the higher the performance. The doubled arrowed line is known as the ordinate of AEC. AEC ordinate points towards either direction from the origin and indicates decreasing stability. Ideal genotypes should show high performance and good stability. GGE biplots were found useful in genotype evaluation (Kang et al., 2004). In hybrid breeding, AEC biplot enabled comparison and identification of hybrids based on both yield and stability (Yan et al., 2000).

3.2.4.5 Heritability in broad-sense for traits recorded across environments

Heritability (H^2) in the broad-sense was analyzed as the proportion of phenotypic variance that is attributable to an effect of the whole genotype, comprising the sum of additive, dominance, and epistatic effects (Falconer and Mackay, 1996; Nyquist, 1991). Under each environment composed of m trials of 3 replications (r), H^2 for each trait recorded were generated based on an entry-mean using the Falconer and Mackay, (1996) model:-

$$H^2 = \sigma^2_G / \sigma^2_P$$

The variance was generated as:-

$$\sigma^2_P = \sigma^2_G + [(\sigma^2_{GE}/_m) + (\sigma^2/rm)]$$

Where:

σ^2_G is the genotypic variance and σ^2_P is the phenotypic variance, σ^2_{GE} is the genotype-environment interaction variance, and σ^2 is the residual error variance.

3.3 Results and Discussion

3.3.1 Analysis of variance under drought stressed environments

Results on analysis of variance under managed drought stress (MDS) and random drought stress are shown in Tables 3.3 and 3.4 respectively. Highly significant (*P≤0.01*) differences were revealed amongst locations for most traits evaluated under MDS and all traits studied under random drought. Differences amongst locations under MDS were not significant for ASI. This implied that the response of ASI to MDS was similar across locations under drought. Differences amongst the VHs, for all traits evaluated under drought, were not significant implying that drought tolerance in the VHs was similar.

Table 3. 3: **Mean squares for grain yield and secondary traits evaluated in entries under managed drought stress**

Source of variation	df	GY t ha^{-1}	EPP #	EA 1-5	DTP day	ASI day	DTS day
Environment (E)	1	2.06***	0.64***	18.7***	1613.80***	1.70	1510.51***
Rep(E)	4	2.7***	0.04	3.3**	2.80	10.45	6.04
Entries	24	0.26***	0.03**	0.47*	9.6***	37.1**	74.***
Hybrids (VHs)	9	0.19	0.03	0.34	1.40	5.50	17.60
Parents	10	0.11	0.02	0.32	4.55*	12.80	24.90
Checks	3	0.74**	0.09	1.2*	52.4***	179.9***	399.9***
Hybrids vs. Parents	1	0.67**	0.05	1.09	14.04***	73.56*	151.9**
Hybrids vs. Checks	1	1.04**	0.04	1.1*	1.37	88.69*	112.1*
Entries x E	24	0.26***	0.03	0.51*	4.20***	23.10***	38.30***
Hybrids x E	9	0.27*	0.04	0.7*	0.90	8.30	9.20
Parents x E	10	0.14	0.03	0.39	3.90*	8.50	15.10
Checks x E	3	0.74**	0.21	0.60	17.50*	109.70**	207.80**
Error	99	0.93	0.20	0.29	1.70	8.90	9.80

*, **, *** significant at *P* ≤ 0.05 P ≤ 0.01 P ≤ 0.001 probability levels

† Traits are: GY= grain yield; DTS=days to 50 % emergence of silk; DTP=days to 50 % shed of pollen; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect.

Contrary to findings in the current study, Pswarayi and Vivek, (2008) reported significant variation amongst early maturing classical maize hybrids evaluated under drought stress. The VHs used in the current study were progenies of CIMMYT drought and low nitrogen tolerance inbred lines Muasya 2012, personal communication). The similarity in their reaction to drought might be attributed to the common parentage of the VHs studied. Parent vs. hybrids effect were significant (*P<0.05*) for male and female flowering and for ASI and non significant for ear related traits under MDS (Table 3.3). Except for plant height, parent vs. hybrid effects were non-significant for all traits evaluated under RDS (Table 3.4). Significant parent vs. hybrids effects indicated presence of heterosis (Hallauer and Miranda, 1988). Significant heterosis for plant height, earliness, male and female flowering suggested that these traits were associated to enhanced drought tolerance.

Table 3. 4: **Mean squares for grain yield and secondary traits of entries evaluated under random drought stress condition**

Source of variation	**† df**	**GY t ha^{-1}**	**EPP #**	**EA 1-5**	**DTS day**	**DTP day**	**ASI day**	**ET 1-5**	**PH cm**
Environment (E)	2	91.4***	1.9***	30.7**	3288.0***	2578.7***	152.0***	28.6**	35882.7***
Rep (E)	6	1.0*	0.2***	0.5*	23.3*	1.7	8.1***	0.99***	285.9
Entries	24	0.6*	0.04	0.7***	37.2***	48.5***	9.5**	0.3**	625.3***
Hybrids (VHs)	9	0.3	0.03	0.5	3.9	4	8.7	0.1	115.6
Parents	10	0.2	0.01	0.7	23.3***	25.6***	5.9	0.3	551.2*
Checks	3	2.9**	0.1	1.5***	171.4**	266.5***	23.0*	1.0**	2536.3**
Hybrids vs. Parents	1	1.0	0.03	0.4	12.7	9.2	3.1	0.3	813.6*
Hybrids vs. Checks	1	0.06	0.01	0.01	109.2***	71.9***	9.2	0.3	34.8
Entry x E	48	0.4	0.03	0.5***	12.7	10.9**	6.3	0.2	480.0***
Hybrids x E	18	0.3	0.01	0.5***	4.3	2.8	4.6	0.2	450.1*
Parents x E	20	0.3	0.01	0.3	5.7	6.4	4.8	0.2	255.1
Checks x E	6	0.7	0.1	0.8**	53.5	42.3	19.2*	0.4	1340.1*
Error	144	0.37	0.03	0.2	10.3	6.3	7.4	0.15	191.6

*, **, *** significant at $P \leq$ 0.05 $P \leq$ 0.01 $P \leq$ 0.001 probability levels
† Traits are: GY= grain yield; DTS=days to 50 % emergence of silk; DTP=days to 50 % shed of pollen; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; PH= plant height; ET=turcicum leaf blight.

Hybrids x environment interaction was significant (*P<0.05*) for grain yield. This suggested that heterosis in a particular hybrid changed depending on the location. Similarly, heterosis in maize was reported to be influenced by the environments of growth (Betrán et al., 2003b). Under drought, a reduced anthesis silking interval was highly correlated with kernel set (Edmeades et al., 2000). Higher yields were a result of more number of ears per plant and reduction in time to 50 % of pollen shed (Bolaños and Edmeades, 1993; Bolaños et al., 1993). On the contrary, in the current study, ears per plant did not seem to enhance GY in the evaluated VHs. In the literature, plant height affects grain yield in maize plants under stressed conditions. Stalk of plants were viewed as useful reserves for carbohydrates which could be remobilized during drought period and thus enabling increased drought tolerance (Blum, 1998). Other studies showed that prolonged drought stress during the vegetative stages affects the length of the internodes by influencing the cell size development (Denmead and Shaw, 1960). As such, under drought stress, heterosis for plant height could suggest rapid growth and early attainment of reproductive stage hence leading to enhanced drought tolerance.

3.3.2 Analysis of variance under optimal environment

Amongst locations under optimal environment, differences were highly significant (*P<0.001*) for all traits evaluated (Table 3.5).

Table 3. 5: **Mean squares for grain yield and secondary traits of entries evaluated across optimal environments**

Source of variation	**† df**	**GY t ha^{-1}**	**EPP #**	**ER %**	**EA 1-5**	**ASI d**	**DTS D**	**PH cm**	**ET 1-5**
Environment (E)	11	147.6***	1.6***	1355.9***	18.5***	3.5	3491.3***	72257.0***	72.1***
Rep (E)	22	1.9	0.1**	54.0***	0.5***	1.7	15.9***	1091.8***	0.5***
Entries	24	12.4***	0.06***	43.8**	0.8***	1.1	118.9***	916.9***	0.2***
Hybrids	9	2.4**	0.3	38.7**	0.3**	1.1	22.9	228.9	0.1
Parents	10	0.5	0.9***	47.6***	0.3*	1.8	62.1**	590.8**	0.1*
Checks	3	56.3**	0.4	53.7	4.2***	6.4	977.4***	4602.9***	0.1
Hybrids vs. Parents	1	11.56***	0.92*	15.24	4.04	1.30	0.57	2684.48	0.03
Hybrids vs. Checks	1	5.36*	2.37***	0.29	0.46	14.63*	47.20	702.17	0.17
Entry x E	253	1.5***	0.03	21.2	0.3***	2.8***	13.2**	366.8***	0.2**
Hybrids x E	99	1.1*	0.2	15.3	0.1	1.5	15.5	358.9**	0.1
Parents x E	110	0.8	0.7***	19.1*	0.3***	2.5***	25	171.3	0.1
Checks x E	66	3.3***	0.3	17.6	0.3***	15	70.4	528.4	0.3
Error	576	5	0.02	1.2	0.02	1.6	0.4	0.5	0.1

*, **, *** significant at $P \leq 0.05$ $P \leq 0.01$ $P \leq 0.001$ levels of probability
† Traits are: GY= grain yield; DTS= days to 50 % silking; ASI = anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; ER=ear rot; ET= Turcicum leaf blight.

This implied that performance of a hybrid at one site changed in another location. ANOVA revealed significant (*P≤0.01*) variation amongst entries for most traits evaluated except for anthesis-silking interval. This suggested that except for ASI, the entries showed useful genetic variability and one could identify desirable VHs amongst the checks and the parents. Amongst the VHs, variation for GY, ER, and EA was significant (*P≤0.01*). Findings that agrees with significant variation amongst early maturing maize germplasm reported previously by (Pswarayi and Vivek, 2008). It seemed reaction of hybrids to ear rots diseases was different and this could have had an effect on grain yield. Parent vs. hybrids effect was significant (*P<0.05*) for ears per plant under optimal conditions (Table 3.5). Significant parent vs. hybrids effect indicated presence of heterosis (Hallauer and Miranda, 1988). Parent vs. hybrids effect was also significant for GY. Higher yields were as a result of more number of ears per plant (Bolaños and Edmeades, 1993; Bolaños et al., 1993). Thus variation in heterosis for ears per plant could indicate that the evaluated OPVs possess dominant genes conditioning prolificacy and which could be useful when selection for enhanced grain yield under optimal conditions. Amongst the VHs x environment interactions were significant (*P≤0.05*) for grain yield and for plant height (Table 3.5). This implied that performance of these traits was different across locations or rather ranks of the hybrids changed depending on the location it was evaluated. This change in rank indicated presence of genotype x environment interaction or instability. As such selection for hybrids that yielded highly across optimal conditions was challenging and stability analysis was required.

Selection studies have shown that the tolerance of tropical maize to drought and N stress can be improved more rapidly when selection environments comprise managed levels of those stresses than when the same germplasm is selected only under high-yielding, unstressed conditions, or under randomly occurring levels and types of stresses (Bolaños and Edmeades, 1993; Byrne et al., 1995). In the current study, ANOVA under MDS and RD revealed a similar reaction amongst the evaluated varietal hybrids. As such further analysis was based on data collected from locations under managed drought stress and those under optimal conditions.

3.3.3 Performance of varietal hybrids and their parents under managed drought stress

Amongst the VHs, performance under managed drought differed significantly ($P \leq 0.05$) for ear aspect, male and female flowering. Variations amongst the hybrids were not-significant for grain yield, ears per plant, ear rot, anthesis-silking interval and plant height implying similar performance in these traits (Table 3.6). The average yield in the varietal hybrids evaluated was 1.45 t ha^{-1}. The hybrids average EPP at 0.6 and ASI at 3.8 days indicated no-prolificacy and delayed emergence of silks traits associated with low yield under drought stress (Bolaños and Edmeades, 1996). On average, hybrids yielded higher than parents and checks under MDS conditions. Further analysis of performance showed that the hybrids had an ASI that was 2.74 days shorter, a higher prolificacy, 6.4 cm taller and of better ear quality. Ultimately, the hybrids yielded more than the parental OPVs under managed drought stress (Table 3.6). The high yielding parents did not necessarily produce the highest yielding hybrid. Higher yield from hybrids of low yielding parents could be attributed to heterosis and not necessarily due to genetic improvement since both parent and hybrids were of narrow genetic variation in ASI or EPP. Grain yields in the varietal hybrids were not significantly different under MDS. Varietal hybrids number 1 and 2 showed best grain yields, yield advantage of 32.5 % over the worst OPV check (entry 12) and its yield was not significantly different from that of the commercial classical hybrid check (entry 13) (Table 3.6). The phenotypic correlation between grain yield and ear aspect was -0.59 implying that ear quality was moderately associated with yields. Weak and negative correlation between grain yield and male (-0.08) and female (-0.36) flowering respectively were realized (Table 3.7). It emerged that, in the VHs that flowering was not a major determinant of grain yield.

Table 3. 6: **Performance of the varietal hybrids and their parents under managed drought stress**

Entry Type and No.	Entry Name	GY t ha [1]	EPP #	EA 1-5	ER %	DTS day	DTP day	ASI day	PH cm
Varietal hybrids									
1	P1 x P11	1.62	0.66	2.27	0.18	64.97	61.41	3.46	114.25
2	P2 x P11	1.63	0.63	2.82	0.08	65.62	61.32	4.35	131.23
3	P3 x P11	1.49	0.49	2.97	0.83	64.84	63.77	1.31	118.71
4	P4 x P11	1.33	0.47	3.06	0.12	67.60	63.14	4.42	125.87
5	P5 x P11	1.39	0.50	2.79	0.13	64.65	61.91	3.14	118.33
6	P6 x P11	1.54	0.68	2.58	0.00	65.66	62.09	3.67	117.24
7	P7 x P11	1.32	0.58	2.70	0.18	66.20	62.63	3.59	125.93
8	P8 x P11	1.16	0.64	2.98	0.00	65.60	61.14	4.42	118.54
9	P9 x P11	1.45	0.57	2.84	0.58	67.47	61.62	5.74	117.89
10	P10 x P11	1.59	0.60	2.56	0.17	65.91	62.16	3.60	123.00
Checks									
11	ECA-EE-55	1.53	0.69	2.66	0.00	65.20	62.79	2.49	108.50
12	Katumani	0.90	0.47	3.65	0.04	58.21	57.62	0.62	96.98
13	Duma 43	1.59	0.34	2.82	0.09	86.33	67.75	18.57	133.27
Parents									
14	P1	1.30	0.60	3.04	0.00	65.90	61.84	4.16	112.19
15	P2	1.19	0.53	3.31	1.43	69.48	62.83	6.57	112.39
16	P3	0.99	0.36	3.37	0.00	77.02	65.03	12.14	107.22
17	P4	1.35	0.53	3.04	0.74	68.77	63.17	5.69	130.68
18	P5	1.22	0.41	2.95	0.73	69.60	63.78	5.78	131.03
19	P6	1.44	0.55	2.61	0.07	69.01	63.43	5.52	103.36
20	P7	1.06	0.46	2.79	0.18	70.87	61.78	9.02	114.73
21	P8	1.05	0.54	3.07	0.79	68.02	61.67	6.36	120.07
22	P9	1.47	0.60	3.02	0.05	67.33	63.38	3.98	118.56
23	P10	0.84	0.48	3.06	0.00	70.93	63.70	7.25	106.65
24	P11	1.41	0.64	2.72	0.00	66.00	60.90	5.09	104.67
Mean of hybrids		**1.45**	**0.58**	**2.80**	**0.20**	**65.90**	**62.10**	**3.80**	**122.00**
Mean of parents		**1.21**	**0.52**	**3.00**	**0.30**	**69.40**	**62.90**	**6.50**	**114.70**
p-values		**0.04**	**0.01**	**0.08**	**0.16**	**13.90**	**1.74**	**7.40**	**68.77**
LSD (0.05)		**ns**	**ns**	**0.77**	**ns**	**1.65**	**3.77**	**ns**	**ns**
CV (%)		**14.30**	**6.00**	**13.00**	**141.00**	**1.90**	**1.70**	**87.20**	**39.80**
Heritability (%)		**30.0**	**33.0**	**0.0001**	**0.0012**	**45.0**	**46.0**	**40.0**	**0.0113**

† GY = Grain Yield; DTP = days to 50 % pollen shed; DTS = days to 50 % emergence of silk; ASI = anthesis-silking interval; EPP = ears per plant; EA = ear aspect; ER = ear rot; PH = plant height;

In other maize studies, early flowering was thought to penalize grain yield under stress (Moreno et al., 2005). High yielding varietal hybrids seemed to utilize drought escape or avoidance mechanism to yield more under drought. It also emerged that the association of ASI to grain yield was absent (Table 3.7). Mean ASI was 3.8 days and ranged from 1.31 to 5.74 days (Table 3.6). The observed weak association between ASI and GY in the VHs evaluated could be attributable to two aspects.

***Table 3. 7*: Correlation amongst traits of the varietal hybrids at 3 environments**

Traits	**GY**	**EPP**	**EA**	**DTS**	**DTP**	**ASI**	**PH**	**ER**	**ET**
Managed drought									
Grain yield	1								
Ears per plant	0.30								
Ear aspect	-0.59	-0.63							
Days to 50 % silking	-0.36	-0.22	0.40						
Days to 50 % pollen shed	-0.08	-0.73*	0.42	0.28					
Anthesis-silking interval	-0.24	0.39	0.02	0.58	-0.61				
Plant height	-0.01	-0.20	0.45	0.56	0.09	0.41	1	.	.
Random drought									
Grain yield	1								
Ears per plant	0.48								
Ear aspect	-0.46	-0.64							
Ear rot	0.13	0.06	0.47						
Days to 50 % silking	-0.61	-0.27	0.56	0.03					
Days to 50 % pollen shed	-0.45	-0.26	-0.20	-0.38	0.25				
Anthesis-silking interval	-0.20	-0.10	0.64	0.25	0.69*	-0.52			
Plant height	-0.06	0.40	-0.03	0.01	0.25	0.05	0.15		
Turcicum leaf blight	0.21	0.16	-0.19	-0.08	0.39	0.17	0.21	0.25	1
Optimal-rainfed									
Grain yield	1								
Ears per plant	0.76**								
Ear aspect	-0.71*	-0.54							
Ear rot	-0.58	-0.45	0.61						
Days to 50 % silking	0.23	-0.23	0.12	0.13					
Days to 50 % pollen shed	0.11	-0.29	0.19	0.97***	0.15				
Anthesis-silking interval	-0.32	-0.08	0.18	0.20	-0.23	-0.19			
Plant height	0.20	0.07	0.24	0.50	0.70*	0.69*	-0.23		
Turcicum leaf blight	-0.01	-0.06	-0.33	-0.42	-0.23	-0.26	0.32	-0.69*	1

First, the direct effects of insufficient pollen supply on ear per plant occur when the ASI exceeds 8 days (Bassetti and Westgate, 1993). In the current study, the longest ASI was 5.74 days (Table 3.6) and EPP was strongly associated (-ve 0.73) with DTP (Table 3.7) suggesting that early pollen shed was associated to reduced barrenness. Secondly the poor association could be because the studied VHs were progenies of early maize and as such evaluation under drought might have yielded little raw material for selection or variation. Low variation for ASI in maize populations formerly selected for drought tolerance has been reported in literature. Non-significant variations for earliness were found in drought tolerant maize populations while evaluated under drought (Monnneveux et al., 2008).

3.3.4 Performance of varietal hybrids and their parents across optimal locations

Analysis of performance showed that the hybrids had lower score for ear aspect as well as foliar and ear diseases than the OPV parents. The hybrids were 2 cm taller and more prolific than the OPV parent. Ultimately, the hybrids yielded more than the parental OPVs (Table 3.8). This suggested that due to heterosis of these traits, hybrids reaction to stresses under optimal conditions was better than that of the OPV parents. Performance in the studied VH was significantly ($P \leq 0.05$) varied for grain yield, ear aspect and ear rots implying that VHs reaction to optimal conditions were varied. Performance was non-significant for EPP, DTS, DTP, ASI and ET implying similar reaction in the hybrids evaluated. Entry 1 showed best score for ear aspect (2.48) compared to that of best OPV commercial check (3.15). The 3WC classical hybrid showed better EA score than the VH. Amongst the VHs, percent ear rot was generally low. Highest rots were observed in the commercial OPV check (Table 3.8). Hybrids differed in their performance for grain yield and ranged from 3.5 to 4.47 t ha^{-1}. Entry 1 yield was the best amongst the hybrids and it yields were 40 % higher than that of the commercial OPV check. Performance of the classical commercial hybrid was higher than that of the best varietal hybrid.

Table 3. 8: **Performance of varietal hybrids and their parents under optimal conditions**

Entry type and No.	Entry Name	GY	EPP	EA	ER	DTS	DTP	ASI	PH	ET
		t ha^{-1}	#	1-5	%	day	day	day	cm	1-5
Varietal hybrids										
1	P1 x P11	4.47	0.96	2.48	4.11	61.82	59.44	2.62	202.57	1.45
2	P2 x P11	4.02	0.97	2.58	5.36	59.99	57.66	2.80	196.68	1.59
3	P3 x P11	3.89	0.94	2.52	5.21	61.52	59.46	2.85	199.97	1.67
4	P4 x P11	3.90	0.94	2.70	6.27	62.21	59.94	2.99	203.78	1.50
5	P5 x P11	4.16	0.97	2.65	6.09	61.75	59.47	2.63	206.50	1.47
6	P6 x P11	4.06	0.99	2.58	4.13	60.53	58.67	2.78	200.38	1.46
7	P7 x P11	3.50	0.93	2.65	7.22	60.05	58.06	2.88	200.32	1.46
8	P8 x P11	4.40	0.99	2.46	3.57	60.49	58.16	2.87	196.76	1.66
9	P9 x P11	4.19	0.98	2.57	4.26	60.34	58.22	2.95	199.50	1.58
10	P10 x P11	3.67	0.92	2.67	3.95	60.77	58.73	2.75	194.98	1.63
Checks										
11	ECA-EE-55	3.53	0.92	2.79	3.29	60.59	58.97	2.60	186.27	1.54
12	Katumani	2.70	0.85	3.15	7.27	57.43	55.24	3.09	194.75	1.62
13	Duma 43	5.54	0.98	2.41	4.18	65.14	62.19	2.99	209.42	1.33
Parents										
14	P1	3.87	0.91	2.73	6.41	60.62	58.95	2.88	188.39	1.58
15	P2	3.74	0.96	2.77	5.42	60.56	58.57	2.74	202.64	1.54
16	P3	3.75	0.91	2.75	5.05	63.34	61.01	2.96	195.37	1.66
17	P4	3.67	0.91	2.66	7.17	61.24	58.89	3.15	203.41	1.58
18	P5	3.98	1.01	2.57	5.47	61.34	59.10	2.95	198.66	1.60
19	P6	3.65	0.92	2.72	3.31	60.40	58.57	2.79	189.66	1.66
20	P7	3.70	0.94	2.77	2.78	60.45	58.77	2.87	199.34	1.62
21	P8	3.55	0.90	2.79	7.06	60.16	58.38	2.70	204.47	1.63
22	P9	4.10	1.03	2.70	4.96	60.41	58.54	2.50	201.34	1.75
23	P10	3.37	0.91	2.84	5.38	60.96	58.59	3.03	194.25	1.83
24	P11	3.79	0.94	2.59	3.72	59.38	57.81	2.76	200.56	1.63
Mean of hybrids		**4.03**	**0.96**	**2.59**	**5.02**	**60.95**	**58.78**	**2.81**	**200.14**	**1.55**
Mean of parents		**3.74**	**0.94**	**2.72**	**5.16**	**60.81**	**58.83**	**2.85**	**198.01**	**1.64**
p values		**0.04**	**0.00**	**0.01**	**0.82**	**0.41**	**0.35**	**0.08**	**11.44**	**0.01**
LSD (0.05)		**0.53**	**ns**	**0.22**	**2.49**	**1.77**	**1.62**	**ns**	**9.32**	**ns**
CV (%)		**12.7**	**5.0**	**9.0**	**87.7**	**2.0**	**2.1**	**36.0**	**39.8**	**36.0**
Heritability (%)		**90.0**	**67.0**	**76.0**	**53.0**	**85.0**	**81.0**	**0.001**	**66.0**	**0.014**

† P = Parent; DTP = days to 50 % pollen shed; DTS = days to 50 % emergence of silk; ASI = anthesis-silking interval; EPP = ears per plant; EA = ear aspect; ER = ear rot; PH = plant height; ET = turcicum leaf blight.

3.3.5 Performance and yield stability of varietal hybrids across 17 locations

Yield in the studied varietal hybrids under managed drought was 36 % that under optimal conditions. The 64 % yield reductions in the varietal hybrids is above the range given in previous report on tropical classical maize under managed drought (Betrán et al., 2003a; Makumbi et al., 2010). However, yield reductions in the studied varietal hybrids were below 76 % (Bolaños et al., 1993). ANOVA across environments revealed highly significant (*P≤0.001*) variation amongst locations indicating that the hybrids' reaction at each location was different.

Table 3. 9: **Analysis of variance for grain yield data of the entries across locations**

Source of variation	Df	Mean square	Percent of total sum of squares
Environment (E)	16	203.5***	74.2
Rep (E)	32	2.9***	2.4
Entries	24	13.5***	3.6
Hybrids	9	2.8*	1.0
Parents	10	1.4*	0.4
Checks	3	80.9***	17.6
Hybrids vs. Parents	1	26.5***	0.2
Hybrids vs. Checks	1	60.8***	0.1
Entries* E	384	1.2***	7.5
Hybrids* E	144	1.1**	6.5
Parents* E	160	0.7	5.5
Checks* E	48	2.9***	18.5
Error	812	0.7	13.2

*, **,***, Significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ probability level

Significant (*P≤0.05*) variation was revealed amongst the VHs (G) and the hybrids /G x E interaction (GEI) was significant (*P≤0.01*) (Table 3.9). This indicated presence of interaction between yield and environment across locations. This change presented a challenge during selection for hybrids that had desirable yield across environment and this necessitated the need for stability analysis for each hybrid across environment. Stability was analyzed as the performance of all the VHs at a specific location (Eberhart and Russel, 1966). Stability results are shown in Table 3.11. A range of b values from 0.88 to 1.15 was revealed. The b-values of varietal hybrids 1, 4, 6 and 7 were above unit and their yields were below average. Yield in varietal hybrid 5 was above average and its b-value was above 1. The b-values of above 1 indicated that the varietal hybrids were highly responsive to change in environment and such entries performance under favorable environment was above average.

Table 3. 10: **Grain yields in the varietal hybrids and checks evaluated across 17 locations**

Hybrids and checks		**Environments**																	
		Managed Drought		**Random drought**			**Optimal**												
Entry No.	**Entry Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	P1 x P11	1.4	1.9	3.5	1.4	1.6	2.6	3.0	2.6	1.9	4.1	4.1	4.4	5.5	5.9	5.9	6.4	7.4
2	P2 x P11	1.6	1.7	3.5	1.3	1.8	2.9	2.1	2.4	3.0	3.9	3.8	4.5	4.9	3.9	3.9	5.5	7.0
3	P3 x P11	1.1	1.8	2.7	1.1	2.1	2.2	2.3	2.5	1.7	3.1	4.7	4.1	4.3	3.4	3.4	6.5	7.1
4	P4 x P11	1.2	1.4	3.6	0.8	1.2	2.8	2.3	2.0	1.9	2.8	3.5	3.5	4.9	6.8	6.8	5.4	6.9
5	P5 x P11	1.3	1.5	3.0	1.0	1.8	2.7	2.9	2.4	2.1	3.4	3.7	4.1	4.6	7.1	7.1	5.6	7.2
6	P6 x P11	1.9	1.2	3.2	1.3	1.5	2.8	1.4	2.0	2.4	2.7	3.2	3.8	5.3	4.3	4.3	5.9	6.4
7	P7 x P11	1.4	1.3	2.9	1.0	1.2	3.7	2.3	2.3	3.4	3.3	3.3	3.7	5.5	3.4	3.4	5.2	7.3
8	P8 x P11	1.4	1.1	3.3	0.7	2.1	2.1	2.7	2.1	1.7	3.4	3.5	3.1	3.8	2.8	2.8	5.2	7.0
9	P9 x P11	1.4	1.5	3.4	1.1	1.5	3.6	2.6	2.3	4.3	3.2	3.8	4.1	4.4	3.7	3.7	7.8	7.6
10	P10 x P11	1.3	1.8	3.7	0.9	1.9	3.0	2.5	2.1	3.2	3.0	4.3	4.3	4.3	4.1	4.1	6.7	8.0
11	ECA-EE-55	1.5	1.5	2.4	0.7	1.7	2.1	2	2.1	1.1	2.6	4.1	3.6	3.9	3.9	3.9	6.4	6.4
12	Kat OPV	0.9	0.9	2.1	0.3	0.4	1.5	1.9	1.6	1.3	1.9	2.1	3.4	2.1	2.4	5.8	3.0	4.3
13	DUMA43	1.0	2.2	3.5	1.9	2.1	4.0	4.2	3.6	6.0	5.5	4.0	5.8	4.5	5.0	6.8	8.8	9.0
Hybrid means		**1.23**	**1.40**	**3.10**	**1.00**	**1.60**	**2.82**	**2.51**	**2.26**	**2.52**	**3.31**	**3.73**	**3.96**	**4.20**	**4.28**	**5.34**	**5.87**	**6.74**
p-value		**0.03**	**0.05**	**0.01**	**0.00**	**0.04**	**0.14**	**0.01**	**0.00**	**0.01**	**0.00**	**0.01**	**0.02**	**0.00**	**0.00**	**0.24**	**0.00**	**0.00**
LSD (0.05)		**0.48**	**0.68**	**0.67**	**0.48**	**0.87**	**Ns**	**0.97**	**0.51**	**2.08**	**0.89**	**1.16**	**1.44**	**1.12**	**1.20**	**Ns**	**1.92**	**0.80**
CV (%)		**23.5**	**29.3**	**13.7**	**30.0**	**32.6**	**34.0**	**23.4**	**13.7**	**49.8**	**16.2**	**18.8**	**21.0**	**16.1**	**15.6**	**17.0**	**19.8**	**7.20**

Key: P = parent; entry 1-10 = varietal hybrids; entry 11 to 15 = checks

In the current study, except in entry 5, response of most varietal hybrids was not similar to that reported by (Eberhart and Russel, 1966). VHs 1 and 6 yielded above average under MDS and under optimal conditions implying these hybrids are lowly responsive to change in environment. Entry 2, 8, 9 and 10 showed b-values of below 1 indicating that they could be lowly responsive to change in environment. Under managed drought stress, yields in entry 2 and 10 were above average and same as the best checks while entry 8 and 9 yielded above average under optimal conditions. Across all environments, yield in entries 1, 2, 5, 6 and 7 were above average and about 50 % higher than OPV commercial check (entry 12). Based on *b*-values, entries 1 and 6 seemed to be desirable for use under environment prone to diverse field stresses. The predictability of the reaction of the varietal hybrids to environment was estimated using S^2_{di}. The varietal hybrids exhibited S^2_{di} values of very narrow range and of above 0.0 implying that they were not stable. Similarly, S^2_{di} values of above 1 were reported in maize (Ombakho et al., 2007). High S^2_{di} suggested that this statistic may not be effective in assessing stability in the evaluated VHs.

Table 3. 11: **Yield stability in varietal hybrids and checks across 17 locations**

Entry No.	Entry code	Grain Yield		Eberhert and Russels statistics		
		t ha^{-1}	Rank	Deviation from mean regression (S^2_{ij})	Rank	regression coefficient (b_{ij})
1	P1 x P11	3.73	1	0.24	4	1.15
2	P2 x P11	3.42	4	0.18	1	0.95
3	P3 x P11	3.27	5	0.24	4	1.02
4	P4 x P11	3.23	4	0.42	7	1.15
5	P5 x P11	3.44	2	0.38	6	1.15
6	P6 x P11	3.63	3	0.26	5	1.13
7	P7 x P11	3.51	3	0.18	1	1.13
8	P8 x P11	3.12	5	0.19	2	0.98
9	P9 x P11	3.32	5	0.24	4	0.98
10	P10 x P11	2.99	6	0.23	3	0.88
11	ECA-EE-55	2.96	2	0.25	1	1.00
12	Katumani	2.20	3	0.64	3	0.68
13	Duma43	4.56	1	0.42	2	1.29

Entry 1-10= varietal hybrids, entry 11=OPV standard check; entry 12=OPV commercial check; entry 13= 3-way cross commercial hybrid check

Entries 2, 7 and 8 showed least values S^2_{di} and were considered most stable. Thus the two statistics were considered of equal effectiveness in estimating yield stability in the evaluated genotypes. Based on means, regression coefficient and deviation from the mean regression, entries 1, 2 and 10 appeared to be the most desirable hybrids for drought prone areas.

Yields of the varietal hybrids at each location (Table 3.10) were used to estimate stability in the varietal hybrids using the genotype-genotype by environment (GGE) method. In GGE model, analysis of effect of hybrids (G) and hybrids x environment (GEI) are closely associated to yields and stability respectively. The genotype-scaling average environment coordination GGE biplots revealed that, respectively, PC 1 and PC 2 explained 50.98 % and 25.79 % = 76.77 % of the total GGE variations (Figure 3.2).

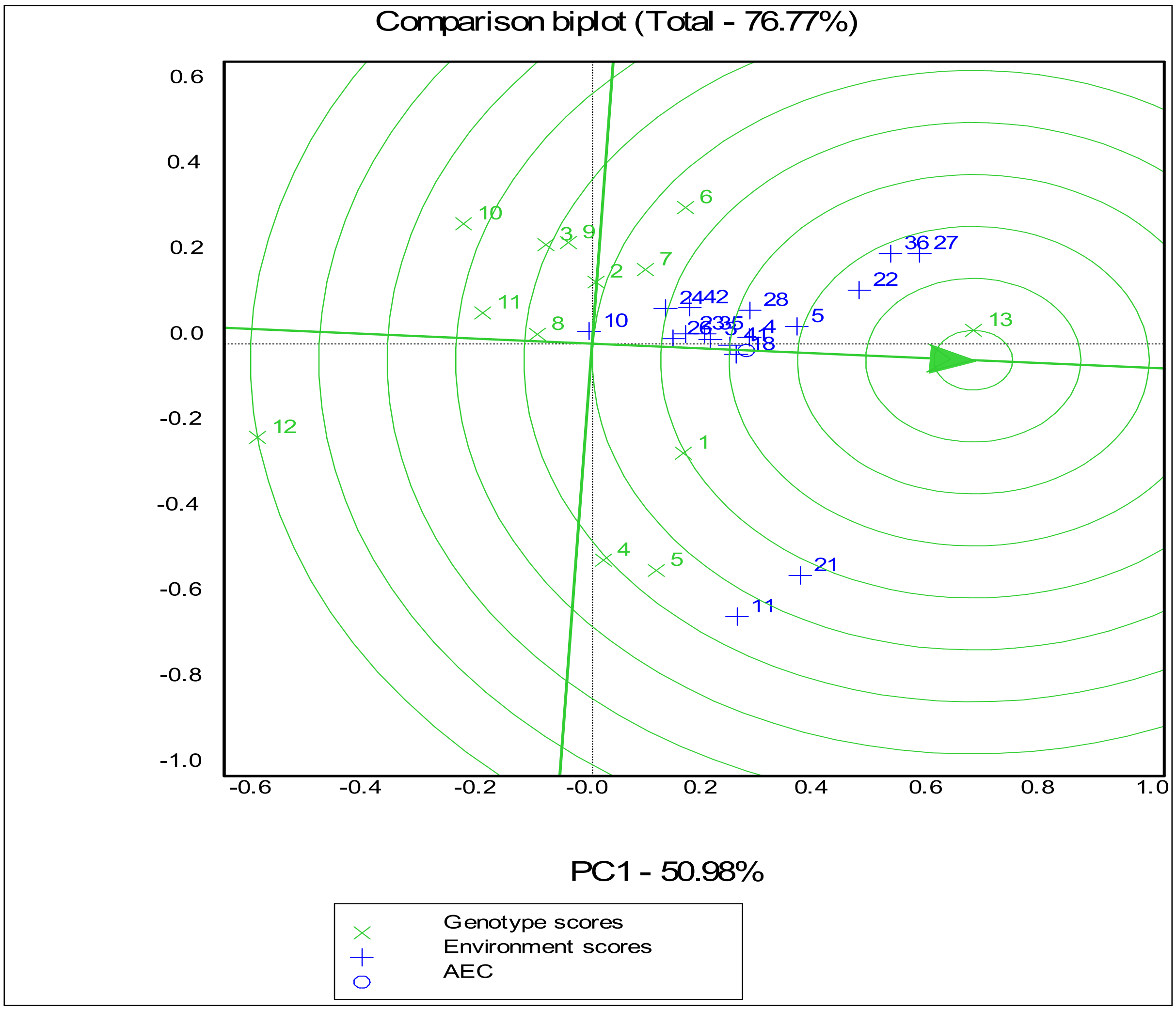

Figure 3. 2 **GGE biplot average environment coordination (AEC) of Yan, 2002 for grain yield in 10 (1-10) varietal hybrids and 3 (11-13) checks evaluated across 17 locations; Locations are in colour blue while entries are in colour green.**

Stability measured as GEI effects was estimated based on the proximity of an entry to the biplot origin and in relation to the ordinate line (y-axis) in the average environment coordination (AEC). Entry 2, 7, 9, and 8 were closest to the biplot origin and were considered stable while the commercial checks (entries 12 and 13) were furthest from the biplot origin and were considered most unstable (Figure 3.2). Yields of the G effect was approximated based on the position of an entry along the AEC unidirectional abscissa (x-axis) line. In a descending order, yields in entry 13, 1 and 6 were best while in entries 10 and 12 were least. A close scrutiny on F_1 hybrids showed that at drought stressed environments, their agronomic traits and grain yields were relatively heterogeneous. Yields in entries number 1, 2 and 10 was however consistently the best and above average at all environments (Table 3.5, 3.6, 3.9). Compared to the checks, the average yield in entries 1, 2 and 10 (1.9 t ha^{-1}) was not significantly varied from that in the 3-waycross commercial hybrid (2.12 t ha^{-1}) and was 50 % higher than that in commercial open pollinated variety (0.95 t ha^{-1}). This suggested that varietal hybrids could be beneficial to hybrid breeding programmes targeted to drought prone ecologies.

3.3.6 Estimates for mid-parent heterosis under different environments

Under managed drought, the variation due to parents' vs. hybrids effect for ASI, grain yield, male and female flowering was significant ($P \leq 0.05$) (Table 3.3) indicating presence of heterosis for these traits (Hallauer and Miranda, 1981). Heterosis values for male and female flowering were mostly negative implying that flowering in the VH was earlier than that in the parents. Heterosis values for ASI were all negative except for entry 9 suggesting a better synchrony in flowering of the VH compared to the parents. Entry 10 showed best heterosis (41.3 %) for grain yield, high heterosis for plant height and low heterosis for ASI at managed drought stress (Table 3.12). Under random drought, parents' vs. hybrids effect was significant ($P \leq 0.05$) for plant height and non-significant for all the other traits evaluated (Table 3.4). Heterosis values for plant height ranged from -7.4 % in entry 8 to 9.6 % in entry 6. Heterotic response for GY ranged from 24 % in entry 7 to -6.7 % in entry 6. Entries with high heterosis for grain yield did not necessarily show high heterosis for plant height (Table 3.12).

Under optimal conditions, parents' vs. hybrids effect was significant for grain yield and EPP (Table 3.5). Heterosis estimates for EPP ranged from -1.1 % in entry 7 to 6.5 % in entry 6. Entry 8 showed best heterosis for GY (19.9 %) and also best heterosis for EPP (7.6 %) indicating that heterosis for prolificacy was important for grain yield (Table 3.13). The values of MPH for GY realized in the evaluated VHs were within ranges previously reported in CIMMYT. Heterosis values of 10 % were reported in lowland adapted maize varieties (Vasal et al., 1992). Negative values of heterosis were similarly reported by in VH evaluated under optimal conditions (Carena, 2005). In addition negative heterosis for grain yield (– 37 %) was reported in classical hybrids under drought stress (Betrán et al., 2003b). In the current study, it was noted that high and diverse ranges of mid-parent heterosis (MPH) were realized at the MDS environment. Ranges and magnitudes of MPH were lower at RD and optimal environments (Table 3.12, 3.13). Similarly, heterosis for grain yield in tropical maize evaluated under drought stress was double that under optimal conditions (Makumbi et al., 2010). This suggested that heterosis in the evaluated VHs was influenced by environment. Hence, selection for heterosis in VHs should be at the target and not across environments. The parents involved in making the current VHs were progenies of CMLs assembled from isolated geographical regions (Table 3.1). Heterosis observed could therefore be attributable to genetic unrelatedness (Moll et al., 1962). In addition the realized heterosis could be associated with the high frequencies of favorable alleles in the CMLs used to form the OPV parents (Reif et al., 2005) .

Table 3. 12: **Percent mid-parent heterosis for grain yield and secondary traits at drought stressed conditions**

Entry No.	Entry Name	Managed drought							Random drought						
		GY	EPP	DTS	DTP	ASI	PH	EA	GY	EPP	DTS	DTP	ASI	PH	EA
		t ha $^{-1}$	#	day	day	day	cm	1-5	t ha $^{-1}$	#	day	day	day	cm	1-5
1	P1XP11	19.6	6.5	-1.5	0.1	-25.2	5.4	-21.2	19.2	2.6	-1.4	1.7	-45.4	3.4	-6.5
2	P2XP11	25.4	7.7	-3.1	-0.9	-25.4	20.9	-6.5	18.2	8.8	-0.6	-0.2	-5.7	2.6	-2.3
3	P3XP11	24.2	-2.0	-9.3	1.3	-84.8	12.0	-2.5	1.3	9.8	-1.0	0.5	-23.7	0.1	0.2
4	P4XP11	-3.6	-19.7	0.3	1.8	-18.0	7.0	6.3	7.4	-7.1	-0.3	0.9	-19.1	0.8	7.2
5	P5XP11	5.7	-4.8	-4.6	-0.7	-42.2	0.4	-1.6	-0.3	8.5	-0.5	1.5	-30.6	4.8	-11.2
6	P6XP11	8.1	14.3	-2.7	-0.1	-30.8	12.7	-3.2	-6.7	-2.6	1.5	1.0	7.6	9.6	9.9
7	P7XP11	6.9	5.5	-3.3	2.1	-49.1	14.8	-2.0	24.0	8.9	-0.1	0.0	-3.3	1.1	3.6
8	P8XP11	-5.7	8.5	-2.1	-0.2	-22.8	5.5	2.9	12.3	6.2	0.6	3.4	-33.7	-7.4	-11.6
9	P9XP11	0.7	-8.1	1.2	-0.8	26.6	5.6	-1.0	8.0	-2.0	1.7	0.9	12.3	4.9	6.4
10	P10XP11	41.3	7.1	-3.7	-0.2	-41.7	16.4	-11.4	11.1	-1.5	-1.7	-0.2	-17.0	-3.0	-7.7

† P = Parent; GY= grain yield; DTP = days to 50 % pollen shed; DTS= days from planting to emergence of silk in 50 % of plants; ASI = anthesis-silking interval; EPP = ears per plant; EA = ear aspect; PH = plant height

Table 3. 13: **Percent mid-parent heterosis for grain yield and secondary traits under optimal conditions**

Entry No.	**Entry Name**	**GY**	**EPP**	**DTS**	**DTP**	**ASI**	**PH**	**EA**	**ET**
		t ha^{-1}	#	day	day	day	cm	**1-5**	**1-5**
1	P1XP11	16.7	3.8	3.0	1.8	-7.1	4.2	-6.8	-9.7
2	P2XP11	6.8	2.1	0.0	-0.9	1.8	-2.4	-3.7	0.3
3	P3XP11	3.2	1.6	0.3	0.1	-0.3	1.0	-5.6	1.5
4	P4XP11	4.6	1.6	3.2	2.7	1.2	0.9	2.9	-6.5
5	P5XP11	7.1	-0.5	2.3	1.7	-7.9	3.5	2.7	-9.0
6	P6XP11	9.1	6.5	1.1	0.8	0.2	2.7	-2.8	-11.2
7	P7XP11	-6.5	-1.1	0.2	-0.4	2.3	0.2	-1.1	-10.2
8	P8XP11	19.9	7.6	1.2	0.1	5.1	-2.8	-8.6	1.8
9	P9XP11	6.2	-0.5	0.7	0.1	12.2	-0.7	-2.8	-6.5
10	P10XP11	2.5	-0.5	1.0	0.9	-5.0	-1.2	-1.7	-5.8

† P = Parent; DTP = days to 50 % pollen shed; DTS= days from planting to emergence of silk in 50 % of plants in a plot; ASI = anthesis-silking interval; EPP = ears per plant; EA = ear aspect; PH = plant height; ET = turcicum leaf blight

3.4 Conclusion and recommendations

Maize OPVs are reported to contain useful genetic variability for survival and productivity under a diversity of stresses (Alexander et al., 2013). Similarly, under drought stress, the OPVs evaluated in the current study showed significant variation for flowering traits and insignicance in variation for grain yield. This confirms that in CIMMYT germplasm, selection for earliness to improve drought tolerance has been effective (Monnneveux et al., 2008). It emerged that, the VHs that flowered early tended to yield more. Hence the evaluated varietal hybrids seemed to utilize the drought escape or avoidance mechanism to survive under drought. Notably, correlation between grain yields and secondary traits for enhanced drought tolerance was absent. Thus using these traits, it would be challenging to screen for drought tolerance in the evaluated varietal hybrids. It was recommended, therefore, that evaluation for drought tolerance in CIMMYT early materials should be pegged more on traits related to sink and source.

Heterosis in the VHs, was influenced by water stress. High heterosis values were expressed more under stress than under optimal conditions. Entries 2, 8 and 10 were identified as the most desirable hybrids as they expressed relatively high stability, heterosis and above average GY across environments. Entry 10 showed highest heterosis under drought and was identified as the most drought tolerant. Yields in the best varietal hybrids were up to 40 % higher than that of the commercial OPV checks or as good as that in classical 3wc hybrid check. Classical hybrids however, showed high response to changes in environment and may not be desirable in marginalized ecologies. Thus in drought prone environments and in areas where infrastructure and technical capacity for seed industry is low, varietal hybrids would offer a good alternative and which would benefit farmers in such regions.

CHAPTER FOUR:

COMBINING ABILITY OF DOUBLED HAPLOID LINES UNDER DROUGHT, LOW N AND OPTIMAL CONDITIONS

Summary

Drought and nitrogen (N) deficiency are important causes of low maize (*Zea mays* L.) yields in Kenya. In the foreseeable future, the expected adverse effects of climate change are likely to augment the impact of these two abiotic stresses. Tolerant hybrids have been developed using the classical methods. Little work has been done in sub-Sahara Africa using the *in vivo* doubled haploid (DH) method which may confer enhanced efficiency and accelerated availability of new and adapted hybrids to the farming communities. The purpose of this study was to evaluate the genetic potential of maize DH lines, derived by crossing lowland adapted populations to a temperate haploid inducer. The objectives were to: i) estimate the general combining ability (GCA) effects of 46 DH lines for grain yield and secondary traits under low N, drought stressed and, optimal conditions and, ii) estimate the specific combining ability (SCA) effects of DH lines under low N, drought stressed and, optimal conditions. The 46 DH lines were crossed to two testers; Tester 1 (CML312/CML442) and Tester 2 (CML395/CML444) that belong to heterotic groups (HG) A and B respectively. The 92 DH hybrids and 4 classical checks were evaluated across 7 locations; 1 under managed drought stress (MDS), 1 under low N stress and 5 under optimal conditions in Kenya, Uganda and Tanzania during the year 2011. Trial under MDS was grown under irrigation during rain free months till 2 weeks to flowering when water was withdrawn to impose water stress. The plots under low N trial had been depleted of nitrogen until the yields were 30 % that of the potential and no fertilizer was applied during growth period. An Alpha lattice design was used replicated twice. The plots measured 5 m long, spaced 0.75 m and 0.25 m between and within rows respectively. Fields were kept out of weeds and pests. Applied as DAP fertilizer, each trial received 90.0 Kg/ha N and 98 Kg/ha P at planting and 100 Kg/ha N as a top-dress at 6 weeks after emergence. Data recorded from all plots were analyzed in MSExcel and SAS and the means were separated using the LSD method. Results revealed H^2 for grain yield of 0.18, 0.77 and 0.60 under low N, drought and optimal conditions respectively. Variations amongst the DH lines were significant ($P \leq 0.001$) for grain yield under both stresses. Differences due to l x t effects were significant ($P \leq 0.05$) for grain yield under drought stress and not significant under low N stress. Several DH lines showed good GCAs for grain yield and secondary traits. The 46 DH lines were separated into 2 HGs: 24 fell into HG A and 22 into HG B; no lines was placed under HG AB. Whereas grain yields in the DH hybrids were shown to be controlled by heterotic effects when grown under stresses, GCA effects were predominant over SCA effects. Whereas yields under low N and drought stresses were 55 % and 43 % that under optimal conditions respectively, across environments, yields of best line (DH Line 29) were consistently higher than that of the best classical-commercial hybrid check. Findings of this study showed that hybrids derived from DH lines have a great potential for use in low N and/or drought prone areas and their potential as revealed in this study should be further investigated.

4.1 Introduction

Maize (*Zea mays* L.) is an important staple food in sub-Saharan Africa. In eastern Africa, the cereal provides about 30 % of the required daily human calories (Hassan et al., 2001). Despite its importance, yield of maize grown particularly in the mid-altitude areas is low. Low yields in maize are mainly due to low soil fertility and drought stress (Bänziger and Diallo, 2004). In the near future, as the effect of climate change takes toll in eastern Africa, maize yields might get even less as more maize is projected to be grown in stressed conditions (World Bank, 2007). One approach that could enhance maize yield in the region is breeding new varieties which are more tolerant to prevailing stresses.

Plant breeders develop varieties by selecting improved phenotypes and genotypes that result from segregation and recombination of parental germplasm. Adoption of methods that are efficient in acquisition of suitable parents and in selection of desirable progenies is critical. Efficiency in progeny selection can be achieved by using methods which reduce breeding cycle time and effectiveness in selection. One of the ways to reduce breeding cycle time is the use of the doubled haploid (DH) technology (Bänziger et al., 1984). The DH technology utilizes cell biology processes to develop pure maize lines. The *in vivo* method is fast and haploids are easily obtained by crossing a segregating population to an inducer (Coe, 1959). This is particularly because, using selection, capacity for haploid-induction has been enhanced (Sarkar et al., 1972).

The process behind haploid induction is not fully understood (Eder and Chalyk, 2002; Röber et al., 2005). In maize, spontaneous haploid is based on two hypotheses. Double fertilization followed by elimination /degeneration of one chromosome (Gernand et al., 2004; Wedzony et al., 2004). In addition, single fertilization caused by low velocity in one of the two sperms could also lead to haploid induction (Hu, 1990). Pollination with an inducer leads to formation of both diploids and haploid kernels and selection for haploids is required. Most widely used inducers carry a dominantly inherited marker gene known as *R1*-nj. The *R1*-nj gene causes purple colouration of the scutellum and the aleurone of diploid kernels (Nanda and Chase, 1966). The *R1*-nj gene causes pigmentation only on the aleurone and not in the scutellum of the haploid kernels. Thus, use of colour markers is most common as it is considered simple and of low risk to flora and fauna (Eder and Chalyk, 2002; Röber, 1999).

The haploid kernels display a normal germination rate and lead to viable haploid seedlings (Geiger and Gordillo, 2009). The majority of haploid plants are however sterile due to disrupted gamete formation (Tang et al., 2010). Spontaneous chromosome doubling occurs albeit at a rate of 0 % to

10 % (Deimling et al., 1997; Kato, 2002). This induction rate is too low and may not be feasible in practice. Artificial duplication of the haploid chromosome is necessary to facilitate propagation. In maize, artificial doubling of chromosomes entails four key stages. The haploids kernels are planted on sand tray. The tips of 3 to 4 days haploid coleoptiles are trimmed to 20 to 30 mm and immersed in a 0.06 % colchicine solution plus 0.5 % dimethyl sulfoxide (DSMO).The seedlings are washed with running water for about 20 minutes and placed in the dark for 12 hours at 18°C (Deimling et al., 1997; Eder and Chalyk, 2002; Gayen et al., 1994). As a result, fertile and viable plants with single cells that contain two identical chromosomes *(n=20)* are formed (Wan et al., 1989). For maize, it may require only 18 months from haploids induction to seed being harvested from a regenerated doubled haploid plant. Thus using DH method, as much as 75 % of time is saved. The time saved could allow breeding programmes to rapidly respond to new challenges by using the new breeding parents as well as delivery of products to the market (Prasanna et al., 2012). Use of DH lines could allow rapid exploitation of genetic variation of a segregating population (Bordes et al., 2006).

In addition, the DH approach provides additional merits over the classical methods of lines development. Classical selfing results into generation of inbred lines that in early generation contain significant heterozygosity. Owing to the heterozygosity, performance in classical lines may not be predictive at later generations (Bernardo, 2003). In contrast, the doubled haploid approach allows breeders to rapidly generate homozygous progenies. Use of the homozygous material could lead to more reliable and predictive testing and selection. This feature is particularly relevant to many traits of agronomic importance because these traits are highly influenced by environment. Consequently, the DH approach could enable enhanced efficiency and precision of field based selection for useful traits (Bonnet et al., 2005).

The DH approach can be used to facilitate development of parental germplasm required for production of hybrid varieties (Heckenberger et al., 2005). In DH lines, the homologous chromosomes are identical and lines undergo less recombination and segregation compared to classical lines (Frisch and Melchinger, 2008). Assuming there is no epistasis and no epigenetic effects, DH lines express and retain high genetic purity. Use of DH lines could facilitate selection of progenies whose genotypic similarity is closer to either parent's than would be when classical lines are used (Bernado and Karler, 2001). Thus, especially for traits with low heritability, selection in DH germplasm could be more efficient than when classical lines are used (Bordes et al., 2006; Bouchez and Gallais, 2000). Using DH lines could facilitate a better differentiation among the testcrosses and consequently to a higher heritability. This is particularly very important while selecting under stressed environment. In such a study, 3 sets of classical lines (CLs) at S_2 and S_3 stages of inbreeding were compared with DH lines. Both the DH and the CLs were derived from the same crosses and evaluated with the same testers in the same environments. On average, the estimated genetic testcross' variances for grain yield amounted to 50, 94, and 124 CLs at S_2, S_3 stages and newly extracted DH lines, respectively (Seitz, 2005).

In the tropical regions, the prevailing field stresses are diverse and challenging. Hence adoption of DH lines which might be of limited genetic base may be challenging. Genotypes of narrow genetic base tend to show high susceptibility to field stresses (Jaradat et al., 2010). In practice, the solution to this problem has been to adapt crosses made using elite lines and locally adapted testers. Maize lines generated by the DH method from a broad-base population were as good as those produced by single seed descent method for grain yield and agronomic traits (Bordes et al., 2006). Studies have also shown that DH hybrids tend to yield more than the varietal hybrids (Wilde et al., 2010). In these studies, mean performances in 3 groups of DH hybrids, developed from European landraces and varietal hybrids did not differ significantly, but the varietal hybrids yielded 22-26 % less than the DH hybrids. Use of DH lines in African maize breeding programmes for the development of stress tolerant germplasm is at its infancy. DH lines derived from tropical germplasm at CIMMYT have been produce since 2009. These DH lines are expected to be used by breeders to form new hybrids. This study was therefore designed to determine the combining ability of 46 tropical DH lines and their yields performance while in hybrid combinations. The objectives were to: i) estimate general combining ability (GCA) effects of the 46 DH lines for grain yield and agronomic traits, ii) estimate the specific combining ability (SCA) effects of the DH hybrids for GY and, iii) determine performance and classify the DH lines into heterotic groups.

4.2 Materials and Methods

4.2.1 Experimental material

Forty six DH lines and two testers (Table 4.1) were used in this study. Source populations of the DH lines were generated from lowland x mid-altitude and lowland x lowland F_1 crosses. The haploid plants were obtained by crossing F_1 of the lowland adapted source population with a temperate haploid inducer. Doubling of the single chromosome in the haploid plants was done at the CIMMYT DH facility in Mexico. 98 DH lines were received in Kenya and planted at KARI-Kiboko research station for visual evaluation on adaptation to the local environment. Out of the 98, 46 lines, used in this study, were selected based on good agronomic traits. The testers were single cross hybrids: CML312/CML442 and CML395/CML444 that belongs to heterotic group (HG) A and HG B respectively. The two testers are commonly used at CIMMYT and in several breeding programmes in eastern and southern Africa due to their excellent characteristics.

Table 4. 1: **The 46 doubled haploid female lines evaluated while in hybrids combinations during year 2011**

Line no.	Pedigree or name	Type of parent
1	(La Posta Seq C7-F86-3-1-1-1-B-B-B/CML495)DH1-B-B	FP 1
2	(La Posta Seq C7-F180-3-1-1-1-B-B-B-B/CML449)DH6-B-B	FP 2
3	(DTPWC9-F104-5-4-1-1-B-B-B-B/CML449)DH6-B-B	FP 3
4	(ZM303c1-32-3-B-1-2-B*5/G16BNSeqC4-(F31x15)-2-2-2-B)DH1-B-B	FP 4
5	(ZM303c1-32-3-B-1-2-B*5/G16BNSeqC4-(F31x15)-2-2-2-B)DH19-B-B	FP 5
6	(ZM303c1-32-3-B-1-2-B*5/G16BNSeqC4-(F31x15)-2-2-2-B)DH20-B-B	FP 6
7	(ZM303c1-32-3-B-1-2-B*5/G16BNSeqC4-(F31x15)-2-2-2-B)DH21-B-B	FP 7
8	(ZM303c1-32-3-B-1-2-B*5/G16BNSeqC4-(F31x15)-2-2-2-B)DH23-B-B	FP 8
9	(ZM303c1-32-3-B-1-2-B*5/G16BNSeqC4-(F31x15)-2-2-2-B)DH24-B-B	FP 9
10	([CML445/ZM621B]-2-1-2-3-1-BB/DTPWC9-F73-2-1-1-1-BBB)DH4-B-B	FP 10
11	([CML445/ZM621B]-2-1-2-3-1-BB/DTPWC9-F73-2-1-1-1-BBB)DH6-B-B	FP 11
12	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH4-B-B	FP 12
13	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH8-B-B	FP 13
14	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH12-B-B	FP 14
15	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH13-B-B	FP 15
16	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	FP 16
17	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH20-B-B	FP 17
18	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH25-B-B	FP 18
19	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH26-B-B	FP 19
20	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH28-B-B	FP 20
21	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH30-B-B	FP 21
22	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH33-B-B	FP 22
23	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH34-B-B	FP 23
24	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH37-B-B	FP 24
25	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH45-B-B	FP 25
26	(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH51-B-B	FP 26
27	([[[NAW5867/P30SR]-111-2/[NAW5867/P30SR]-25-1]-9-2-3-B-2-B/CML388]-B-35-2-B-1-#-1-B*5/G16BNSeqC4-(F20x17)-3-1-5-B)DH5-B-B	FP 27
28	([CML389/CML176]-B-29-2-2-B*5/LaPostaSeqC7-F180-1-1-2-2-BBB)DH3-B-B	FP 28
29	([CML389/CML176]-B-29-2-2-B*5/LaPostaSeqC7-F180-1-1-2-2-BBB)DH5-B-B	FP 29
30	(DTPWC9-F115-1-2-1-2-BBB/NIP25-98-1-2-B-1-B*5)DH3-B-B	FP 30
31	(DTPWC9-F115-1-2-1-2-BBB/NIP25-98-1-2-B-1-B*5)DH7-B-B	FP 31
32	(DTPWC9-F115-1-2-1-2-BBB/NIP25-98-1-2-B-1-B*5)DH12-B-B	FP 32
33	(LaPostaSeqC7-F125-2-1-1-2-BBB/ZEWBc1F2-216-2-2-B-2-B*5)DH4-B-B	FP 33
34	(MAS[MSR/312]-117-2-2-1-B*3/G16BNSeqC4-(F14x36)-2-2-1-B)DH6-B-B	FP 34
35	([LZ956441/LZ966205]-B-3-4-4-B-5-B*5-B-B/LaPostaSeqC7-F64-1-1-1-2-BBB)DH1-B-B	FP 35
36	([LZ956441/LZ966205]-B-3-4-4-B-5-B*5-B-B/LaPostaSeqC7-F64-1-1-1-2-BBB)DH5-B-B	FP 36
37	([LZ956441/LZ966205]-B-3-4-4-B-5-B*5-B-B/LaPostaSeqC7-F64-1-1-1-2-BBB)DH6-B-B	FP 37
38	([LZ956441/LZ966205]-B-3-4-4-B-5-B*5-B-B/LaPostaSeqC7-F64-1-1-1-2-BBB)DH11-B-B	FP 38
39	([LZ956441/LZ966205]-B-3-4-4-B-5-B*5-B-B/LaPostaSeqC7-F64-1-1-1-2-BBB)DH12-B-B	FP 39
40	([LZ956441/LZ966205]-B-3-4-4-B-5-B*5-B-B/LaPostaSeqC7-F64-1-1-1-2-BBB)DH13-B-B	FP 40
41	(CML395/[LZ956441/LZ966205]-B-3-4-4-B-5-BBBBB-B)DH1-B-B	FP 41
42	(CML444-B/[SYN-USAB2/SYN-ELIB2]-35-2-3-1-BBB-B-B)DH2-B-B	FP 42
43	(CML444-B/[SYN-USAB2/SYN-ELIB2]-35-2-3-1-BBB-B-B)DH3-B-B	FP 43
44	([CML202/CML442//[DTP2WC4H255-1-2-2-BB/[[NAW5867/P30-SR]-111-2/[NAW5867/P30-SR]-25-1]-8-1-1-B-1]-1-2-2-B]-1-1-1-1-BBB-B/[CML442/CML197//[TUXPSEQ]C1F2/P49-SR]F2-45-7-3-2-BBB]-2-1-1-1-1-B*4-B)DH3-B-B	FP 44
45	([(CML395/CML444)-B-4-1-3-1-B/CML395//DTPWC8F31-1-1-2-2]-5-1-2-2-BB-B/[CML202/CML442//[DTP2WC4H255-1-2-2-BB/[[NAW5867/P30-SR]-111-2/[NAW5867/P30-SR]-25-1]-8-1-1-B-1]-1-2-2-B]-1-1-1-1-BBB-B)DH1-B-B	FP 45
46	([SYN-USAB2/SYN-ELIB2]-35-2-3-1-BBB-B-B/[LZ956441/LZ966205]-B-3-4-4-B-5-BBBBB-B)DH1-B-B	FP 46

FP= female parent

4.2.2 Pollination and formation of hybrids

The DH hybrids were formed in 2 nurseries established in the year 2010 at KARI Kiboko research station in Kenya. The hybrids were formed by crossing the DH lines to each tester using the line x tester method (Kempthorne, 1957). In each nursery, two rows of each DH line were planted next to a row of one tester. To minimize problems associated with poor synchronization of flowering of testers and DH lines, each of the 2 testers was planted in separate block of 20 rows, 7 days after the date the lines were sown to provide the required extra pollen. Controlled pollination was carried out in the nursery using a reciprocal method. Before silk emergence, the ear shoots were covered with a shoot bag to prevent unwanted pollination. The tassels were bagged a day after the main branch had started shedding pollen but only in cases where the silks were ready for pollination. Pollen from bagged tassels was bulked and was used to pollinate the silks. After pollination, ears were covered using the tassel bags and stapled so as to hold firmly around the stem. At harvest seed from reciprocal crosses was bulked to form 92 hybrids (46 DH lines x 2 testers) used in this study.

4.2.3 Experimental design and field management

The 92 DH hybrids were evaluated along with four commercial checks at five locations in Kenya, and one location each in Uganda and Tanzania (Table 4.2). The trial at all experiments were laid out in two replicates as Alpha (0, 1) lattice design (Paterson and Williams, 1976). Plots size was two rows of 5 metres each. The spacing between and within rows was 0.75 metres and 0.25 metres respectively. A total of 7 trials were planted; 5 under optimal (rain-fed) conditions, 1 under managed drought stress and 1 under low N stress. The managed drought stress experiment was carried out at Kiboko during the dry season (June-October) which is rain free thus allowing for the control of drought stress. Irrigation was applied at the beginning of the season to establish good plant stands. Afterwards drought stress was imposed by withdrawing irrigation water during two weeks to flowering and throughout the flowering and grain filling stages. Plots in the low N trial were grown in blocks where nitrogen nutrients had been depleted by growing unfertilized maize continuously and removing crop biomass after each season until yield of normal genotypes (not improved for low nitrogen stress), averaged between 25 % and 30 % of the well fertilized field. In this trial no nitrogen fertilizer was applied (Bänziger et al., 2000; Worku et al., 2007).

Table 4. 2: **Description of agro-climatic and stress management of sites used in the evaluation**

Location	Country	Longitude	Latitude	Altitude (masl)	Management
Kakamega	Kenya	34°65' E	00° 26'N	1526	Optimal-rainfed
Shikusa	Kenya	34°56' E	00° 16'N	1520	Optimal-rainfed
Embu	Kenya	37° 42'E	04° 49'S	1510	Optimal-rainfed
Kiboko	Kenya	37°75' E	02° 09'S	0975	Low-nitrogen stress
Kiboko	Kenya	37°75' E	02° 29'S	0975	Managed Drought stress
Bulindi	Uganda	31°29' E	01° 30'S	1127	Optimal-rainfed
Arusha	Tanzania	36°37' E	03° 16'S	1507	Optimal-rainfed

masl = metres above sea level; E=east; S=south; N=north.

At all locations, land was prepared by ploughing and harrowing followed by application of 60 kg P ha^{-1} as Di-Ammonium Phosphate (DAP) fertilizer prior to planting. A second dose of 60 kg N ha^{-1} as Calcium Ammonium Nitrate (CAN) was side dressed at four weeks after emergence. All the other agronomic practices were applied as per the recommendation at each location.

4.2.4 Data collection

Data from each plot were recorded on: number of days to 50 % pollen shed (DTP), number of days to 50 % female flowering (DTS). Anthesis-silking interval was calculated as the DTS-DTP. Plant height (‘PH) in centimetres was measured as from the soil to the ligules’ of the leaf subtending the tassel; Leaf blight (ET) caused by *Exerohilium turcicum*, were recorded for disease severity on all plants per plot using a visual scale of 1-5 where 1 = no visible infection, 2 = a few scattered infection on leaves below the ear, 3 = many infection on leaves below the ear, with a few spreading above the ear, 4 = severe infection on all but uppermost leaves, and 5 = severe infection on all leaves with most of the leaf tissue being necrotic. Prolificacy or number of ears plant^{-1} (EPP) determined as number of ears averaged over number of harvestable plants plot^{-1}; Ear rot (ER) as the % of rotten ears over total number of ears harvested; Ear aspect (EA) was rated using a scale of 1–5, with 1 = uniform, large and well filled ears, and 5 = variable, small, and partially filled ears. Excluding ears of plants at each end of the rows, field weight were measured as total weight of all ears less ears with above 50 % rotten kernels. Grain moisture (g kg^{-1} moisture) of grain at harvest was measured using a moisture metre. Grain weight per plot was adjusted to 12.5 % grain moisture and used to calculate grain yield (expressed as yield in t ha^{-1}).

4.2.5 Data analyses

4.2.5.1 Analysis of variance

Analysis of variance (ANOVA) for traits recorded was done for each location, across locations under optimal conditions and across all locations using PROC GLM procedure of SAS (SAS, 2008).

At individual locations:

$$\mathbf{Y_{ijk} = \mu + l_i + t_j + (l \times t)_{ij} + e_{ijkth}}$$

Across locations is:

$$\mathbf{Y_{ijkm} = \mu + l_i + t_j + (l \times t)_{ij} + (lxs)_{im} + (lxs)_{jm} + (lxtxs)_{ijm} + e_{ijkm}}$$

Where:

Y_{ijk} is the $\mathbf{k^{th}}$ observation on $\mathbf{i^{th} \times j^{th}}$ progeny,

μ is trial mean,

l_i is the effects of the $\mathbf{i^{th}}$ lines, $\mathbf{t}_j$ is the effects $\mathbf{j^{th}}$ tester,

$(l \times t)_{ij}$ is the interaction effect of the cross between the i^{th} line and j^{th} tester,

e_{ijk} is the error term associated with each observation,

$\mathbf{Y_{ijkm}}$ is the $\mathbf{k^{th}}$ replication at the $\mathbf{m^{th}}$ site of the $\mathbf{i^{th} \times j^{th}}$ progeny,

$\mathbf{(l \times s)_{im}}$ is the interaction effect of the $\mathbf{i^{th}}$ line and the $\mathbf{m^{th}}$ location,

$\mathbf{(t \times s)_{jm}}$ is the interaction effect of the $\mathbf{j^{th}}$ tester and the $\mathbf{m^{th}}$ location,

$\mathbf{(l \times t \times s)_{ijm}}$ is the interaction effect of the $\mathbf{i^{th}}$ line and the $\mathbf{j^{th}}$ tester at the $\mathbf{m^{th}}$ location,

$\mathbf{e_{ijkm}}$ is the error effect associated with the $\mathbf{ikm^{th}}$ observation,

Genotypes were considered as fixed effects, and replications and blocks within replications as random effects. Across locations, variances were partitioned into relevant sources of variation to test for differences among genotypes and the presence of G × E interaction. The significance of line, tester, and line x tester effects was conducted using their respective interactions with environments. In analysis across environments, tests of significance in means square for line x environment, tester x environment, and line x tester x environment were conducted using the pooled error.

4.2.5.2 Analysis of general, specific combining ability effects and heterotic grouping

Combining ability variance was generated as follows: Variance due to effects of lines and effects of tester were equivalent to GCAs while variance due to line x tester interaction were equivalent to SCAs (Hallauer and Miranda, 1981). The GCAs and the SCAs for each line was generated using the following formulas:-

GCA (Line) effects = $g_i = y_{i.} - Y_{..}$

GCA (Tester) effects = $g_j = y_{j.} - Y_{..}$

SCA (Line x Tester) effects = $S_{ij} = y_{ij} - Y_{..} - g_i - g_j$

Where:

g_i is GCA of line, $y_{i.}$ is mean performance of line x across tester(s); $Y_{..}$ is trial mean; g_i is GCA of tester, $y_{j.}$ is mean performance of tester y in combination with all lines S_{ij} is SCA of hybrid between line x and tester y and Y_{ij} is hybrid of line x and tester y.

Heterotic grouping of the DH lines were generated using SCAs effects for grain yield. Lines expressing negative SCA effects with a specific tester were considered to belong to same heterotic group as the tester (Vasal et al., 1992).

4.2.5.3 Analysis of heritability in broad-sense for grain yield and secondary traits

Heritability (H^2) in the broad-sense was analyzed as the proportion of phenotypic variance that is attributable to an effect of the whole genotype, comprising the sum of additive, dominance, and epistatic effects (Falconer and Mackay, 1996; Nyquist, 1991). For each location, with 2 replicates (r), H^2 for each trait recorded were generated based on an entry-means using the Falconer and Mackay, (1996) model:-

$$H^2 = \sigma^2_G / \sigma^2_P$$

The phenotype was the means of a genotype across r replicates per location. This had variance and which was generated as:-

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

Where:

σ^2_G is the genotypic variance and σ^2_P is the phenotypic variance, σ^2_{GE} is the genotype-environment interaction variance, and σ^2 is the residual error variance.

4.3 *Results and Discussion*

4.3.1 Analysis of variance (ANOVA) at individual environments

4.3.1.1 ANOVA for grain yield and secondary traits under managed drought stress at Kiboko

Analysis of variance results under managed drought are shown in Table 4.3. There were significant differences (*P ≤0.001*) among the DH hybrids for grain yield. Significant variation in tropical DH hybrids evaluated under drought was similarly reported by Beyene et al., (2012). Significant variation amongst genotypes implied presence of drought tolerance (Fischer et al., (1989). Thus there was a good scope for selection for drought tolerance amongst the studied DH hybrids.

Table 4. 3: **Mean squares for traits evaluated under managed drought stress in Kiboko**

Source	†	GY	EPP	EA	ASI	DTS	PH	EH	PA	ER
	df	t ha^{-1}	#	1-5	day	day	cm	cm	1-5	1-5
Replication	**1**	0.4	10.6	0.6	0.3	0.7	5522.1***	15.3	0.6	15.7
Hybrids	**91**	1.3***	11.4	0.5***	31.9***	43.9***	245.1***	246.1***	0.4***	53.4
Lines	**45**	1.9***	10.9	0.8***	44.2***	64.8***	366.0***	292.8	0.6***	76.5**
Testers	**1**	5.7***	15.4	0.1	30.6	1.6	1110.3**	6257.2***	0.4	2.2
Line*Tester	**45**	0.6*	11.8	0.2	17.4**	22.4***	104.8	65.7***	0.3*	31.5
Error	**91**	0.4	11.5	0.2	9.7	9.9	134	65.9	0.2	40.8

GY= grain yield; DTS=days to emergence of silk in 50 % plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; ER= ear rot: *, **, ***, Significant at *P* < 0.05, 0.01 and 0.001 probability levels, respectively

Mean squares for lines effects were significant (*P ≤0.01*) for grain yield. This implied that while in hybrids combination, grain yield in the DH lines was different. Similar results were obtained for grain yield performance in fixed maize lines under drought stress (Makumbi et al., 2010). Means squares for ASI were significant (*P ≤0.01*) while that for ears per plant were not significant indicating that additive gene action conditioning ASI was important while that for ears per plant was not important for grain yield under drought stress. Means squares for line x tester was significant (*P ≤0.01*) for grain yield, ASI and not significant ears per plant. This implied that dominance effect associated with specific combining ability effects and conditioning ASI was important for grain yield in DH hybrids while that conditioning EPP might not be important. Significance in lines effects indicated that additive gene action associated with general combining ability was important for the trait under study (Sprague and Tatum, 1942). Results however showed that mean squares for lines effects were larger than mean squares for line*tester. This indicated that in the DH hybrids, the additive gene action was more predominant. Predominance of additive gene action over dominant gene action in maize grain yields under drought was similarly reported by Makumbi et al., (2010) and Betrán et al., (2003a). The results clearly indicated that DH lines could be suitable seed parents for hybrid breeding programmes that target drought prone ecologies.

4.3.1.2 ANOVA for grain yield and secondary traits under low nitrogen stress at Kiboko

Analysis of variance results under low nitrogen stress are shown in Table 4.4. Significance (*P ≤0.05*) variation among the DH hybrids for grain yield was revealed indicating differences in tolerance to low N. Means square for lines effects were significant (*P ≤0.05*) for grain yield, results that were in agreement with to those on classical lines studied under low nitrogen stress (Makumbi et al., 2010; Worku et al., 2007). Significance in lines effects indicated that additive gene action associated with general combining ability was important for grain yield. Means squares for ASI were significant (*P ≤0.01*) while that for ears per plant were not significant indicating that additive gene action conditioning ASI was important while that for ears per plant was not important for grain yield under LNS.

Table 4. 4 : **Mean squares for traits evaluated under low-Nitrogen stress in Kiboko**

		GY	EPP	EA	ASI	DTS	PH	ER
Source of variation	**df**	**t ha^{-1}**	**#**	**1-5**	**day**	**day**	**cm**	**%**
Rep	1	14.2*	0.4*	0.01	9.1	22.3	2483.5*	113.0*
Hybrids	91	3.3*	0.01	0.4**	6.8**	40.7**	740.9*	12.8
Lines	45	3.7*	0.01	0.6*	7.9*	50.3*	906.2*	13.6
Testers	1	20.3*	0.02	0.8	17.6*	556.5*	350.6	29.8
Line*Tester	45	2.4	0.01	0.2	5.5	19.7	584.4	11.7
Error	91	0.4	0.02	0.3	4	14.7	464.1	10.4

GY= grain yield; DTS= days from planting to emergence of silk in 50 % of plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; ER= ear rot: *, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively

Variation due to effect of line x tester was not significant for all traits evaluated. This therefore indicated that dominance effects associated with specific combining ability were not important for grain yield under low N. However contribution of GCA to total genetic variation for grain yield and ASI was larger than that of SCA. This implied that in the DH hybrids, additive gene action was more predominant than non-additive gene action. Some of these DH lines would be suitable seed parents for hybrid breeding programmes that target marginalized ecologies.

4.3.1.3 ANOVA for grain yield and secondary traits at five locations under optimal conditions

ANOVA at individual optimal locations is shown in Appendices 4.1, 4.2, 4.3, 4.4 and 4.5. Variation amongst the hybrids were significant (*P≤0.001*) for EPP at Shikusha and at Kakamega and not-significant at the other locations. Variations for ASI were significant (*P≤0.001*) at Embu and not significant at the other locations. Non-significant variations for ear rot were revealed at Bulindi and Arusha and significant (*P≤0.001*) variations in all the other sites. The hybrids were not significantly different for ET only at Shikusha and Embu. At every location, the DH hybrids showed significant

($P \leq 0.05$) differences for grain yield suggesting that, depending on environment, selection for secondary traits could enhance grain yield in the evaluated DH hybrids.

Except in Embu and in Kakamega, the variation amongst the lines was not significant for EPP. Lines were significantly ($P \leq 0.05$) varied for ASI at Embu and Kakamega and non-significant at all the other locations. Significant ($P \leq 0.05$) variations amongst the lines were revealed at Embu, Kakamega and at Shikusha and non-significant at Kakamega, Bulindi and Arusha for ear rot. At Shikusha and Embu, the lines were not significantly varied for ET but significant ($P \leq 0.05$) variations were realized in the other 4 locations. Ultimately, lines were significantly ($P \leq 0.05$) different for grain yield at all locations except in Shikusha and Kakamega. These findings suggest that depending on the location, while in hybrid combinations, the lines reactions to optimal environment were different. It seemed that additive gene action associated with general combining ability and conditioning ear rot, turcicum leaf blight, earliness and prolificacy were important for grain yield under optimal conditions.

ANOVA revealed varied difference in lines x tester effects amongst the hybrids evaluated at different locations under optimal conditions. Line x tester means squares were not significant for grain yield at all the other locations, except at Bulindi and Kakamega, Lines x tester effects were non-significant for most secondary traits evaluated at all optimal locations. This implied that in the DH hybrids, under optimal conditions, non-additive genetic effects were generally not important for enhanced grain yield. Clearly results showed that at all optimal locations and in all traits evaluated, contribution of GCA was higher than that of SCA. This implied that additive gene action conditioning grain yield and special traits was more important that the dominant gene action.

4.3.2 Performance of the doubled haploid hybrids at specific environments

4.3.2.1 Performance of DH hybrids under managed drought stress at Kiboko

Except for ears per plant, DH hybrids differed significantly for all traits evaluated under MDS (Table 4.5). Similarly, Makumbi et al., (2010) reported significant variation for grain yield in tropical maize evaluated under managed drought stress. Significant differences amongst the DH hybrids implied that their reaction to drought stress was different for most traits and similar for prolificacy. Heritability in the broad sense (H^2) for grain yield and ASI was about 77 %. Heritability for ears per plant was 0.01 % (Table 4.7). This indicated that the variation realized in ears per plant could be 100 % due to non-genetic factors while that in ASI was 77 % due to genetic factors. Unlike environmental variations, genetic variation could be reproducible and as such selection for ASI could enhance grain yield in the DH lines at drought prone areas. In the evaluated DH hybrids, grain yield and ASI correlation was strong, negative and significant (Table 4.9). This implied that a reduced ASI led to higher yields in the DH hybrids. Similarly, a reduced anthesis silking interval was highly correlated with kernel set and consequently high yields (Edmeades et al., 2000). Thus selection for ASI might enhance grain yields in the evaluated DH hybrids. In maize under drought stress, higher yields were as a result of more number of ears per plant and reduction in time to 50 % of pollen shed (Bolaños and Edmeades, 1993; Bolaños et al., 1993). Contrary, in the DH hybrids evaluated, selection for ears per plant may not be effective since the hybrids reaction in EPP was similar and any variation realized was due to non-genetic factors. Mean yield under managed drought stress was 2.1 t ha^{-1} and ranged from 0.3 t ha^{-1} to 4.6 t ha^{-1} (Table 4.5). Clearly, the difference between 10 top hybrids and least 10 hybrids was very large at 80 % (Table 4.11). Genetic variance is one of the determinants of gain from selection (Falconer and Mackay, 1996).

***Table 4. 5:* Mean for plants growth and grain yield in 92 DH hybrids under drought stress**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	EPP #	EA 1-5	ASI day	DTS day	PH cm	ER %	PA 1-5
1	1	1	2.0	0.50	3.5	8.5	77.8	234.9	7.2	2.1
2	1	2	2.5	0.48	4.5	4.0	74.9	254.4	16.4	2.7
3	2	1	3.0	0.54	3.3	2.0	70.7	224.1	0.0	2.9
4	2	2	2.3	0.62	3.3	2.0	71.8	222.5	3.0	3.2
5	3	1	1.3	0.32	3.8	17.0	83.9	225.1	4.6	3.0
6	3	2	1.0	0.32	3.8	15.0	83.9	231.0	0.0	2.7
7	4	1	1.4	0.37	4.3	5.0	68.8	212.3	21.6	3.2
8	4	2	1.9	0.55	4.0	4.5	71.3	222.3	5.6	3.2
9	5	1	1.4	0.44	3.8	4.5	71.3	230.0	6.2	2.7
10	5	2	0.6	0.26	4.0	11.5	79.8	230.7	8.4	3.2
11	6	1	2.2	0.68	3.3	2.0	68.8	211.9	1.9	2.2
12	6	2	2.7	0.92	3.5	1.0	68.3	217.8	3.4	2.9
13	7	1	2.2	0.70	3.0	2.0	68.9	225.2	0.0	3.4
14	7	2	2.5	0.64	3.0	1.5	68.9	230.4	0.0	2.5
15	8	1	1.8	0.66	3.5	2.0	68.8	231.7	2.7	3.5
16	8	2	2.4	0.45	3.0	2.0	68.3	224.3	2.5	3.0
17	9	1	2.1	0.76	3.3	1.5	67.8	233.4	4.0	2.7
18	9	2	2.9	0.86	3.3	0.5	68.3	230.7	13.7	3.2
19	10	1	4.6	0.90	2.3	1.0	68.2	227.1	0.0	2.1
20	10	2	3.2	0.69	2.3	1.0	67.8	240.5	0.0	2.7
21	11	1	2.4	0.53	3.3	3.5	68.4	208.8	0.0	3.2
22	11	2	2.7	0.63	3.0	1.5	67.1	208.6	0.0	3.1
23	12	1	1.8	0.51	3.8	4.0	70.7	228.4	10.0	3.1
24	12	2	2.8	0.65	3.5	1.0	67.7	234.6	1.9	2.4
25	13	1	3.7	0.72	2.5	1.0	68.3	242.5	2.1	3.2
26	13	2	1.6	0.45	4.0	4.5	70.8	230.6	6.1	3.1
27	14	1	3.1	0.66	3.0	1.5	67.4	227.9	0.0	2.2
28	14	2	2.5	0.64	3.3	1.0	67.7	236.5	6.5	3.1
29	15	1	3.5	0.72	2.5	0.5	67.2	218.4	1.6	2.7
30	15	2	3.4	0.77	2.8	1.0	66.1	215.6	4.5	2.9
31	16	1	1.1	0.37	3.8	12.0	80.8	209.0	7.4	3.4
32	16	2	2.2	0.46	3.5	5.0	73.3	213.2	0.0	2.7
33	17	1	2.3	0.34	3.3	2.0	69.2	221.0	17.1	2.4
34	17	2	2.2	0.42	3.8	0.0	66.9	226.9	7.2	3.0
35	18	1	2.6	0.61	3.3	0.5	67.4	223.7	0.0	3.0
36	18	2	1.9	0.51	3.8	5.5	73.8	229.9	1.9	3.2
37	19	1	1.9	0.49	3.5	3.0	70.9	228.2	0.0	3.0
38	19	2	2.3	0.44	3.0	2.0	72.4	233.8	0.0	2.9
39	20	1	1.4	0.37	3.8	11.0	77.7	236.0	3.0	3.4
40	20	2	1.6	0.53	3.8	7.0	74.3	238.4	0.0	2.9
41	21	1	2.3	0.50	3.0	9.0	78.4	219.1	0.0	2.2
42	21	2	2.7	0.62	3.0	2.5	73.4	236.1	2.5	2.5
43	22	1	1.3	0.59	3.8	7.0	72.2	206.3	0.0	3.9
44	22	2	3.1	0.56	3.5	1.0	67.7	202.9	1.7	2.4
45	23	1	1.2	0.33	4.0	4.0	69.9	213.5	4.6	3.0
46	23	2	2.2	0.70	3.5	2.0	68.3	210.6	2.1	2.9
47	24	1	1.7	0.54	3.8	7.5	73.7	228.3	3.0	3.4
48	24	2	2.7	0.63	3.5	6.5	73.8	229.7	2.5	2.9
49	25	1	1.8	0.45	3.3	5.0	70.9	212.3	0.0	3.5
50	25	2	2.4	0.61	3.3	2.5	69.3	222.3	5.5	2.7
51	26	1	1.8	0.60	3.5	3.5	68.0	206.6	0.0	2.5

Traits are: GY= grain yield; DTS= days from planting to emergence of silk in 50 % of plants in a plot; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect;

Table 4. 5 continued: **Mean for plants growth and grain yield in 92 DH hybrids under drought stress**

Entry No.	Line No.	Tester No.	GY	EPP	EA	ASI	DTS	PH	ER	PA
			t ha^{-1}	#	1-5	day	day	cm	%	1-5
52	26	2	3.1	0.81	3.0	2.0	68.9	223.4	2.2	2.7
53	27	1	2.3	0.56	3.3	2.0	68.3	210.5	0.0	2.4
54	27	2	3.4	0.71	2.8	1.0	68.9	235.6	1.7	2.5
55	28	1	3.2	0.72	2.0	0.5	69.4	247.9	1.9	2.2
56	28	2	2.7	0.63	3.3	3.0	73.7	247.4	2.1	2.4
57	29	1	2.9	0.64	3.0	1.0	70.3	238.7	0.0	2.2
58	29	2	3.7	0.83	2.8	2.0	71.9	225.3	0.0	1.7
59	30	1	1.3	0.50	4.0	5.5	71.5	215.6	0.0	2.7
60	30	2	2.1	0.56	3.3	2.0	68.2	227.5	0.0	2.4
61	31	1	1.5	0.79	4.0	4.5	69.3	223.4	5.2	2.7
62	31	2	2.1	0.60	3.3	2.0	66.7	230.5	2.2	2.9
63	32	1	1.3	0.56	4.0	5.5	72.7	225.4	21.5	3.4
64	32	2	2.5	0.72	3.5	3.0	70.8	224.2	15.0	3.2
65	33	1	1.0	0.28	3.8	18.0	83.8	206.2	0.0	3.7
66	33	2	1.7	0.63	3.8	7.5	73.7	219.8	0.0	3.4
67	34	1	1.3	0.34	4.0	7.5	75.3	212.5	0.0	3.2
68	34	2	2.9	0.68	3.5	2.0	69.9	231.2	0.0	3.0
69	35	1	0.4	0.08	4.5	0	69.3	219.1	0.0	4.0
70	35	2	1.3	0.39	4.0	8.5	80.3	240.6	3.6	2.6
71	36	1	1.9	0.62	3.8	8.5	75.7	232.3	2.1	3.4
72	36	2	1.6	0.47	4.3	9.5	77.8	226.2	4.6	3.2
73	37	1	1.5	0.47	3.5	8.0	75.0	213.5	0.0	3.0
74	37	2	1.3	0.40	3.8	11.0	79.9	218.7	10.7	3.4
75	38	1	2.2	0.43	3.0	5.5	74.4	235.2	0.0	2.5
76	38	2	2.7	0.77	3.5	3.5	74.2	241.2	8.8	2.6
77	39	1	1.2	0.37	3.5	13.0	79.8	207.3	0.0	2.4
78	39	2	2.9	0.69	2.8	5.0	72.7	216.5	0.0	2.7
79	40	1	2.0	0.61	3.5	3.0	71.8	238.2	6.8	2.4
80	40	2	2.1	0.47	3.5	5.0	74.9	216.3	12.5	2.7
81	41	1	2.1	0.52	3.3	2.5	71.7	239.4	0.0	2.6
82	41	2	2.0	0.52	3.0	6.5	78.8	247.3	2.2	2.5
83	42	1	1.6	0.39	3.8	12.0	82.3	236.6	0.0	3.4
84	42	2	1.2	0.59	3.8	10.0	82.2	235.4	0.0	3.4
85	43	1	1.4	0.42	4.0	2.0	69.2	222.7	15.3	3.7
86	43	2	2.0	0.68	3.8	2.0	68.4	230.3	12.5	3.5
87	44	1	0.7	0.23	4.3	15.0	82.8	232.4	3.4	4.2
88	44	2	1.8	0.51	3.8	0.5	67.8	234.0	2.5	2.7
89	45	1	0.7	0.11	4.5	1.0	70.2	219.2	0.0	3.6
90	45	2	1.0	0.26	4.0	8.5	79.8	242.6	3.9	3.5
91	46	1	0.5	0.14	4.3	1.5	68.4	236.8	16.7	3.5
92	46	2	0.3	0.49	4.5	16.0	89.1	228.8	0.0	3.4
Classical commercial hybrids checks										
93	WH403		1.2	0.4	3.8	11.5	80.3	230.6	0.0	2.7
94	H513		1.8	0.6	3.8	4.5	71.9	227.0	12.7	2.5
95	DUMA43		0.9	0.7	4.5	7.0	70.3	233.7	3.1	3.2
96	DK8031		1.5	0.5	3.8	10.0	76.8	246.6	8.4	2.7
Mean for hybrids			**2.1**	**0.5**	**3.5**	**4.7**	**72.4**	**226.3**	**3.8**	**2.9**
Min			**0.3**	**0.1**	**2.0**	**0.0**	**66.1**	**202.9**	**0.0**	**1.7**
Max			**4.6**	**0.9**	**4.5**	**18.0**	**89.1**	**254.4**	**21.6**	**4.2**
LSD (0.05)			**1.2**	**ns**	**0.8**	**5.9**	**1.3**	**22.6**	**12.7**	**0.9**
CV			**29.4**	**29.9**	**12.2**	**57.3**	**4.0**	**5.0**	**164.8**	**15.1**

† Traits are: GY= grain yield; DTS= days from planting to emergence of silk in 50 % of plants in a plot; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect;

As such the high variations amongst the DH hybrids could result to increased gain from selections under drought. The ranges of means in secondary traits of the DH hybrids evaluated were similar to those of the hybrids made using the classical breeding methods (Table 4.5). In terms of grain yield, the 10 best yielding DH hybrids yielded 50 % more than H513 the best classical hybrid check (Table 4.11). Mean grain yield across optimal locations was 4.9 t ha^{-1} indicating that in the DH hybrids, a reduction of 57 % could be attributed to drought stress. Yields reduction in DH hybrids associated with MDS was within the recommendable range of 30 % to 60 % in tropical classical maize (Bänziger et al., 2000). Reductions were similar to those realized in DH hybrids under MDS (Beyene et al., 2012). Similarly, yield reductions in hybrids derived from fixed classical maize lines was 58 % (Makumbi et al., 2010). Reduction realized in the DH hybrids were however, higher than (50 %) in fixed lines (Derera et al., 2007) and (Betrán et al., 2003a). This implied that the performance of hybrids developed using DH technique under drought was better than that of the classical hybrids. In addition, the DH hybrids had as acceptable agronomic traits as the hybrids developed using the classical breeding methods. Yields in DH hybrids of lines 10 (4.6 t ha^{-1}) and 29 (3.7 t ha^{-1}) were exemplarily high suggesting that lines 10 and 29 are likely to be efficient in utilizing fertilizer and/ or water (Castelberry et al., 1984). Performance in these lines should be further investigated to ascertain their usefulness to breeders targeting drought prone ecologies.

4.3.2.2 Performance of DH hybrids under low nitrogen stress at Kiboko

The DH hybrids were significantly ($P \leq 0.05$) different for grain yield and all secondary traits except for ears per plant. Significant variances for grain yield amongst classical hybrids under low N stress was realized in maize (Makumbi et al., 2010). Significant variations in grain yield implied that tolerance of the evaluated DH hybrids to low nitrogen stress was different (Table 4.6). Significance in differences for ASI and plant height could particularly be important for grain yield under stress.

Increased height in plants under stress is desirable as it could indicate availability of higher amounts carbohydrates reserves which could be remobilize to enhance stress tolerance (Blum, 1997). Prolonged stress periods during the vegetative stages could influencing the cell size development, reduce length of internodes and overall height of plant (Denmead and Shaw, 1960). As such, plants height could indicate tolerance to nitrogen deficiency as it shows rapid growth and early attainment of reproductive stage. The correlation between grain yield and plant height was positive. Similarly there was positive and significant correlation between PH and grain yield suggesting that plant height might be a useful indicator of stress tolerance in maize (Wajid et al., 2011). Broad sense heritability (H^2) under LNS for grain yield and ears per plant was 18 % and 6 % respectively while that for ASI and plant height was about 30 % each (Table 4.7). This suggested that amongst the DH hybrids, unlike if selection is based on prolificacy, selection for plant height and earliness may more effectively enhance grain yield under LNS. Mean grain yield under LNS was 2.7 t ha^{-1} and ranged from 1.0 t ha^{-1} to 4.0 t ha^{-1} (Table 4.6). A wide and clear difference of 63 % between 10 top hybrids and least 10 hybrids (Table 4.11) were also realized. Genetic variance is one of the determinants of gain from selection (Falconer and Mackay, 1996). As such the high variations amongst the DH hybrids could result to increased gain from selections under LNS. Notably, range of means in secondary traits of the evaluated DH hybrids was similar to those of the hybrids made using the classical breeding methods (Table 4.6). In terms of grain yield, the 10 best yielding DH hybrids yielded 15 % more than DK8031 the best classical hybrid check (Table 4.11). Mean grain yield across optimal locations of 4.9 t ha^{-1} indicated that in the DH hybrids evaluated in this study, a reduction of 45 % could be attributed to LNS.

***Table 4. 6:* Mean for grain yield and agronomic traits for 92 DH hybrids under low N at Kiboko**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	EPP #	ER %	EA 1-5	ASI day	DTS day	PH cm	PA 1-5
1	1	1	3.3	0.9	4.6	2.5	4.6	66.1	170.7	2.8
2	1	2	2.7	0.7	6.5	2.5	3.8	70.6	163.0	3.3
3	2	1	3.2	0.8	0.0	2.5	3.9	63.5	148.8	2.3
4	2	2	3.1	0.9	1.8	2.4	3.9	66.3	140.9	2.8
5	3	1	2.1	0.7	11.9	2.7	7.8	72.8	134.2	3.5
6	3	2	2.0	0.7	5.4	2.4	7.4	76.1	144.0	3.3
7	4	1	2.5	0.9	6.1	2.7	6.1	63.4	141.3	2.0
8	4	2	2.0	0.7	2.7	2.3	8.2	69.9	140.7	2.8
9	5	1	2.0	0.7	3.9	3.0	10.1	70.2	143.1	3.5
10	5	2	2.3	0.8	3.5	2.8	5.6	66.5	163.7	3.3
11	6	1	2.3	0.8	6.7	2.6	3.7	61.7	149.1	3.3
12	6	2	3.3	0.8	6.1	2.4	4.9	64.2	148.1	2.5
13	7	1	2.7	0.7	4.5	2.5	2.4	66.2	162.8	2.0
14	7	2	2.4	0.6	8.9	2.6	6.8	73.0	138.5	3.3
15	8	1	2.2	0.6	2.6	2.6	0.7	66.5	129.0	3.0
16	8	2	3.5	0.8	1.1	2.3	4.8	64.2	148.0	2.5
17	9	1	3.2	0.7	8.6	2.2	3.4	63.6	153.9	3.0
18	9	2	2.6	0.8	3.9	2.6	6.4	67.0	161.1	3.0
19	10	1	2.9	0.8	10.4	2.3	2.5	65.0	175.2	2.8
20	10	2	2.1	0.7	26.5	3.0	5.1	71.0	145.5	3.8
21	11	1	1.0	0.7	22.8	3.3	4.4	67.6	119.6	3.8
22	11	2	3.1	0.7	8.0	2.2	3.4	65.0	143.1	3.5
23	12	1	3.4	0.9	11.9	2.4	5.6	63.5	162.9	2.8
24	12	2	2.9	0.8	7.7	2.5	6.3	67.4	143.3	3.3
25	13	1	1.5	0.6	13.6	3.3	5.5	69.2	135.2	3.8
26	13	2	3.9	0.8	2.0	2.2	6.0	64.3	190.2	2.8
27	14	1	3.9	0.9	6.8	2.1	2.6	60.4	167.1	2.8
28	14	2	3.3	0.8	7.2	2.3	4.3	63.9	188.4	2.8
29	15	1	3.3	0.8	9.2	2.8	5.0	63.6	150.6	2.8
30	15	2	3.8	0.8	4.2	2.3	3.4	61.0	183.0	2.8
31	16	1	2.5	0.9	2.8	2.6	4.8	68.4	140.7	2.5
32	16	2	2.7	0.8	8.1	2.2	5.7	70.1	145.3	3.0
33	17	1	3.7	0.8	4.0	2.1	2.8	62.3	154.4	2.3
34	17	2	2.8	0.7	8.6	2.6	2.4	65.4	145.6	2.5
35	18	1	4.0	0.9	4.5	1.8	3.9	63.5	158.8	3.0
36	18	2	3.0	0.8	8.4	2.7	2.3	64.0	157.3	3.3
37	19	1	2.6	0.8	1.6	2.3	5.1	66.4	149.2	2.0
38	19	2	1.3	0.7	4.1	3.3	7.6	72.3	110.3	3.5
39	20	1	2.9	0.7	19.6	2.8	5.1	64.9	145.5	3.0
40	20	2	1.6	0.6	13.8	3.3	7.0	72.3	124.0	4.0
41	21	1	2.5	0.8	6.3	2.4	5.1	68.1	166.2	2.5
42	21	2	2.6	0.8	3.7	2.6	6.7	73.3	131.9	3.0
43	22	1	3.0	0.8	17.4	2.5	7.2	65.5	137.7	2.8
44	22	2	2.9	0.9	9.8	2.8	6.8	64.6	140.0	3.3
45	23	1	3.6	1.0	13.1	1.9	3.8	61.8	156.6	2.8
46	23	2	3.2	0.7	4.7	2.6	3.2	65.1	157.7	3.0
47	24	1	2.5	0.8	4.6	2.8	8.9	68.6	145.4	3.0
48	24	2	2.9	0.7	9.3	2.5	6.0	68.3	147.4	3.5
49	25	1	2.9	0.7	4.7	2.6	5.9	67.1	141.4	3.0
50	25	2	1.3	0.6	12.2	3.3	9.6	74.8	133.5	3.8
51	26	1	2.6	0.9	9.6	2.8	4.8	62.8	160.2	3.3

† Traits are: GY= grain yield; DTS= days from planting to emergence of silk in 50 % of plants in a plot; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect

Table 4.6 continued: **Mean for grain yield and agronomic traits for 92 DH hybrids at Kiboko under low N**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	EPP #	ER %	EA 1-5	ASI day	DTS day	PH cm	PA 1-5
52	26	2	1.8	0.7	16.4	2.9	7.6	71.4	128.8	3.3
53	27	1	2.5	0.9	6.2	2.9	7.1	66.3	135.8	2.8
54	27	2	2.2	0.8	5.7	2.6	6.9	68.5	133.9	2.8
55	28	1	3.0	0.8	3.5	2.3	5.9	69.9	172.3	2.3
56	28	2	2.6	0.7	3.5	2.5	3.5	69.7	166.9	3.0
57	29	1	3.7	1.0	8.2	2.5	1.8	65.9	173.3	1.3
58	29	2	2.7	0.9	21.7	2.5	4.8	71.6	142.9	3.0
59	30	1	2.8	0.8	4.2	2.7	6.8	66.3	132.5	3.0
60	30	2	3.3	0.7	9.3	2.4	4.9	63.7	158.7	2.3
61	31	1	2.6	0.8	16.2	2.6	7.0	65.6	126.0	3.3
62	31	2	3.7	0.9	7.0	2.6	2.6	58.8	171.9	2.5
63	32	1	3.1	0.9	0.5	2.5	3.7	63.7	164.2	2.5
64	32	2	2.9	0.8	8.5	2.8	7.7	69.7	135.1	2.8
65	33	1	2.8	0.8	15.7	2.6	4.9	63.1	137.9	2.8
66	33	2	2.2	0.6	29.1	3.0	11.1	70.1	161.8	3.0
67	34	1	2.9	0.9	9.3	2.5	6.6	66.5	173.6	3.0
68	34	2	2.0	0.8	5.2	2.8	6.3	73.0	130.2	3.5
69	35	1	2.9	0.8	11.5	2.4	5.7	70.7	146.8	2.5
70	35	2	3.3	0.8	2.6	2.5	3.5	67.9	176.5	2.3
71	36	1	2.8	0.8	31.8	2.6	6.2	68.6	142.8	2.3
72	36	2	2.9	0.9	27.0	2.7	5.4	68.0	146.5	3.3
73	37	1	3.1	0.8	9.8	2.2	5.7	68.3	134.0	2.3
74	37	2	3.1	0.9	17.5	2.7	6.8	69.9	148.7	2.8
75	38	1	3.2	0.9	6.7	2.1	4.4	66.9	156.6	2.5
76	38	2	3.0	0.8	2.4	2.5	4.0	67.4	184.5	3.3
77	39	1	2.5	0.8	7.9	3.2	6.8	72.1	138.1	3.5
78	39	2	2.3	0.8	1.7	2.7	5.7	70.5	126.7	4.0
79	40	1	2.6	0.7	18.3	2.9	3.2	69.9	135.3	2.5
80	40	2	3.0	0.8	13.6	2.0	2.7	67.1	162.2	2.8
81	41	1	3.1	0.7	1.8	2.0	2.4	66.3	189.4	2.3
82	41	2	3.2	0.8	2.5	2.5	2.3	70.1	177.8	3.3
83	42	1	2.8	0.9	15.4	2.7	1.8	68.9	160.1	3.3
84	42	2	1.1	0.7	41.7	3.5	13.8	81.0	131.2	3.5
85	43	1	2.9	0.7	18.9	2.4	8.2	66.5	150.9	3.0
86	43	2	1.6	0.6	23.2	3.2	4.7	67.1	149.3	3.5
87	44	1	2.1	0.8	18.2	2.9	7.1	69.6	136.0	3.0
88	44	2	2.8	0.8	35.8	2.8	5.2	66.7	164.5	3.3
89	45	1	1.5	0.6	9.1	3.2	10.5	75.9	182.2	4.0
90	45	2	2.6	0.8	0.3	2.6	4.1	69.5	177.6	3.5
91	46	1	2.2	0.7	24.4	3.2	5.0	66.9	163.3	3.3
92	46	2	2.5	0.7	21.9	2.8	6.3	73.3	151.4	3.3
classical commercial hybrids										
93	WH403		1.8	0.7	17.2	2.8	8.7	77.9	134.5	3.3
94	H513		1.9	0.8	4.8	3.1	4.3	67.0	155.0	3.5
95	DUMA43		2.2	0.8	20.9	3.1	8.2	68.3	144.9	3.5
96	DK8031		3.4	0.8	10.8	2.6	6.4	65.8	173.8	2.8
Mean of hybrids			**2.7**	**0.8**	**10.2**	**2.6**	**5.4**	**67.7**	**151.3**	**3.0**
CV			**30.2**	**13.9**	**79.1**	**19.1**	**49.5**	**4.0**	**13.0**	**19.0**
LSD (0.05)			**1.6**	**ns**	**16.1**	**1.0**	**5.4**	**4.0**	**39.4**	**1.1**
Max			**4.0**	**1.0**	**41.7**	**3.5**	**13.8**	**81.0**	**190.2**	**4.0**
Min			**1.0**	**0.6**	**0.3**	**1.8**	**0.7**	**58.8**	**110.3**	**1.3**

† Traits are: GY= grain yield; DTS= days from planting to emergence of silk in 50 % of plants in a plot; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect

The yield reduction realized in the DH hybrids were lower than that of 65 % (Betrán et al., 2003a). Reductions of 60 % were also realized in classical maize evaluated under low nitrogen stress (Pswarayi and Vivek, 2008). These results suggested that DH hybrids could be tolerant to nitrogen deficiency when compared to hybrids formed using lines developed using classical methods. In addition, the DH hybrids had as acceptable agronomic traits as the hybrids developed using the classical breeding methods. Amongst the best 10, yields in hybrids of lines 14 and 18 were exemplarily desirable suggesting that lines 14 and 18 are likely to be efficient in utilizing fertilizer and/ or water (Castelberry et al., 1984). Lines 14 and 18 should be investigated further for performance under stress prone areas.

4.3.2.3 Performance of DH hybrids at five locations under optimal conditions

At all the 5 trials under optimal conditions, variation amongst the DH hybrids was significant ($P \le 0.05$) for grain yield (Appendices 4.6, 4.7, 4.8, 4.9 and 4.10). Similar results on significant differences for grain yield in maize doubled haploid hybrids were reported under optimal conditions (Röber et al., 2005). Yields advantage of the 10 top DH hybrids over the least 10 was from 45 % to 77 % (Table 4.11). This indicated availability of a wide scope and clear difference for selection of desirable DH hybrids.

High (>60 %) broad sense heritability for grain yield was realized at all the trials under optimal conditions, except the one in Arusha. High heritability values ear rots and for turcicum leaf blight diseases were realized at some locations (Table 4.7). This suggested that over 60 % of grain yield variation realized in the DH hybrids under optimal conditions was attributable to genetic factors and could be reproducible. Gain from selection is a function of selection intensity, variance and heritability (Falconer and Mackay, 1996). Selection amongst DH germplasm could result into high gains under optimal conditions.

***Table 4. 7*: Percent heritability in the broad-sense for traits evaluated at 7 locations**

Name of Trait	Managed drought	Low-nitrogen stress	Optimal				
	Kiboko	Kiboko	Kakamega	Shikusa	Embu	Bulindi	Arusha
Grain yield	77	18	83	81	70	60	18
Ears per plant	0.001	06	0.002	44	28	0.001	07
Ear aspect	66	0.01	81	60	62	55	22
Ear rot	22	53	71	43	19	03	0.007
Anthesis-silking interval	76	30	50	0.005	64	06	14
Days to 50 % silking	89	59	73	67	89	80	78
Days to 50 % anthesis	92	76	73	76	91	80	78
Plant height	55	34	44	-	77	15	0.007
Ear height	74	40	23	-	79	46	26
Turcicum leaf blight	-	-.	79	07	21	46	55

Comparison of grain yield in the 4 commercial check-hybrid used showed that at dry mid altitude environments, H513 and DK8031 out performed WH403 and DUMA 43 which seemed to perform better at the highlands. Thus choice of checks should be based on target environments. At the five optimal locations, yield advantage of the best 10 DH hybrids over the best commercial check classical hybrid ranged from –ve 3.3 % to + 29 % (Table 4.11). The ranges of means in secondary traits of the DH hybrids evaluated were similar to those of the hybrids made using the classical breeding methods (Appendices 4.6, 4.7, 4.8, 4.9 and 4.10). This also indicated that, generally, under optimal conditions, DH hybrids outperformed and showed acceptable agronomic traits similar to hybrids developed using the classical breeding methods. Similarly, (Bordes et al., 2006; Seitz, 2005) found that maize lines generated by the DH method from a broad-base population were as good as those produced by SSD methods for grain yield and agronomic traits. Hybrids of DH lines number 39, 7, 41, 5 and 7 showed exemplarily desirable performance for grain yield at locations under optimal conditions.

4.3.3 Analysis of variance across 5 optimal locations

Results on analysis of variance in the DH hybrids evaluated are shown in Table 4.8. Analysis of variance revealed highly significant (*P≤0.001*) differences amongst the environments for all traits recorded. High and significant variation amongst the optimal locations indicated the hybrids response at different locations was different. Highly significant (*P≤0.001*) variations for grain yield were realized amongst the DH hybrids for grain yield. Similar results were reported in temperate DH hybrids evaluated under optimal conditions (Röber et al., 2005). Results similar to those found in the DH hybrids studied in this study were reported in tropical DH hybrids under optimal conditions (Beyene et al., 2012). Significance in variation amongst DH hybrids suggested presence of a good scope for selection of desirable hybrids.

Table 4. 8: **Mean squares for traits evaluated in DH hybrids across 5 optimal locations**

Source	df	GY $t\ ha^{-1}$	EPP #	ER %	EA 1-5*	ASI day	DTS day	PH cm*	ET 1-5
Environment (E)	4	158.1***	1.1***	17709.1***	28.8***	213.7***	2054.9***	128082.6***	165.6***
Replication (E)	4	11.4	0.0	45.5	1.7***	2.3	56.3***	1527.3***	1.8***
Hybrid	91	9.2***	0.02***	218.4***	0.9***	2.8*	56.8***	876.4***	0.9***
Lines	45	1.8	0.03**	144.2***	1.0***	3.4**	78.3***	1288.2***	1.4***
Testers	1	0.4	0.0	753.1**	1.3*	3.8	318.1***	4416.9***	0.3
Line*Tester	45	2.5	0.0	108.9	0.4	1.7	6.3	385.9	0.2
Hybrids*E	364	2.3***	0.02*	97.0***	0.3***	2.2	5.1	475.9*	0.4***
Line*E	180	3.2***	0.0	113.8**	0.4***	2.7**	8.9***	564.8**	0.6***
Tester*E	4	4.2	0.0	346.9**	0.3	0.7	45.7***	337.6	0.3
Line*Tester*E	180	2.1	0.0	72.4	0.2	2.0	4.3	390.2	0.2
Error	455	1.8	0.0	75.9	0.2	3.5	6.6	308.1	0.2

GY= grain yield; DTS=days to emergence of silk in 50 % plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; ER= ear rot: *, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively

Notably, hybrids x environment was significant for grain yield. This suggested presence of GEI and which could pose a challenge during selection for desirable hybrids. It was however noted that the hybrids were significantly (*P≤0.001*) different for all secondary traits evaluated. This suggested that amongst the DH hybrids, there could be useful genetic diversity. In maize, genetic diversity was associated with enhanced productivity and survival under varied stresses (Alexander et al., 2013).

Differences amongst the DH lines were significant (*P≤0.01*) for secondary traits and not-significant for grain yield. This indicated presence of additive genetic effect conditioning enhanced survival in DH hybrids evaluated in this study. Similar reports of presence of useful alleles for enhanced production and survival in maize under varied stresses has been reported before (Alexander et al., 2013). Some of the DH lines could be good sources of special traits such as diseases resistance. Significant differences due to effect of line x environment were revealed suggesting that the additive genetic effects conditioning the expression of the special traits were influenced by environment. As such selection for lines with special traits should be at target locations and not across environments. The effects due to line by tester interaction and lxt * environment were not significant for GY and all the other recoded traits implying that the role of non-additive genetics effect was similar at all the sites under optimal conditions. Mean squares of lines effect and of line*tester effects for grain yield were equal while those for secondary traits were greater than that of line*tester. Similar to these results, GCA mean squares were far much larger than SCA mean squares under well-watered environments (Makumbi et al., 2010). This suggested that, though the role of additive and non-additive genetic effect conditioning GY was equal, additive genetic effects conditioning secondary traits were more important than non-additive effects under optimal conditions.

4.3.4 Performance of the DH hybrids across optimal locations

Difference amongst the DH hybrids across optimal environment was not significant for grain yield; significant differences were however revealed for secondary traits evaluated. Yield in the ten top hybrids was 57 % higher than that of the 10 least yielding hybrids (Table 4.10). This suggested that though the reaction of the DH hybrids to optimal conditions was similar for grain yield some outperformed others in terms of plant height, prolificacy, foliar and reaction to ear diseases. The ranges for secondary traits were as follows: DTS; 67.9 days to 77.6 days; ASI; 0.4 days to 2.9 days, PH; 173.6 cm to 225.0 cm, EPP; 0.8 to 1.1; ER; 3.5 % to 31.1 %, EA; 2.3 to 3.6 and ET 2.3 to 3.5 (Table 4.10).

Table 4. 9: **Correlation amongst the traits evaluated at different environments**

a) Managed drought

	GY	EPP	EA	ER	ASI	SD	AD	PH	RL	ET
GY	1									
EPP	0.49**	1								
EA	-0.88**	-0.45**	1							
ER	-0.84**	-0.45**	0.80**	1						
ASI	-0.04	0.00	-0.04	0.01	1					
SD	0.57**	0.26	-0.44**	-0.32*	0.2	1				
AD	0.62**	0.30*	-0.47**	-0.37*	0.01	0.98**	1			
PH	0.30*	-0.01	-0.12	-0.18	0.02	0.65**	0.65**	1		
RL	-0.44**	-0.08	0.35*	0.33*	0.04	-0.2	-0.23	-0.08	1	
ET	-0.82**	-0.59**	0.75	0.68**	0.04	-0.49**	-0.53**	-0.18	0.16	1

b) Optimal

	GY	EPP	EA	ER	ASI	SD	AD	PH	RL	ET
GY	1									
EPP	0.58**	1								
EA	-0.91**	-0.47**	1							
ER	-0.42*	-0.17	0.51**	1						
ASI	-0.66**	-0.53**	0.56**	0.11	1					
SD	-0.39**	-0.57**	0.25	-0.02	0.52**	1				
AD	0.09	-0.22	-0.18	-0.12	-0.22	0.72**	1			
PH	0.22	-0.12	-0.23	-0.18	-0.17	0.37*	0.57**	1		
RL	-0.18	-0.05	0.13	0.02	0.21	0.07	-0.09	-0.1	1	
ET	-0.24	0.12	0.31*	0.13	0.02	-0.41	-0.48**	-0.37*	0.1	1

GY=grain yield; EPP=ear per plant; ER=ear rot; EA=ear aspect; ASI=anthesis-silking date; DTS= days from planting to emergence of silk in 50 % of plants; PH= plant height; ET=Turcicum leaf blight: ** Significant at $P \leq 0.01$ probability level

The wide ranges suggested that genetic diversity amongst the DH hybrids was important for grain yield under optimal conditions. Correlation analysis showed varied association between grain yield and ER (-0.84**), ET (-0.82**), DTS (0.57**), EPP (0.49**), ASI (-0.04) and PH (0.30*) (Table 4.9). This implied that ET and ear rot were strongly and significantly associated with grain yield under optimal conditions. At optimal condition, the mean ET was 2.9 suggesting the DH hybrids were moderately susceptible to high land leaf blight and which was expected since the DH lines are derived from low-land adapted germplasm. ET score in the 10 top yielding hybrids was 2.8 and in the least yielding hybrids was 3.2 indicating that ET caused a GY reduction of 57 % in susceptible hybrids. These losses are similar to 60 % yield losses reported in maize susceptible to turcicum blight (Raymundo and Hooker, 1981). Ear rot in the top ten yielding DH hybrids at 7.9 % was much lower compared to 17.2 % in least 10 yielding hybrids. Selection for resistance to ear rots and turcicum leaf blight could improve GY at the optimal locations. Under optimal environment, mean ears per plant was 1.0 and ranged from 0.8 to 1.1. In maize, higher yields were as a result of more number of ears per plant (Bolaños and Edmeades, 1993; Bolaños et al., 1993). DH hybrids with a high EPP tended to yield more suggesting that prolificacy was important for grain yield under optimal conditions. Across optimal conditions yield in the best 10 DH hybrids (13, 68, 77, 81, 58, 82, 49, 2, 71 and 89) was not significantly different from the yield in the best classical hybrid check WH403 (7.1 t ha-1). Similarly, maize lines generated by the DH method from a broad-base population were as good as those produced by single seed descent method for grain yield and agronomic traits (Bordes et al., 2006; Seitz, 2005). Under optimal conditions, tropical DH hybrids were as good as tropical classical hybrids in terms of grain yield and agronomic traits performance (Beyene et al., 2012).

Table 4. 10: **Means of the double haploid hybrids across 5 optimal locations**

Entry no	Line No.	Tester No.	GY t ha^{-1}	EA 1-5	EPP #	ER %	ASI day	DTS day	PH cm	ET 1-5
1	1	1	5.3	2.8	1.0	6.1	1.9	74.0	204.7	2.9
2	1	2	6.2	2.8	1.0	5.8	1.7	76.1	212.4	2.7
3	2	1	5.9	2.5	1.0	9.4	1.5	72.1	187.9	2.9
4	2	2	5.6	2.4	1.0	9.1	1.2	75.4	193.5	2.8
5	3	1	4.7	2.8	1.0	14.3	1.9	73.3	212.3	3.2
6	3	2	5.1	2.5	1.0	4.9	2.4	77.0	211.3	3.3
7	4	1	4.4	3.3	0.9	18.4	1.2	67.9	191.9	2.7
8	4	2	3.4	3.1	1.0	11.7	1.1	70.5	193.6	3.2
9	5	1	5.2	2.7	1.0	7.6	2.9	70.6	198.0	2.7
10	5	2	5.7	2.6	1.0	10.2	1.5	73.4	214.1	2.8
11	6	1	5.2	2.8	1.0	10.4	1.3	69.4	191.8	2.8
12	6	2	4.6	2.8	0.9	12.2	2.2	72.0	197.4	2.9
13	7	1	6.8	2.4	1.0	6.2	1.1	71.8	207.9	2.6
14	7	2	5.9	2.7	1.0	5.8	1.5	73.5	198.1	2.8
15	8	1	4.5	3.2	0.9	16.9	1.8	69.5	200.3	3.1
16	8	2	4.3	3.2	0.9	8.4	1.5	71.1	194.9	3.1
17	9	1	4.2	3.0	0.9	16.5	0.7	69.8	200.1	3.1
18	9	2	3.8	3.1	0.9	12.9	1.4	71.3	196.6	3.2
19	10	1	5.9	2.7	1.0	9.5	0.8	70.9	206.1	2.8
20	10	2	5.2	2.7	1.0	10.6	0.7	72.0	202.3	3.2
21	11	1	4.0	2.9	1.0	12.4	1.1	68.5	186.1	3.2
22	11	2	4.3	2.8	1.0	10.7	0.8	69.6	201.2	3.0
23	12	1	4.9	2.9	1.0	11.2	2.0	71.2	212.1	2.7
24	12	2	3.7	3.3	1.0	11.6	1.5	72.4	199.3	2.9
25	13	1	2.9	3.6	0.8	24.7	1.4	73.5	193.9	3.3
26	13	2	3.7	3.2	0.9	15.9	1.8	73.4	220.1	3.5
27	14	1	4.0	3.2	0.9	14.8	0.8	70.7	214.1	3.3
28	14	2	4.4	3.1	0.9	11.9	1.0	71.4	213.3	3.2
29	15	1	3.1	3.5	0.9	24.5	1.8	70.6	196.1	3.5
30	15	2	3.8	2.9	0.9	15.8	0.9	70.7	213.4	3.4
31	16	1	4.1	3.3	1.0	15.3	1.8	75.6	197.9	3.1
32	16	2	5.1	2.4	1.0	8.2	1.3	73.5	207.8	3.0
33	17	1	5.1	3.1	1.0	12.2	1.4	70.5	202.8	3.1
34	17	2	4.6	3.1	1.0	12.0	1.0	71.1	216.6	2.9
35	18	1	3.9	3.0	1.0	17.4	0.5	71.4	204.0	3.2
36	18	2	3.7	3.2	0.9	14.3	0.9	72.2	201.9	3.2
37	19	1	5.3	2.7	1.0	13.0	1.0	72.7	204.3	3.0
38	19	2	5.0	2.8	1.0	7.9	0.4	74.5	202.6	2.8
39	20	1	4.2	3.1	0.9	13.3	1.0	70.8	215.6	3.4
40	20	2	4.1	2.9	0.9	8.6	1.4	71.5	217.9	3.3
41	21	1	4.7	3.0	0.9	11.9	0.9	74.4	203.3	2.8
42	21	2	5.6	2.8	1.0	11.8	0.5	74.0	208.0	2.9
43	22	1	3.8	3.1	1.0	17.8	1.5	68.3	193.0	3.3
44	22	2	3.9	3.1	0.9	9.1	0.7	69.9	184.1	3.1
45	23	1	2.8	3.5	0.9	31.1	1.9	69.8	191.9	3.4
46	23	2	3.5	3.2	0.9	11.2	0.9	70.7	196.1	3.5
47	24	1	3.9	3.0	0.9	18.1	2.9	72.2	206.1	3.3
48	24	2	4.5	2.6	0.9	10.4	2.0	72.1	212.9	3.3
49	25	1	6.4	2.4	1.0	6.4	1.3	70.4	193.5	2.7
50	25	2	5.5	2.5	0.9	5.8	1.8	73.4	202.9	2.6
51	26	1	4.2	3.1	1.0	10.5	1.3	69.1	187.1	3.2

† GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; ET=Turcicum leaf blight

Table 4.10 continued: **Means of the doubled haploid hybrids across 5 optimal locations**

Entry no	Line No.	Tester No.	GY t ha^{-1}	EA 1-5	EPP #	ER %	ASI day	DTS day	PH cm	ET 1-5
52	26	2	4.0	3.0	1.0	15.1	1.1	72.1	192.0	2.9
53	27	1	4.9	2.8	1.0	5.3	1.4	71.0	190.8	3.3
54	27	2	5.3	2.5	0.9	8.8	1.4	72.3	206.3	3.1
55	28	1	6.0	2.6	1.0	7.8	1.5	73.3	222.3	2.7
56	28	2	5.2	2.4	1.0	7.0	0.9	77.2	221.3	2.5
57	29	1	5.2	2.8	1.0	10.0	1.2	73.4	197.1	2.4
58	29	2	6.3	2.3	1.0	8.2	0.4	74.0	208.6	2.5
59	30	1	4.2	3.0	1.0	15.3	2.3	71.3	197.9	3.1
60	30	2	4.3	2.9	1.0	11.7	2.0	72.3	202.4	3.1
61	31	1	4.2	2.8	1.0	14.5	1.2	70.3	191.9	2.9
62	31	2	4.1	2.8	1.0	13.3	1.5	69.8	201.1	2.7
63	32	1	4.6	2.6	1.0	12.8	2.2	71.7	187.5	3.3
64	32	2	4.8	2.8	1.0	13.6	1.3	72.7	183.7	2.9
65	33	1	5.0	2.6	1.0	4.4	0.6	69.0	173.6	2.8
66	33	2	4.9	2.6	1.0	5.5	1.3	70.7	207.2	2.7
67	34	1	5.9	2.6	1.1	3.5	1.4	72.2	203.8	2.8
68	34	2	6.8	2.3	1.0	5.9	1.1	73.9	211.6	2.3
69	35	1	5.8	2.7	0.9	6.7	2.2	76.5	209.1	2.8
70	35	2	5.7	2.6	1.0	6.8	2.0	76.8	209.6	2.6
71	36	1	6.4	2.5	0.9	9.9	1.5	72.7	212.4	2.6
72	36	2	5.0	2.9	0.9	5.5	1.3	75.2	204.2	3.0
73	37	1	5.7	2.6	1.0	16.1	1.9	73.7	198.1	2.5
74	37	2	5.6	2.7	1.0	6.4	0.5	75.2	215.4	2.8
75	38	1	5.2	2.9	1.0	10.7	1.1	74.2	216.1	2.9
76	38	2	5.5	2.7	0.9	6.6	1.1	76.6	225.0	2.8
77	39	1	6.7	2.4	1.0	5.5	1.3	70.4	195.5	2.5
78	39	2	5.4	2.6	1.0	6.5	2.1	74.1	194.3	2.6
79	40	1	3.9	3.2	1.0	16.2	1.6	73.8	204.3	3.1
80	40	2	5.2	2.9	0.9	12.6	1.6	76.0	218.6	3.0
81	41	1	6.5	2.3	1.0	9.2	1.2	75.2	209.8	2.3
82	41	2	6.5	2.4	1.0	7.3	0.4	76.4	222.1	2.5
83	42	1	5.7	2.6	1.0	11.1	1.4	76.8	206.4	2.9
84	42	2	4.1	3.1	0.8	11.6	1.7	76.6	222.2	2.9
85	43	1	3.6	3.3	1.0	15.2	1.1	69.3	201.2	3.3
86	43	2	3.2	3.4	1.0	11.9	1.6	71.5	192.6	3.2
87	44	1	4.6	3.0	1.0	7.2	1.3	70.9	211.7	3.2
88	44	2	5.0	2.9	1.0	7.8	1.0	71.8	215.2	3.1
89	45	1	6.4	2.9	1.1	14.6	1.5	75.3	216.7	2.6
90	45	2	5.4	2.6	1.0	9.4	1.3	77.6	219.3	2.8
91	46	1	6.1	2.7	1.0	8.7	2.1	74.7	215.6	2.4
92	46	2	3.9	2.9	1.1	13.8	2.3	77.5	204.6	2.5
classical commercial hybrids checks										
93	WH403		7.1	2.9	1.0	5.5	1.3	70.7	207.2	2.7
94	H513		5.7	2.9	1.0	13.6	1.3	72.7	183.7	2.9
95	DUMA43		5.8	2.9	1.0	14.3	1.9	73.3	212.3	3.2
96	DK8031		5.5	2.8	0.9	11.9	0.9	74.4	203.3	2.8
Trial mean			**4.9**	**2.8**	**1.0**	**11.2**	**1.4**	**72.6**	**203.9**	**2.9**
Min			**2.8**	**2.3**	**0.8**	**3.5**	**0.4**	**67.9**	**173.6**	**2.3**
Max			**6.8**	**3.6**	**1.1**	**31.1**	**2.9**	**77.6**	**225.0**	**3.5**
LSD (0.05)			**0.9**	**0.3**	**0.1**	**6.8**	**1.2**	**1.8**	**19.0**	**0.4**
CV			**20.4**	**15.3**	**12.7**	**69.8**	**102.3**	**2.9**	**9.4**	**15.8**

† = GY=grain yield; EPP=ear per plant; ER=ear rot; EA=ear aspect; ASI=anthesis-silking date; DTS= days from planting to emergence of silk in 50 % of plants; PH= plant height; ET=Turcicum leaf blight

Performance in lines 29 and 34 was above average under both environments and that line 29 was above average at stresses suggesting that amongst the DH hybrids some have potentials for replacing the existing commercial varieties currently used in drought prone ecologies.

Table 4. 11: **Yield advantage of DH hybrids evaluated under stressed and optimal conditions**

Entries evaluated	Evaluation locations and environments						
	MDS	LNS	Opt1	Opt 2	Opt 3	Opt 4	Opt 5
Best classical hybrid check	1.8	3.4	7.2	7.7	7.6	6.3	4.4
Trial mean	2.0	2.7	3.7	5.4	6.0	3.9	4.7
Top 10 DH hybrid	3.5	3.7	7.0	9.1	8.1	6.1	6.2
Least 10 DH hybrid	0.7	1.5	1.6	3.2	4.1	2.2	3.4
Lsd 5 % level of probability	0.7	1.6	2.0	1.5	1.5	2.0	1.9
YA of top 10 DH hybrids over best classical check hybrid	48.0	8.0	(2.9)	15.4	6.2	(3.3)	29.0
YA of top 10 DH hybrids over least 10 DH hybrids	80.0	60.0	77.0	64.8	49.4	64.0	45.2

MDS = managed drought stress conditions at Kiboko; LNS = low nitrogen stress conditions at Kiboko; Opt 1= optimal conditions at Shikusha; Opt 2 = optimal conditions at Embu; Opt 3 = optimal conditions at Bulindi; Opt 4 = optimal conditions at Selian and Opt 5 = optimal conditions at Kakamega.

4.3.5 Estimates of general combining abilities effects at different environments

4.3.5.1 General combining abilities effects under managed drought stress at Kiboko

General combining ability effects (GCAs) are presented in Table 4.12. GCAs estimates for grain yield ranged from –ve1.64 t ha^{-1} in line 46 to 1.83 t ha^{-1} in line 10. This indicated that while in hybrids combination, the performance of the evaluated DH lines was different. GCA effects of 18 DH lines were significant for grain yield. Out of the 18, DH lines 2, 10, 13, 14, 15, 27, 28 and 29 showed positive GCAs. Notably, DH lines with significant GCAs for grain yield also showed significant GCAs for ear aspect and days to 50 % silking.

Table 4. 12: **Estimates for GCA effects of lines evaluated under managed drought stress**

Line No.	GY (t ha^{-1})	EPP(#)	EA (1-5)	ER (%)	ASI (day)	DTS(day)	PH (cm)
1	0.20	-0.31	0.52*	7.99*	1.72	4.05*	17.05**
2	0.63*	-0.21	-0.23	-2.31	-2.53	-0.95	-2.70
3	-0.92***	-0.49	0.27	-1.51	11.47***	11.55***	0.55
4	-0.40	-0.34	0.64**	9.79**	0.22	-2.20	-8.20
5	-1.00***	-0.44	0.39	3.49	3.47*	3.30*	4.80
6	0.40	-0.01	-0.11	-1.19	-3.03	-3.70*	-11.20*
7	0.30	-0.11	-0.48*	-3.79	-2.78	-3.45*	0.55
8	0.02	-0.24	-0.23	-1.21	-2.53	-3.70*	3.30
9	0.40	0.01	-0.23	5.01	-3.53*	-4.20**	7.30
10	1.83***	-0.01	-1.23***	-3.79	-3.53*	-4.20**	6.80
11	0.50	-0.21	-0.36	-3.79	-2.03	-4.45**	-16.95**
12	0.22	-0.19	0.14	2.16	-2.03	-2.95	5.30
13	0.64*	-0.21	-0.23	0.31	-1.78	-2.70	9.30
14	0.75**	-0.16	-0.36	-0.54	-3.28*	-4.70**	5.05
15	1.42***	-0.06	-0.86***	-0.76	-3.78*	-5.45**	-8.20
16	-0.45	-0.36	0.14	-0.09	1.22	2.05	-15.95**
17	0.17	-0.41	0.02	8.36*	-3.53*	-4.20**	-1.70
18	0.22	-0.24	0.02	-2.86	-1.53	-1.70	-0.45
19	0.05	-0.34	-0.23	-3.79	-2.03	-0.70	3.30
20	-0.53*	-0.34	0.27	-2.31	4.47**	3.80*	11.80*
21	0.40	-0.24	-0.48*	-2.54	1.22	3.55*	0.80
22	0.17	-0.21	0.14	-2.94	-0.53	-2.20	-20.95***
23	-0.38	-0.26	0.27	-0.46	-2.03	-3.70*	-15.45**
24	0.12	-0.19	0.14	-1.06	2.47	1.55	3.55
25	0.07	-0.26	-0.23	-1.06	-0.78	-2.20	-8.20
26	0.40	-0.09	-0.23	-2.71	-1.78	-3.95*	-11.45*
27	0.83**	-0.16	-0.48*	-2.96	-3.03	-3.70*	-3.45
28	0.95**	-0.14	-0.86***	-1.81	-2.78	-0.70	21.80***
29	1.25***	-0.04	-0.61**	-3.79	-3.03	-1.20	6.30
30	-0.33	-0.26	0.14	-3.79	-0.78	-2.45	-5.20
31	-0.25	-0.09	0.14	-0.14	-1.28	-4.20**	0.05
32	-0.15	-0.14	0.27	14.44***	-0.28	-0.45	-0.20
33	-0.74**	-0.31	0.27	-3.79	8.22***	6.55***	-12.70*
34	0.02	-0.29	0.27	-3.79	0.22	0.30	-4.95
35	-1.22***	0.34	0.77***	-1.99	0.22	3.05	3.55
36	-0.30	-0.26	0.52*	-0.46	4.47**	4.55**	2.05
37	-0.73*	-0.36	0.14	1.56	4.97**	5.05**	-11.45*
38	0.40	-0.21	-0.23	0.59	-0.03	2.05	11.30*
39	-0.03	-0.29	-0.36	-3.79	1.47	1.05	-12.70*
40	0.02	-0.24	0.02	5.86	-0.53	1.05	-0.20
41	-0.03	-0.29	-0.36	-2.71	-0.03	3.05	17.80***
42	-0.72*	-0.34	0.27	-3.79	6.47***	10.05***	9.05
43	-0.40	-0.21	0.39	10.09**	-2.53	-3.45*	1.55
44	-0.82**	-0.44	0.52*	-0.86	3.22	3.05	7.05
45	-1.33***	-0.59	0.77***	-1.86	0.72	3.80*	5.30
46	-1.64***	-0.46	0.89***	4.54	0.97	4.05*	6.80

GY= grain yield; DTS=days to emergence of silk in 50 % plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; ER= ear rot: *, **, ***, Significant at *P* < 0.05, 0.01 and 0.001 probability levels, respectively.

DH line 7, 10, 15, 21, 27, 28, 29, 35, and 36 showed negative and significant GCAs effects for ear aspect implying that they contributed to increased ear quality. The GCAs of DTS in lines 9, 10, 14 15 and 17 was negative and significant which indicated that earliness was important for grain yield. Yields in hybrids of DH lines 10, 15, 27, 29 were above average (Table 4.5) suggesting that effect of additive genes conditioning female flowering enhanced drought tolerance. Similarly, high yields were as a result of useful genetic diversity including more number of ears per plant, increase in kernel number, reduction in time to flowering and a reduced anthesis silking interval as reported by (Edmeades et al., 2000). The DH lines showed narrow ranges of GCAs for grain yield. Low GCAs ranges for grain yield indicated presence of stability in yield conditioned by additive genetic effects as also reported by (Hohls et al., 1995). DH lines 10, 15, 27, 29 were identified as suitable as seed parents for drought tolerant hybrids

4.3.5.2 General combining abilities effects under low nitrogen stress at Kiboko

General combining ability effects (GCAs) under low nitrogen stress are presented in Table 4.13. The GCAs for grain yield ranged from –1.43 t ha^{-1} in line 18 to 2.15 t ha^{-1} in line 45. Results showed that GCAs in 29 lines were significant for grain yield and out of the 29, effects in 12 (1, 2, 5, 10, 19, 21, 27, 36, 39, 40, 41 and 45) were positive. Lines with positive and significant GCAs for grain yield did not necessarily yield above average. The GCAs for ASI ranged from – 3.13 to 3.13 days 13 implying that the lines were different in regard to earliness. Lines 2, 21, 28, 30 and 45 had significant and negative GCAs for ASI. Under stress, these lines are expected to yield above average. However, except line 21, crosses of most lines that showed desirable GCAs for earliness did not yield above average. GCAs were significant for plant height and ranged from – 32.15 cm to 49.85 cm suggesting that under LNS, the DH lines performance for plant height was different.

Table 4. 13 : **Estimates for GCA effects of 46 DH line under low-nitrogen stressed conditions**

Line No.	GY (t ha^{-1})	EPP (#)	ER (%)	EA (1-5)	ASI (day)	DTS (day)	PH (cm)
1	1.67***	-0.03	-3.35*	-0.40	-0.63	-0.40	49.85***
2	0.87*	0.00	-2.55	-0.40	-2.13*	-1.40	1.10
3	0.65	-0.05	0.58	-0.27	1.63	4.10**	13.60
4	-1.00**	0.12*	1.65	0.35	1.63	-3.65**	-14.65
5	1.85***	0.05	-3.12*	-0.15	-0.88	-4.90***	11.60
6	-0.20	0.12*	-0.32	-0.15	1.38	-4.40**	-11.90
7	-1.03**	0.00	4.05**	0.23	-0.13	0.35	-19.65*
8	-1.30***	-0.08	1.03	-0.15	-0.63	-1.90	-32.15***
9	-0.83*	-0.05	1.85	-0.27	-0.88	-5.65***	-10.40
10	1.60***	0.02	-2.10	-0.52	-1.88	-3.90**	20.10*
11	-1.10**	-0.08	1.55	-0.40	-1.38	-1.40	-18.90*
12	-0.90**	-0.03	0.33	0.10	0.38	-0.40	-10.90
13	-0.75*	0.02	-0.42	0.48	3.13**	2.60	22.60**
14	-0.73*	0.02	2.55	0.73**	-1.63	-2.40	-5.65
15	-1.38***	0.00	3.38*	0.60*	0.13	-1.40	-4.90
16	-0.35	0.00	0.10	-0.40	-0.63	2.60	-7.40
17	0.65	0.05	0.18	0.23	-0.63	-3.15*	17.60*
18	-1.43***	-0.13*	2.60	0.23	1.13	0.35	-12.15
19	1.25***	-0.05	-2.35	-0.65*	-0.38	-0.40	2.35
20	-1.13**	-0.03	2.28	0.48	0.88	-0.90	-3.15
21	1.17**	0.02	-1.22	-0.27	-2.13*	2.85*	16.6*
22	0.25	-0.03	0.08	0.60*	0.38	-6.4***	-9.40
23	-0.60	0.05	1.25	0.73**	1.13	-2.15	-8.40
24	-0.73*	-0.08	2.28	0.60*	2.63**	1.35	-10.90
25	0.32	-0.03	-2.00	-0.27	0.88	-1.15	-3.65
26	-1.3***	0.07	2.40	0.60*	1.13	0.10	-11.65
27	1.12**	0.07	-2.77*	-0.27	-0.63	-3.90**	-0.40
28	0.22	-0.08	-1.52	-0.27	-2.38*	5.60***	20.60**
29	0.10	-0.05	-0.77	0.35	-1.63	5.10***	-1.15
30	-0.20	0.02	-0.62	-0.52	2.38*	0.85	-13.15
31	-0.70*	0.10	0.08	-0.15	0.63	-2.90*	-10.90
32	0.57	0.02	-0.30	-0.15	-0.13	-2.15	-18.15*
33	0.60	0.00	-2.50	-0.02	-1.38	-4.65***	-3.90
34	-0.85*	-0.10	1.65	-0.40	0.63	3.60**	-11.40
35	0.17	0.05	-0.30	-0.27	1.63	8.85***	2.85
36	0.80*	0.02	-1.25	-0.40	1.38	1.10	-3.15
37	-0.15	-0.05	2.35	-0.02	1.88	2.85*	-5.15
38	-0.73*	-0.03	-0.50	-0.52	0.38	6.85***	0.35
39	0.82*	0.02	-1.60	0.10	0.88	-0.90	-1.90
40	1.02**	0.00	-1.50	0.23	-0.63	0.60	8.10
41	1.17**	0.02	-1.22	-0.52	-1.38	1.35	24.85**
42	-0.88*	0.07	-0.10	0.10	0.13	5.35***	6.10
43	-0.35	-0.03	1.88	0.48	-1.38	-3.65**	17.60*
44	-0.53	0.02	0.48	0.23	-0.13	-1.65	-1.40
45	2.15***	0.07	-1.87	0.35	-3.13**	4.10**	21.85**
46	0.07	-0.03	-0.42	0.10	0.38	5.35***	8.85

† GY= grain yield; DTS= days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; ER= ear rot: *, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively

GCAs in lines 1, 10, 14, 17, 21, 28, 41, 43 and 45 were positive and significant while that in line 7, 8, 11 and 32 was significant and negative. Lines that showed good GCAs for plant height did not necessarily yield above average. Stress tolerance has been reported to be associated with enhanced earliness and plant height (Edmeades et al., 2000). Contrary, in DH lines under low N stress, expression of alleles conditioning plant height and earliness did not necessarily result in enhanced grain yield. This deviation could have been contributed by action of non-genetic factors and which was clearly indicated by the 18 % heritability for grain yield under LNS. Compared to GCAs under MDS, GCAs under LNS were greater and wider ranges. Small GCAs and of low ranges indicates stability in yield (Hohls et al., 1995). At MDS and LNS conditions, lines 2, 10 and 27 consistently showed high amounts and significant GCAs suggesting that they might have allele conditioning low N and drought tolerance (Castelberry et al., 1984). It is however recommended that further investigation on performance of the DH lines under LNS is conducted.

4.3.5.3 General combining ability effects across optimal locations

General combining ability effects (GCAs) under optimal condition is presented in Table 4.14. Under optimal conditions GCAs of 23 lines were positive and non-significant, of 22 lines were negative and non-significant and, line 42 showed negative and significant GCAs. GCAs for grain yield ranged from – 0.82 t ha^{-1} to 0.70 t ha^{-1}. These results suggested that additive genetic effects conditioning GY were not important for enhanced production in DH hybrids at optimal conditions. Significant and desirable GCAs were realized; for ear aspect in lines 2, 25, 28, 34, 41, for ear rots in lines 3 and 7, for prolificacy in lines 34, 41 and 46, for plant height in lines 20, 28, 38, 41, 45 and for turcicum blight in lines 29, 39 and 42.

***Table 4. 14*: Estimate for GCA effects of DH lines evaluated 5 across optimal locations**

Line No.	GY (t ha^{-1})	EPP (#)	ER (%)	EA(1-5)	ASI (day)	DTS(day)	PH (cm)	ET (1-5)
1	-0.1	0.0	-4.5	0.13	0.4	1.9**	4.7	-0.2
2	0.2	0.0	-1.6	-0.29*	-0.2	1.20	-13.16*	-0.1
3	0.3	0.0	-2.1	-0.27	0.76*	2.05**	7.9	0.2
4	-0.1	0.0	3.5	0.28*	0.0	-3.45***	-11.1	0.1
5	0.5	0.0	-1.3	-0.09	0.6	-0.55	2.2	-0.2
6	0.2	0.0	-1.3	-0.09	0.3	-1.15	-9.3	-0.1
7	-0.3	0.0	-4.86*	-0.17	-0.4	-0.35	-0.9	-0.1
8	0.2	-0.07*	-0.7	0.33*	0.2	-2.05**	-6.3	0.1
9	-0.5	-0.06*	4.0	0.23	0.3	-2.1**	-5.5	0.2
10	0.1	0.0	-0.5	-0.09	-0.6	-1.20	0.4	0.0
11	0.0	0.0	0.2	-0.07	-0.5	-2.95***	-10.2	0.2
12	0.4	0.0	0.2	0.23	0.4	-0.35	1.8	-0.1
13	-0.5	-0.1	6.16*	0.53***	0.1	-0.05	3.2	0.3
14	-0.1	0.0	3.2	0.23	-0.2	-1.55*	9.9	0.4
15	-0.1	0.0	2.2	0.21	-0.3	-1.30	0.9	0.51**
16	-0.2	0.0	3.1	0.03	0.6	1.6*	-1.0	0.1
17	0.0	0.0	-0.3	0.16	-0.3	-0.90	5.8	0.1
18	0.1	0.0	-0.8	0.16	-0.7	-0.35	-0.9	0.2
19	0.1	0.0	-0.5	-0.04	-0.74*	0.95	-0.4	0.0
20	-0.1	-0.1	-0.1	0.08	0.1	-1.25	12.93*	0.4
21	0.1	0.0	1.4	0.11	-0.3	1.30	1.8	0.0
22	0.0	0.0	3.3	0.23	-0.2	-3.3***	-15.29*	0.2
23	-0.4	0.0	5.49*	0.43**	0.1	-2.5***	-9.9	0.46*
24	0.0	0.0	0.7	-0.04	1.01**	0.00	5.6	0.4
25	0.7	0.0	-4.0	-0.34*	0.1	-0.55	-5.7	-0.2
26	0.0	0.0	0.8	0.08	-0.1	-1.6*	-14.32*	0.2
27	0.5	0.0	-3.3	-0.19	0.1	-0.85	-5.3	0.2
28	0.2	0.0	-1.3	-0.29*	-0.6	2.75***	17.96**	-0.3
29	0.5	0.0	-2.7	-0.27	-0.2	1.00	-1.0	-0.54**
30	-0.3	0.0	2.3	0.06	0.7	-0.70	-3.7	0.2
31	-0.4	0.0	2.8	-0.02	0.1	-2.05**	-7.4	-0.1
32	-0.1	0.0	3.7	-0.17	0.4	-0.30	-18.25**	0.2
33	-0.4	0.0	-3.5	-0.27	-0.2	-2.2**	-13.44*	-0.1
34	0.0	0.09**	-4.0	-0.44**	-0.3	0.55	3.9	-0.3
35	0.2	0.0	-0.9	-0.12	0.3	4.55***	5.5	-0.2
36	0.2	0.0	-0.5	-0.17	-0.1	1.00	4.4	-0.2
37	-0.1	0.0	-0.6	-0.09	0.1	1.4*	2.9	-0.3
38	0.4	0.0	-0.3	0.01	-0.3	1.85**	16.71**	-0.1
39	-0.1	0.0	-1.5	-0.27	0.0	-0.40	-8.9	-0.37*
40	0.0	0.0	2.4	0.18	-0.3	2.25**	7.6	0.2
41	0.1	0.07*	-3.2	-0.42**	-0.4	2.3**	12.09*	-0.49**
42	-0.82*	-0.1**	2.1	0.06	0.0	3.45***	10.5	-0.1
43	-0.5	0.0	1.2	0.36*	0.3	-2.25**	-6.9	0.3
44	0.1	0.0	-3.9	0.10	-0.2	-1.35*	9.6	0.2
45	0.1	0.0	1.0	0.03	-0.2	3.5***	14.15*	-0.3
46	-0.2	0.11***	-1.5	-0.09	0.91*	3.85***	6.3	-0.52**

Traits: GY= grain yield; DTS=days to emergence of silk in 50 % plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; ER= ear rot; ET=turcicum leaf blight: *, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively

Good GCAs for secondary traits indicated that additive gene action conditioning the secondary traits were important for grain yield under optimal conditions. GCA x environment effects were significant for GY and all secondary traits recorded except for EPP. This implied that though some lines may show good GCA and hence would be desirable, their differential performance across environment could pose a challenge during the selection process. Across locations, yields in hybrids of lines 24 and 44 were above average suggesting that some of the DH lines can serve as rich donor parents of alleles conditioning special traits.

4.3.6 Specific combining ability effects of DH lines for grain yield and heterotic grouping

Under managed drought stress, SCAs ranged from –1.2 t ha^{-1} to 1.2 t ha^{-1}. Six DH lines; 5, 10, 13, 22, 34 and 39 showed significant and relatively higher SCAs (Table 4.15). Lines that showed significant SCAs for grain yield with one tester did not necessarily show the same while in hybrid combination with the second tester. For instance, line 10 showed high yield while crossed to tester 1 or tester 2 (Table 4.5). This suggested that expression of non-additive genetic effect was influenced by environment and the maternal effect. Under low nitrogen stress, SCAs ranged from – 0.4 t ha^{-1} to 0.4 t ha^{-1}. Six DH lines; 11, 12, 15, 22, 32 and 36 showed significant and relatively higher SCAs (Table 4.15). In hybrid combination, grain yield in lines that showed significant SCAs were all below average and the yield did not also depend on the male parent involved (Table 4.6). For instance, crossed to tester 1 or tester 2, yields in the five lines were similar. Under optimal conditions, the SCAs ranged from – 0.81 t ha^{-1} to 0.81 t ha^{-1}. Lines number 24, 39 and 44, showed relatively high and significant SCAs (Table 4.15). Yield of hybrids 24x2, 39x1 and 44x2 were above average (Table 4.10). Across all environments, lines number 1, 5, 6, 7, 10, 13, 14, 15, 19, 26, 29, 30, 32, 38, 39, 40 and 41 showed inconsistent directions of SCAs depending on environments. In numerous studies, significant SCA effects is indicative of higher grain yield due to presence of heterosis which could be attributable to predominance of non-additive gene effects (Betrán et al., 2003a). This assumption did not hold true with the studied DH lines since hybrids from good specific combiners did not always yield above average (Table 4.5, 4.6 and 4.10). It seemed that SCA effects were influenced by environments and allelic interaction between the parents involved in making the hybrid (Fan et al., 2009). Similar findings were reported by (Pswarayi and Vivek, 2008). From previous studies in CIMMYT, the testers used in the current experiment, (that is, tester 1; CML312/CML442 and tester 2; CML395/CML444) were known to belong to heterotic A and heterotic group B respectively. Hence using SCAs for GY the DH lines were classified into respective heterotic groups (Vasal et al., 1992). Positive SCA effects indicated that lines are in opposite heterotic groups while negative SCA effects indicated that lines are in the same heterotic group (Vasal et al., 1992). Line number 1, 2, 6, 8, 9, 12, 13, 14, 16, 19, 20, 21, 22, 23, 24, 25, 27, 31, 33, 34, 40 and 44 showed negative SCA effects with tester 1 across all the environments. Thus they were considered to belong to heterotic group A. While all the other 24 lines showed negative SCA effects with tester 2 and were placed under heterotic group B (Table 4.15). None of the DH lines studied that showed positive SCA effects with both testers and which implied that CML312/CML442 and CML396/CML444 aligned the new lines to two distinct and known HGs. Contraly, classical maize lines studied using molecular markers were aligned to three HGs (Warburton et al., 2002). Magnitudes of SCA effects were generally low and not significant except for lines 1 and 24 which showed high and significant SCAs (Table 4.15). DH ines with good SCA did not necessarily yield highest. Contraly good SCA was closely associated with yield (Betrán et al., 2003a; Makumbi et al., 2010). This suggested that in DH hybrids, heterotic effect due to additive genetic effect was predominant over non-additive.

Table 4. 15: **Estimates for specific combining abilities for grain yield and heterotic grouping**

Line No.	MDS		LNS		Across Optimal		Across all		Heterotic group based on SCA for grain yield across all
	T1	T2	T1	T2	T1	T2	T1	T2	
1	0.0	-0.0	0.1	-0.1	-0.6	0.6	-0.48*	0.48*	A
2	0.5	-0.5	-0.1	0.1	0.4	-0.4	0.3	-0.3	B
3	0.3	-0.3	-0.2	0.2	0.0	-0.0	0.0	-0.0	B
4	-0.1	0.1	0.3	-0.3	0.2	-0.2	0.3	-0.3	B
5	0.6*	-0.6*	-0.1	0.1	-0.4	0.4	-0.2	0.2	A
6	-0.1	0.1	-0.1	0.1	-0.1	0.1	-0.3	0.3	A
7	0.0	0.0	0.1	-0.1	0.3	-0.3	0.3	-0.3	B
8	-0.1	0.1	-0.1	0.1	-0.2	0.2	0.0	0.0	A
9	-0.2	0.2	0.1	-0.1	-0.1	0.1	-0.1	0.1	A
10	0.8**	-0.8**	0.1	-0.1	-0.1	0.1	0.0	0.0	B
11	0.0	0.0	-0.4*	0.4*	0.2	-0.2	0.0	0.0	B
12	-0.3	0.3	0.4*	-0.4*	-0.1	0.1	-0.2	0.2	A
13	1.2***	-1.2***	-0.1	0.1	-0.4	0.4	-0.1	0.1	A
14	0.5	-0.5	-0.2	0.2	-0.3	0.3	-0.1	0.1	A
15	0.3	-0.3	0.4*	-0.4*	-0.4	0.4	0.0	0.0	B
16	-0.4	0.4	0.1	-0.1	-0.4	0.4	-0.4	0.4	A
17	0.2	-0.2	-0.3	0.3	0.2	-0.2	0.1	-0.1	B
18	0.5	-0.5	-0.3	0.3	0.1	-0.1	0.3	-0.3	B
19	0.0	0.0	-0.1	0.1	0.2	-0.2	0.0	0.0	A
20	0.1	-0.1	-0.2	0.2	-0.1	0.1	-0.1	0.1	A
21	0.0	0.0	-0.2	0.2	-0.2	0.2	-0.1	0.1	A
22	-0.8**	0.8**	0.4*	-0.4*	-0.2	0.2	-0.3	0.3	A
23	-0.3	0.3	0.1	-0.1	0.0	0.0	-0.2	0.2	A
24	-0.3	0.3	-0.3	0.3	-0.74*	0.74*	-0.64**	0.64**	A
25	-0.2	0.2	0.1	-0.1	-0.2	0.2	-0.2	0.2	A
26	-0.5	0.5	0.2	-0.2	0.1	-0.1	0.1	-0.1	B
27	-0.4	0.4	-0.1	0.1	-0.2	0.2	0.0	0.0	A
28	0.4	-0.4	-0.2	0.2	0.4	-0.4	0.4	-0.4	B
29	-0.2	0.2	-0.2	0.2	0.1	-0.1	0.1	-0.1	B
30	-0.3	0.3	0.3	-0.3	0.1	-0.1	0.1	-0.1	B
31	-0.1	0.1	-0.2	0.2	-0.5	0.5	-0.4	0.4	A
32	-0.4	0.4	0.4*	-0.4*	0.2	-0.2	0.1	-0.1	B
33	-0.2	0.2	0.3	-0.3	0.3	-0.3	-0.1	0.1	A
34	-0.6*	0.6*	-0.3	0.3	0.0	0.0	-0.3	0.3	A
35	-0.3	0.3	-0.2	0.2	0.6	-0.6	0.5	-0.5	B
36	0.3	-0.3	0.4*	-0.4*	0.4	-0.4	0.3	-0.3	B
37	0.3	-0.3	-0.3	0.3	0.3	-0.3	0.4	-0.4	B
38	-0.1	0.1	-0.3	0.3	0.3	-0.3	0.1	-0.1	B
39	-0.7**	0.7**	0.1	-0.1	0.81*	-0.81*	0.3	-0.3	B
40	0.1	-0.1	0.1	-0.1	-0.4	0.4	-0.3	0.3	A
41	0.2	-0.2	-0.1	0.1	-0.1	0.1	0.1	-0.1	B
42	0.4	-0.4	0.1	-0.1	0.3	-0.3	0.2	-0.2	B
43	-0.1	0.1	-0.2	0.2	-0.1	0.1	0.1	-0.1	B
44	-0.4	0.4	0.1	-0.1	-0.74*	0.74*	-0.4	0.4	A
45	0.0	0.0	-0.1	0.1	0.6	-0.6	0.5	-0.5	B
46	0.3	-0.3	0.3	-0.3	0.5	-0.5	0.4	-0.4	B

SCA=specific combining ability; MDS=managed drought stress; LNS=low N stress; T1=CML312/CML442 that belong to heterotic group A; T2=CML395/CML444 that belong to heterotic group B; *, **= significant at P≤0.05, significant at P≤0.01 probability levels

4.4 Conclusions and recommendations

Under drought and under low N stress, mean squares for lines and for line* tester were significant for grain yield. Contribution of GCA to the total genetic variance was larger than that of SCA for traits evaluated. Mean squares for lines were significant for ASI and most secondary traits evaluated and not significant for ears per plant. For all secondary traits evaluated, contribution of GCA to the total genetic variance was larger than that of SCA. Thus though non-additive and additive gene effect could be important for GY under stress, additive genes played a more predominant role in enhancing stress tolerance. More importantly, GCAs were generally small and of narrow ranges implying that the additive effects could show good stability across environments. Significant differences were revealed amongst the DH hybrids for grain yield under drought and under low N stress. Yield difference between best and least yielding hybrids were as high as 49 %. Under drought yield in stress tolerant DH hybrids were significantly higher than that in the best commercial classical checks. Performance of secondary traits in the DH hybrids was as good as that in classical check hybrids. Yields under managed drought stress and under low N was 43 % and 57 % that of optimal conditions and within ranges acceptable in tropical maize. Thus tropical DH hybrids developed using a temperate inducer performed better than the existing classical hybrids. Clearly, the used testers aligned the DH lines into two opposite heterotic patterns each consisting of about 50 % of the tested DH lines. Yield in DH hybrids did not depend on dominant effect alone and was also influenced by environment. It was likely that the testers used in screening the DH lines were of low effectiveness and there may be need for using different type and number of testers.

CHAPTER FIVE:
GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Assessment of new germplasm in targets environments was shown to enable breeders identify high yielding and adapted hybrids (Bänziger et al., 2000). In agreement with Hede et al., (1999) reports concerning tropical maize growing areas, variations amongst our test locations were highly significant for all traits evaluated. This suggested that our test sites gave adequate and diverse stresses and which could lead to effective selection for hybrids suitable for eastern Africa region.

The heritability in the broad senses (H^2) values revealed in the current study corroborates previous finding in maize evaluated under stress. Our findings showed that under stresses, H^2 were lower than that under optimal conditions: 0.30 for varietal hybrids (VH) and 0.55 for doubled haploid (DH) hybrids under managed drought; 0.20 for DH hybrids under low N and, 0.90 for VHs and 0.60 for DH hybrids across optimal conditions. This suggested that up to 90 % of phenotypic variance was attributable to additive, dominance, and epistatic genetic effects (Falconer and Mackay, 1996; Nyquist, 1991). In multi-environments evaluation studies, H^2 is a measure of precision of the trials and a high H^2 indicates that the evaluation process was highly precise and was able to capture variation caused by genetic factors (Piepho and Mőhring, 2007). Thus, generally, the data collected from the *Experiment 1* and *Experiment 2* could effectively enable selection for hybrids which are tolerant to low nitrogen and to drought. Specifically, however, the trial under low N revealed low H^2 for grain yield suggesting that 80 % of the variation realized was due to environmental factors. Further investigation on performance of the DH hybrids under low Nitrogen stress should be conducted.

The significant differences amongst effects of DH lines and effects of line x tester indicated that the performance of the DH lines while in hybrids combinations was different. Similarly classical maize lines were found to be significantly different under abiotic stresses (Makumbi et al., 2010) and (Pswarayi and Vivek, 2008). GCA estimates were generally low but several DH lines showed good GCA estimates for grain yields and for secondary traits indicating that the performance of their hybrids was above average (Sprague and Tatum, 1942). Classical lines with large, positive and significant GCAs estimates for grain yield and secondary traits were considered good for forming hybrids and creation of genetic diversity respectively (Pswarayi and Vivek, 2008). Contraly, in our study, the DH lines of good SCAs did not necessarily produce best yielding hybrids. Notably, in all traits recorded, lines' mean squares were larger than lxt mean squares implying that GCA effects were preponderance to SCA effects. It was therefore concluded that expression of grain yield in DH hybrids was controlled mainly by additive genetic effects. Predominance of low GCA indicates that the lines could form hybrids of high stability (Hohls et al., 1995). Lines with good GCAs for secondary traits could be useful source of genetic diversity (Pswarayi and Vivek, 2008). The studied DH lines could be useful in breeding programmes targeted to ecologies where stresses are diverse and unpredictable. However, DH lines with large, significant but negative GCA estimates should be tested using a different tester.

Upon crossing to the two single cross hybrids testers, 50 % of the DH lines were aligned to HG A and the other 50 % to HGB; no line fell under HG AB. This suggested that, testers CML312/CML442 and CML395/CML444 commonly used in CIMMYT due to their good GCA for grain yields could assist breeders to group new DH lines into known heterotic groups. It would be however important to further explore benefit of the heterotic patterns revealed in the current study.

The variations amongst the VHs and DH hybrids were non-significant and significant for grain yield. In other studies on classical maize under stress, variation for grain yield were very small or non-significant (Rosielle and Hamblin, 1981). Variations amongst the VHs were significant for flowering traits under drought stress suggesting presence of useful genetic diversity for adaptive traits. These findings corroborates and affirms the reports that tropical maize possess genetic diversity which could be useful for stress tolerance (Warburton et al., 2002). Suppressing, in both sets of hybrids, aviations were not significant for ears per plant. Notably, the two sets of hybrids were progenies of maize populations which were improved by selecting for earliness and not for prolificacy. This revelation suggested that though good gain from selection could be achieved by selecting for earliness, breeding efforts should also be geared towards enhancing diversity in ears per plant.

Heterosis was important for drought tolerance and its expression was highly dependent of the type of parental materials used. In a descending order, under stresses, yields were highest in DH hybrids, classical hybrids, varietal hybrids and open pollinated varieties. Other studies also revealed higher yield in DH hybrids while compared to classical hybrids (Beyene et al., 2012) and (Bordes et al., 2006). Temperate DH hybrids yielded more than varietal hybrids (Wilde et al., 2010). In the tropical maize, lower yields were reported in OPVs while compared to hybrids (Bänziger et al., 1999b). It was therefore inferred that under stresses, buffering associated with germplasm of broad genetic base may not be effective in enhancing yields, rather the ability for a genotype to express the favourable alleles conditioning the target traits is more imperative. Overall, our findings revealed that lines development using the DH technology could enable maize farmers in areas prone to increasing adverse effects of drought and low nitrogen stresses reap the benefits of genetic diversity in tropical maize populations.

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TABLES OF APPENDICES

Appendix 4. 1: **ANOVA for traits of DH hybrids evaluated at Shikusha under optimal conditions**

Traits	Source of variation	Rep	Hybrids	Line	Tester	Line*Tester	Error
	df	**1**	**91**	**45**	**1**	**45**	**91**
GY (t ha^{-1})		7.2	5.3***	2.7	11.6	3.4	3.4
EPP (#)		0.0	0.03**	0.02	0.09	0.02	0.3
EA ('1-5)		0.02	0.2***	0.2	0.2	0.2	0.2
ASI (day)		1.2	2.5	2.7	0.9	2.9	2.5
DTS(day)		19.6	11.2***	10.8	0.8	4.7	7.2
PH (cm)		-	-	-	-	-	-
PA (1-5)		1.2*	0.2***	0.1	0.05	0.2	0.2
ER (%)		266.4	227.3**	132.7	9.2	131.3	229.9
ET (1-5)		0.1	0.2	0.1	1.0**	0.1**	0.10

*, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively

† GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; PA= plant aspect; ER= ear rot; ET=Turcicum leaf blight;

Appendix 4. 2: **ANOVA for traits of DH hybrids evaluated at Embu under optimal conditions**

Traits	Source of variation	Rep	Hybrids	Lines	Tester	Line*Tester	Error
	df	**1**	**91**	**45**	**1**	**45**	**91**
GY (t ha^{-1})		0.1	2.8***	3.6*	0.2	1.0	2.1
EPP (#)		0.0	0.01	0.02*	0.005	0.01	0.01
EA ('1-5)		3.1***	0.34***	0.5***	1.6**	0.2	0.2
ASI (day)		0.3	3.4***	5.6***	0.1	1.4	1.4
DTS(day)		0.1	20.7***	31.2***	282.5***	4.3	3.9
PH (cm)		2454.7***	750.4***	1176.6***	1155.0*	315.2*	207.9
PA (1-5)		0.2	0.6***	0.9***	5.2***	0.2	0.2
ER (%)		77.1	226.2	132.3*	113.5	81.1	80.4
ET (1-5)		0.5**	0.01	0.1	0.1	0.1	0.20

*, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively

† GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; PA= plant aspect; ER= ear rot; ET=Turcicum leaf blight

Appendice 4. 3: **ANOVA for traits of DH hybrids evaluated under optimal conditions at Bulindi**

Traits	Source of variation	Rep	Hybrids	Line	Tester	Line*Tester	Error
	df	1	91	45	1	45	91
GY (t ha^{-1})		0.3	2.7***	2.9***	1.6	2.4**	1.2
EPP (#)		0.13*	0.02	0.02	0.02	0.02	0.02
EA ('1-5)		0.2	0.4***	0.6***	0.2	0.2	0.2
ASI (day)		4.6	1.7	1.6	0.05	1.8	1.6
DTS(day)		34.8**	11.3***	16.5***	86.3***	4.5	3.8
PH (cm)		762.1	616.7	747.8	1891.9	457.3	518.3
PA (1-5)		0.03	0.6***	0.8***	1.3*	0.4**	0.2
ER (%)		0.02	0.9	1.0	0.2	0.9	0.9
ET (1-5)		6.6***	0.7*	1.2***	0.01	0.6	0.6

*, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively
† GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; PA= plant aspect; ER= ear rot; ET=Turcicum blight

Appendix 4. 4: **ANOVA for traits of DH hybrids evaluated at Kakamega under optimal conditions**

Traits	Source of variation	Rep	Hybrids	Line	Tester	Line*Tester	Error
	df	1	91	45	1	45	91
GY (t ha^{-1})		1.39***	13.9***	1.3***	0.2	0.3*	0.2
EPP (#)		0.9***	0.02	0.02	0.1*	0.02	0.03
EA (1-5)		1.4***	0.4***	0.7***	0.1	0.1	0.1
ASI (day)		1.2	13.9***	18.6***	0.3	9.6	7.0
DTS (day)		30.6	233.6***	24.9***	399.1***	10.3	9.8
PH (cm)		2367.4***	109.8	367.1***	106.5	102.9	126
ER (%)		2011.0***	165.8***	230.5***	116.6	102.1	93.6
ET (1-5)		0.4*	0.4***	0.7***	1.4***	0.1	0.10

*, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively
† GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants in a plot; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; ER= ear rot; ET =Turcicum blight

Appendix 4. 5 : **ANOVA for traits of DH hybrids evaluated at Arusha under optimal conditions**

Traits	Source of variation	Rep	Hybrids	Line	Tester	Line*Tester	Error
	df	1	91	45	1	45	91
GY (t ha^{-1})		9.8	1.3*	1.5*	2.2	1.2	0.9
EPP (#)		0.0	0.02	0.02	0.0	0.01	0.01
EA (1-5)		3.3**	0.6*	0.6*	0.1	0.6*	0.4
ASI (day)		0.04	1.0	1.1	3.4	0.9	1.0
DTS (day)		3.1	19.3***	30.7***	128.9***	5.3	4.9
PH (cm)		3452.2***	351.4	373.2	51.1	336.2	386.9
PA (1-5)		1.7**	0.2	0.2	0.1	0.2	0.2
ER (%)		22.1	6.1	5.4	11.4	6.7	6.8
ET (1-5)		1.0*	0.3***	0.5***	0.1	0.1	0.1

*, **, ***, Significant at $P < 0.05$, 0.01 and 0.001 probability levels, respectively
† GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; PH= plant height; EPP=ears per plant; EA= ear aspect; PA= plant aspect; ER= ear rot; ET=Turcicum leaf blight

Appendix 4. 6: **Mean for traits evaluated under optimal conditions at Kakamega**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	DTP day	ASI day	DTS day	PH cm	EPP #	ER %	ET 1-5	EA 1-5	PA 1-5
1	1	1	2.7	81.5	0.2	81.7	188.6	1.2	6.1	3.5	2.7	2.9
2	1	2	2.5	80.8	2.0	82.8	178.8	1.0	1.7	3.2	3.1	2.5
3	2	1	2.9	75.7	1.1	76.8	158.7	1.0	0.0	3.5	2.4	3.6
4	2	2	2.5	81.4	4.1	85.4	153.8	1.0	8.1	3.5	2.4	3.2
5	3	1	1.4	79.5	5.4	84.9	186.0	0.7	24.5	3.7	3.4	3.0
6	3	2	1.4	80.8	3.9	84.7	174.0	0.9	1.0	3.6	3.4	2.6
7	4	1	2.4	70.6	4.0	74.5	164.0	0.9	2.1	3.5	3.3	2.2
8	4	2	1.5	77.1	4.6	81.7	175.3	1.0	3.3	3.8	3.0	2.2
9	5	1	2.5	70.4	3.9	74.3	169.0	0.9	0.7	3.2	2.7	2.4
10	5	2	2.1	78.5	6.5	85.0	178.9	0.9	2.2	3.5	3.2	3.1
11	6	1	1.9	76.5	4.0	80.5	153.8	0.9	2.5	3.7	2.9	2.7
12	6	2	1.6	81.3	1.0	82.2	153.2	1.0	4.0	3.4	3.3	2.7
13	7	1	1.8	71.3	1.5	72.7	171.9	0.8	5.0	4.0	3.0	2.6
14	7	2	1.8	73.3	9.5	82.7	174.2	1.0	5.1	3.8	3.1	3.1
15	8	1	1.5	73.5	4.6	78.1	161.8	1.0	14.8	3.7	3.4	2.8
16	8	2	1.4	81.7	1.4	83.1	178.8	1.1	2.5	3.5	3.5	2.7
17	9	1	1.8	77.2	1.7	78.9	167.9	1.0	2.5	3.3	3.0	2.4
18	9	2	2.0	75.3	6.1	81.4	175.1	1.0	3.1	3.4	3.0	2.7
19	10	1	3.2	72.8	1.1	74.0	189.1	1.0	2.7	3.4	2.0	2.0
20	10	2	2.6	73.3	4.4	77.7	172.7	1.0	6.2	3.3	2.7	2.3
21	11	1	2.1	74.5	5.4	80.0	158.3	1.1	1.5	3.7	3.0	2.7
22	11	2	1.7	77.5	3.5	80.9	148.9	0.9	12.9	3.6	3.3	3.5
23	12	1	2.2	83.2	0.9	84.1	172.8	1.0	9.6	3.5	2.5	3.3
24	12	2	2.4	79.8	2.1	81.9	174.5	1.0	0.7	3.5	3.0	3.0
25	13	1	0.8	77.8	3.0	80.8	166.0	1.0	20.9	4.2	4.1	4.4
26	13	2	1.6	77.9	3.1	81.0	177.1	1.1	4.5	3.7	3.6	3.5
27	14	1	2.1	73.2	3.9	77.1	183.7	0.9	2.0	3.6	3.0	2.3
28	14	2	2.1	80.2	7.0	87.2	186.3	1.0	5.3	3.5	3.1	2.7
29	15	1	1.5	74.2	4.1	78.3	171.8	0.8	4.2	4.5	3.2	3.3
30	15	2	1.3	77.7	0.7	78.4	167.7	0.8	0.8	4.0	3.6	3.8
31	16	1	1.4	78.5	4.0	82.5	178.6	1.1	3.5	3.7	3.1	2.5
32	16	2	2.7	81.4	-0.1	81.4	176.5	0.9	1.8	3.3	2.5	2.7
33	17	1	1.5	75.7	2.5	78.2	178.6	0.9	6.7	4.0	3.3	3.0
34	17	2	1.3	78.6	2.1	80.7	168.2	1.1	12.7	3.2	3.4	3.7
35	18	1	1.6	81.7	0.0	81.7	161.2	0.9	4.1	4.3	3.1	3.1
36	18	2	1.7	81.2	2.1	83.3	168.9	1.2	0.3	3.7	3.0	3.6
37	19	1	2.7	81.3	-0.1	81.2	185.3	0.9	4.8	3.5	2.4	2.1
38	19	2	3.0	82.3	-0.1	82.2	176.9	1.1	2.8	3.3	2.6	2.5
39	20	1	0.9	70.0	8.7	78.6	179.6	0.9	4.0	4.5	3.7	2.7
40	20	2	1.4	79.9	2.4	82.3	159.7	1.0	4.6	4.0	3.7	4.0
41	21	1	2.9	82.1	-1.5	80.6	197.7	0.9	9.7	3.3	2.4	1.9
42	21	2	3.3	77.4	0.5	77.9	184.5	0.9	7.0	3.0	2.6	2.7
43	22	1	1.7	71.2	6.4	77.6	169.3	0.8	23.3	3.7	3.3	2.0
44	22	2	1.3	78.5	2.9	81.3	162.9	0.9	15.3	3.8	3.4	3.1
45	23	1	0.9	69.9	8.5	78.3	171.0	1.0	14.2	4.0	3.7	3.1
46	23	2	2.2	76.6	5.1	81.7	163.7	1.0	16.9	4.1	3.7	3.9
47	24	1	1.1	71.7	7.2	78.9	157.9	0.9	10.5	3.8	4.0	3.9
48	24	2	1.7	79.1	3.1	82.2	171.9	1.0	2.1	3.8	3.1	3.3
49	25	1	2.3	72.8	4.6	77.4	176.2	0.8	5.0	3.3	2.8	2.6
50	25	2	2.2	73.3	4.5	77.8	166.2	1.1	4.8	2.7	2.8	2.8
51	26	1	1.5	69.2	8.5	77.7	181.4	1.0	3.7	3.7	3.0	3.2

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect ET=turcicum leaf blight

Appendix 4.6 continued: Mean for traits evaluated under optimal conditions at Kakamega

Entry No.	Line No.	Tester No.	GY t ha^{-1}	DTP day	ASI day	DTS day	PH cm	EPP #	ER %	ET 1-5	EA 1-5	PA 1-5
52	26	2	2.0	77.1	2.1	79.2	166.6	0.9	3.0	3.2	2.9	3.4
53	27	1	2.1	72.7	6.6	79.3	171.2	0.8	7.7	4.0	3.0	2.1
54	27	2	1.6	78.1	4.7	82.8	162.1	1.1	2.8	3.8	3.1	3.1
55	28	1	3.0	78.7	0.4	79.1	192.9	1.0	0.7	3.3	2.3	2.0
56	28	2	2.3	82.8	0.5	83.2	181.7	1.0	5.0	3.5	2.4	2.2
57	29	1	2.5	81.8	0.1	82.0	184.0	1.0	21.5	2.8	3.1	2.1
58	29	2	2.2	85.5	1.0	86.4	168.0	1.0	6.1	3.0	2.8	3.1
59	30	1	1.4	71.4	5.5	76.9	171.9	0.8	3.8	4.0	3.5	2.7
60	30	2	2.0	71.2	6.0	77.2	169.0	0.9	8.6	4.0	3.3	3.4
61	31	1	1.6	71.8	6.9	78.7	165.2	0.9	10.2	3.9	3.4	3.0
62	31	2	2.4	71.8	8.0	79.8	156.2	1.1	3.6	3.2	2.8	3.4
63	32	1	2.0	76.8	2.5	79.3	175.5	1.0	2.4	3.1	2.7	2.2
64	32	2	1.9	83.5	1.8	85.4	179.3	1.0	2.5	3.2	3.0	3.7
65	33	1	1.9	72.4	3.6	76.0	161.8	0.9	10.8	3.5	3.0	2.6
66	33	2	1.1	75.3	5.7	81.0	167.6	0.8	16.8	2.7	3.4	3.3
67	34	1	2.4	78.6	2.4	81.1	184.5	1.0	1.1	3.1	2.6	2.5
68	34	2	3.0	75.1	3.0	78.1	196.7	0.8	4.4	3.0	2.3	2.0
69	35	1	3.0	81.9	0.0	81.9	186.1	0.9	0.7	3.2	2.4	2.2
70	35	2	2.1	81.6	6.6	88.2	185.5	1.1	5.9	3.5	2.7	2.8
71	36	1	2.5	80.4	0.9	81.3	164.3	1.0	6.1	3.0	2.6	2.1
72	36	2	2.0	82.5	3.1	85.6	165.9	1.0	3.5	3.3	2.9	3.4
73	37	1	2.0	77.8	2.2	80.0	169.8	1.0	5.6	3.6	2.6	2.7
74	37	2	2.1	82.4	2.9	85.4	164.2	1.1	0.0	3.6	3.0	2.6
75	38	1	2.2	84.1	0.3	84.4	168.2	0.8	4.7	3.5	2.9	2.7
76	38	2	2.2	85.4	-1.1	84.3	203.8	0.9	8.2	3.0	2.7	2.7
77	39	1	3.4	74.8	3.9	78.7	176.1	0.9	0.2	3.0	2.4	2.1
78	39	2	2.9	78.8	6.2	85.0	176.5	1.1	5.8	2.5	2.3	3.1
79	40	1	1.8	84.4	1.6	86.0	179.5	1.0	3.6	3.4	3.2	2.7
80	40	2	1.8	82.7	1.8	84.4	176.6	0.9	5.6	3.5	3.0	3.3
81	41	1	3.3	83.8	0.0	83.8	179.0	1.1	2.0	2.5	2.2	2.4
82	41	2	2.2	84.9	-0.1	84.8	181.7	1.0	4.0	2.7	2.8	3.0
83	42	1	2.2	83.1	2.1	85.3	173.5	0.9	7.2	3.5	2.6	2.3
84	42	2	1.7	82.9	1.1	84.0	171.6	1.2	0.5	3.5	3.2	3.4
85	43	1	0.5	69.0	8.8	77.8	153.9	1.1	29.1	4.0	3.9	3.2
86	43	2	1.0	79.9	1.9	81.9	148.3	0.8	24.9	3.8	3.6	3.8
87	44	1	1.0	74.6	6.3	80.9	165.4	1.0	5.7	3.8	4.0	3.5
88	44	2	0.9	73.8	10.4	84.2	174.7	0.9	20.2	4.3	3.7	3.6
89	45	1	1.8	83.8	2.0	85.8	179.3	1.0	5.6	3.2	3.2	2.8
90	45	2	1.6	85.5	2.6	88.1	186.7	0.9	5.4	2.6	3.2	3.5
91	46	1	2.3	76.9	4.6	81.5	180.3	0.7	3.2	2.5	3.3	2.5
92	46	2	1.4	82.7	6.1	88.8	179.5	1.2	2.8	2.0	3.2	3.7
classical commercial hybrid checks												
93	WH403		2.6	82.9	1.2	84.1	180.3	0.9	7.7	2.9	2.6	2.6
94	H513		2.4	73.5	4.0	77.5	199.2	1.0	2.6	3.7	2.5	2.1
95	DUMA43		1.7	70.5	7.0	77.5	165.7	0.8	5.5	2.3	3.2	2.4
96	DK8031		1.0	70.7	4.1	74.7	176.0	0.9	68.4	3.2	3.8	2.7
Trial mean			**2.0**	**77.0**	**3.3**	**80.3**	**171.0**	**0.9**	**6.4**	**3.5**	**3.0**	**2.8**
Max			**3.4**	**85.5**	**10.4**	**88.8**	**203.8**	**1.2**	**29.1**	**4.5**	**4.1**	**4.4**
Min			**0.5**	**69.0**	**-1.5**	**72.7**	**148.3**	**0.7**	**0.0**	**2.0**	**2.0**	**1.9**
LSD (0.05)			**0.7**	**6.2**	**5.3**	**4.8**	**20.4**	**0.3**	**16.5**	**0.6**	**0.6**	**1.2**

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect ET=turcicum leaf blight

Appendix 4. 7: **Mean for traits evaluated at Shikusha under optimal conditions**

Entry No.	Line No.	Tester No.	GY $t\ ha^{-1}$	EPP #	EA 1-5	ASI day	DTS day	ER %	ET 1-5	PA 1-5
1	1	1	5.8	0.9	2.0	-1.0	75.1	6.1	3.0	2.5
2	1	2	6.8	0.9	2.5	-1.5	77.5	5.4	3.0	2.5
3	2	1	6.5	1.0	2.5	-1.5	73.1	12.7	3.0	2.6
4	2	2	4.6	1.0	2.5	-0.5	77.6	17.4	3.0	2.7
5	3	1	3.3	0.9	2.8	-0.5	76.0	14.0	3.2	3.0
6	3	2	3.0	0.9	3.0	0.5	79.4	9.5	2.7	2.9
7	4	1	3.5	0.8	3.5	-1.5	71.6	35.4	2.2	2.8
8	4	2	2.7	1.0	3.0	0.0	74.5	13.7	3.0	2.9
9	5	1	4.4	0.8	2.5	-0.5	72.9	11.2	2.7	2.5
10	5	2	4.2	0.9	2.5	-0.5	75.3	22.3	2.7	2.9
11	6	1	4.6	1.0	2.8	-2.0	70.6	23.9	3.0	3.1
12	6	2	2.7	0.8	3.3	-1.5	75.1	18.5	2.7	3.5
13	7	1	7.9	0.9	2.0	-1.5	75.1	7.6	2.5	1.9
14	7	2	6.6	0.9	2.3	-1.5	78.0	9.7	2.5	2.4
15	8	1	2.9	0.8	3.0	-2.0	72.6	23.2	3.3	2.8
16	8	2	4.6	0.9	3.0	-2.0	72.5	10.7	3.0	2.7
17	9	1	3.7	0.8	3.0	-0.5	73.0	32.0	3.5	3.0
18	9	2	2.7	0.7	3.0	-1.0	74.5	10.4	3.2	3.0
19	10	1	5.4	1.0	2.8	-2.5	72.5	20.4	2.8	3.0
20	10	2	3.9	0.8	2.8	-0.5	75.5	5.7	3.3	3.1
21	11	1	2.7	0.8	2.5	-2.0	70.5	23.5	2.8	2.7
22	11	2	2.3	0.9	2.8	-1.5	72.5	21.5	2.3	3.0
23	12	1	4.1	0.9	3.0	-1.0	72.6	15.1	2.7	2.7
24	12	2	3.3	0.8	3.0	-1.5	74.6	12.2	3.0	3.0
25	13	1	0.6	0.3	3.8	3.0	78.6	42.9	3.0	3.7
26	13	2	1.1	0.4	3.0	3.0	79.1	22.2	3.5	3.0
27	14	1	2.5	0.7	3.0	0.5	73.5	29.8	2.5	3.0
28	14	2	2.6	0.8	3.0	-2.0	74.0	13.6	3.0	3.1
29	15	1	1.2	0.7	3.0	-1.5	72.9	53.3	3.1	3.5
30	15	2	2.1	0.5	3.3	-0.5	75.5	28.0	3.3	3.8
31	16	1	4.7	0.8	3.0	-1.0	76.5	18.8	3.0	2.7
32	16	2	4.2	0.8	2.5	-2.0	74.5	9.0	3.2	3.1
33	17	1	3.6	1.0	3.3	-1.0	72.4	21.6	3.1	3.0
34	17	2	4.2	1.0	2.8	-1.5	74.0	17.6	3.0	2.8
35	18	1	2.0	0.8	3.5	-1.5	72.3	36.0	3.3	3.2
36	18	2	2.4	0.8	3.3	-1.5	74.9	28.4	3.0	3.1
37	19	1	4.7	1.0	2.8	-0.5	75.0	24.8	3.7	2.5
38	19	2	4.7	0.9	2.5	-1.0	76.4	8.5	2.7	3.0
39	20	1	2.7	0.7	3.0	-1.0	73.4	9.3	3.5	2.9
40	20	2	2.3	0.5	3.3	-2.0	72.5	14.2	3.0	3.7
41	21	1	5.5	0.9	2.5	-1.5	75.6	9.4	3.0	2.8
42	21	2	4.6	0.7	2.8	-2.0	76.1	15.4	3.0	2.8
43	22	1	2.4	0.8	2.8	-1.5	71.5	28.5	3.3	3.4
44	22	2	2.1	0.9	2.8	-2.0	73.0	6.2	3.3	3.0
45	23	1	0.7	0.6	3.5	-1.5	73.1	66.6	3.3	3.0
46	23	2	2.2	0.8	3.0	-1.0	74.4	20.1	3.0	3.5
47	24	1	2.8	0.7	3.0	-1.0	73.1	31.3	2.8	3.1
48	24	2	2.8	0.5	2.8	-1.5	74.6	29.6	3.0	3.0
49	25	1	6.1	1.0	2.5	-2.0	73.5	5.4	3.0	2.5
50	25	2	4.6	0.9	2.3	-1.0	75.5	7.8	2.2	3.0
51	26	1	3.0	0.8	3.0	-2.0	70.9	24.3	2.5	3.0

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum leaf blight

Appendix 4.7 continued: **Mean for traits evaluated at Shikusha under optimal conditions**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	EPP #	EA 1-5	ASI day	DTS day	ER %	ET 1-5	PA 1-5
52	26	2	2.6	0.9	3.0	-2.0	73.1	12.7	2.9	3.0
53	27	1	4.4	0.8	2.8	-1.5	72.0	6.1	3.2	3.0
54	27	2	4.2	0.8	3.0	-2.0	74.0	20.0	2.7	3.0
55	28	1	5.8	0.9	2.8	-1.5	74.5	5.6	3.0	2.5
56	28	2	4.8	0.9	2.8	-1.5	79.0	12.2	2.8	2.8
57	29	1	4.7	0.9	2.5	-2.5	73.9	23.4	3.0	2.8
58	29	2	6.3	0.9	2.3	-2.0	75.6	6.6	3.0	2.2
59	30	1	3.0	0.9	3.0	-0.5	74.5	18.7	3.3	2.9
60	30	2	2.3	0.8	3.0	-1.0	76.0	18.9	2.5	3.5
61	31	1	3.9	0.9	2.8	-1.5	71.4	20.8	2.5	3.0
62	31	2	3.7	0.7	3.0	-2.0	72.0	16.0	2.8	2.7
63	32	1	4.5	1.0	2.8	-1.5	73.1	17.9	3.2	2.8
64	32	2	4.2	0.9	3.0	-1.0	75.0	14.1	3.0	2.7
65	33	1	5.2	0.9	2.8	-2.0	72.0	6.4	2.8	3.0
66	33	2	4.1	0.9	2.8	-2.0	72.1	9.9	3.0	3.0
67	34	1	6.3	0.9	2.8	-1.5	74.0	3.4	3.1	2.5
68	34	2	5.9	0.8	2.8	-1.5	74.9	1.8	2.7	2.4
69	35	1	7.4	1.0	3.0	-1.0	78.0	5.0	3.0	2.2
70	35	2	6.0	0.8	2.3	-3.5	76.9	8.3	2.7	2.5
71	36	1	7.3	1.0	2.5	-1.0	75.4	11.3	3.0	2.3
72	36	2	4.9	0.8	2.5	-1.0	77.5	2.2	3.0	2.5
73	37	1	5.4	1.0	2.5	-1.0	74.0	30.8	2.5	2.5
74	37	2	5.3	0.8	2.5	-0.5	78.0	11.3	3.0	2.7
75	38	1	5.2	0.9	2.5	1.0	77.4	5.6	3.0	2.9
76	38	2	4.8	0.8	2.8	-1.0	79.0	20.5	3.0	2.8
77	39	1	7.7	1.0	2.5	-1.5	73.4	7.1	3.0	2.5
78	39	2	4.4	0.9	2.8	-1.0	78.0	11.9	3.0	2.7
79	40	1	2.6	0.8	3.0	-1.5	77.1	18.0	3.0	2.8
80	40	2	2.7	0.7	3.0	0.5	80.5	31.7	2.8	3.2
81	41	1	7.4	1.0	2.0	0.0	77.9	15.3	2.8	2.7
82	41	2	5.2	0.9	2.8	2.5	80.6	15.7	3.0	2.8
83	42	1	5.8	1.0	2.5	-1.0	77.5	14.5	2.9	2.7
84	42	2	2.8	0.7	2.8	-4.5	77.5	11.1	3.0	2.5
85	43	1	2.1	0.7	3.5	-1.5	70.9	26.4	3.3	3.5
86	43	2	1.8	0.8	3.3	-2.5	72.0	15.3	2.4	2.9
87	44	1	4.3	0.9	3.0	-1.5	73.1	13.6	2.7	3.0
88	44	2	3.6	0.8	3.0	-2.0	73.6	13.2	3.0	3.0
89	45	1	4.9	0.9	2.5	-1.5	76.9	25.2	3.0	2.5
90	45	2	4.4	0.9	2.0	-4.0	76.8	20.4	3.2	2.9
91	46	1	5.5	0.9	3.0	-1.5	76.5	18.8	3.0	2.7
92	46	2	3.6	0.8	2.5	-1.0	75.0	23.0	3.0	3.2
classical commercial hybrid checks										
93	WH403	.	7.2	1.0	2.3	-1.5	76.9	8.7	2.7	2.4
94	H513	.	5.3	0.9	2.5	-2.0	72.6	9.5	3.2	2.7
95	DUMA43	.	4.9	0.9	2.8	-1.5	71.0	9.8	3.0	2.8
96	DK8031	.	4.7	0.8	3.3	-1.0	74.6	11.6	3.1	2.6
Mean 92 hybrids			**3.9**	**0.8**	**2.7**	**-1.2**	**71.4**	**16.5**	**2.8**	**2.8**
LSD (0.05)			**2.0**	**0.3**	**0.6**	**3.2**	**3.8**	**21.7**	**0.7**	**0.6**
Min			**0.6**	**0.3**	**2.0**	**-4.5**	**70.5**	**1.8**	**2.2**	**1.9**
Max			**7.9**	**1.0**	**3.8**	**3.0**	**80.6**	**66.6**	**3.7**	**3.8**

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum leaf blight

Appendix 4. 8: **Mean for traits of DH hybrids evaluated at Embu under optimal conditions**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	ASI day	DTS day	PH cm	EPP #	ER %	ET 1-5	EA 1-5	PA 1-5
1	1	1	6.5	3.2	74.8	224.0	0.89	10.8	1.8	3.3	3.2
2	1	2	7.7	1.8	76.6	230.5	0.88	10.0	1.7	3.1	3.8
3	2	1	5.9	2.3	73.3	198.3	0.89	16.2	2.0	2.6	2.7
4	2	2	7.4	1.4	75.2	205.8	0.96	11.0	1.6	2.4	3.2
5	3	1	7.5	3.7	72.8	225.0	0.91	16.5	1.8	3.3	3.4
6	3	2	9.0	4.1	77.7	244.7	0.94	7.7	1.8	2.4	4.1
7	4	1	4.9	1.5	68.0	200.0	0.78	14.9	1.8	4.0	2.6
8	4	2	3.8	3.0	70.0	196.6	0.92	33.8	2.2	3.7	2.7
9	5	1	6.5	2.5	68.8	212.0	0.86	12.4	1.8	2.7	2.6
10	5	2	6.0	2.6	72.7	226.8	1.00	6.9	1.9	2.7	3.7
11	6	1	6.6	1.9	69.8	210.6	1.00	23.1	2.0	3.0	2.9
12	6	2	4.5	1.5	70.9	207.3	0.82	31.7	2.0	3.4	2.9
13	7	1	6.1	-0.3	72.4	230.6	0.94	18.9	1.5	2.3	4.0
14	7	2	5.4	0.1	74.3	232.2	0.85	11.1	1.7	3.1	4.1
15	8	1	4.9	1.6	70.2	205.6	0.85	27.1	1.7	3.5	3.0
16	8	2	3.8	3.1	73.9	203.0	0.87	20.2	1.8	3.5	2.8
17	9	1	4.3	1.2	69.8	208.1	0.79	24.8	1.8	3.3	2.6
18	9	2	4.6	2.1	70.3	223.2	0.60	33.6	1.7	3.4	3.4
19	10	1	7.0	0.4	70.0	216.3	0.95	13.7	1.7	3.4	3.0
20	10	2	6.8	0.5	72.7	213.8	0.91	13.8	1.8	2.7	3.0
21	11	1	6.0	1.6	68.9	202.4	0.93	9.2	1.5	3.0	2.8
22	11	2	6.7	-0.3	68.4	215.8	0.96	3.8	1.4	2.7	3.3
23	12	1	5.4	1.7	70.8	240.6	0.84	20.1	1.5	3.1	3.4
24	12	2	4.4	1.3	73.1	219.7	0.89	29.1	1.5	3.3	3.2
25	13	1	5.1	1.3	71.8	231.3	0.94	26.0	1.6	3.5	3.5
26	13	2	5.8	2.7	74.6	262.7	0.77	19.2	1.8	3.0	4.0
27	14	1	5.8	0.6	69.1	236.5	0.76	25.8	1.8	3.0	3.1
28	14	2	5.5	1.3	73.1	239.0	0.91	20.6	1.5	3.1	3.2
29	15	1	4.5	0.4	70.1	202.1	0.90	27.0	1.8	3.7	2.7
30	15	2	4.6	0.5	68.4	225.1	0.83	14.6	1.5	3.1	3.2
31	16	1	4.6	2.6	74.5	198.6	0.87	25.1	1.8	3.8	3.0
32	16	2	7.0	2.0	73.9	231.5	0.99	12.5	1.8	2.7	4.1
33	17	1	7.7	2.6	72.5	221.6	0.89	15.0	1.8	3.2	3.4
34	17	2	6.5	1.6	72.5	259.2	0.98	92.1	2.1	3.2	4.1
35	18	1	5.1	0.7	71.0	205.3	0.90	13.1	1.7	3.2	2.7
36	18	2	5.0	1.3	71.5	226.9	0.83	26.4	1.6	3.4	3.2
37	19	1	6.9	0.1	71.0	216.8	1.04	8.8	2.0	3.0	3.3
38	19	2	6.2	-0.9	72.3	214.0	0.77	14.1	1.8	3.3	3.5
39	20	1	6.1	1.2	70.1	242.6	0.87	18.3	1.9	3.7	3.6
40	20	2	5.5	1.4	72.8	235.2	0.83	17.6	1.8	3.4	3.7
41	21	1	5.8	-0.3	72.7	230.1	0.86	25.8	1.7	3.2	3.5
42	21	2	6.6	1.2	75.9	242.6	0.97	18.3	1.8	2.9	4.0
43	22	1	4.8	1.7	68.6	206.6	0.95	20.2	1.7	3.3	2.7
44	22	2	4.8	2.8	69.1	199.0	0.82	8.5	1.5	3.5	2.3
45	23	1	5.5	3.1	69.8	199.0	0.90	18.9	2.0	3.7	3.0
46	23	2	4.9	0.8	71.9	174.4	0.88	16.3	1.5	3.5	2.9
47	24	1	4.9	4.6	73.5	209.8	0.83	28.1	2.0	3.1	3.0
48	24	2	5.1	3.7	74.1	205.6	0.96	15.6	1.8	3.1	3.7
49	25	1	6.9	1.5	69.9	206.7	1.00	9.3	1.7	2.9	3.1
50	25	2	7.2	1.8	71.3	237.3	0.92	13.1	1.8	2.6	4.0
51	26	1	7.2	0.7	68.8	211.2	1.01	10.8	2.0	3.2	3.1

Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum blight

Appendix 4. 8 continued: **Mean for traits of DH hybrids evaluated at Embu under optimal conditions**

Entry No.	Line No.	Tester No.	GY $t\ ha^{-1}$	ASI day	DTS day	PH cm	EPP #	ER %	ET 1-5	EA 1-5	PA 1-5
52	26	2	5.5	1.7	74.0	201.0	0.99	23.3	1.4	3.3	3.2
53	27	1	7.4	0.8	69.7	217.2	0.85	9.9	2.0	2.8	2.7
54	27	2	7.5	1.0	70.7	235.5	0.91	14.6	1.7	2.3	3.8
55	28	1	7.3	1.1	75.0	257.2	0.96	11.4	1.6	2.8	4.1
56	28	2	7.3	0.2	77.3	231.0	0.94	12.5	1.8	2.4	4.2
57	29	1	5.8	0.7	71.4	210.2	0.97	15.9	2.0	3.5	3.1
58	29	2	5.9	1.0	75.3	220.0	0.92	17.9	2.0	3.1	3.6
59	30	1	5.6	3.6	72.2	222.9	0.88	34.3	1.7	3.2	2.9
60	30	2	6.4	2.4	71.4	231.4	0.92	19.2	2.0	3.3	3.7
61	31	1	5.1	2.7	69.9	200.3	0.92	18.8	1.5	3.3	2.5
62	31	2	3.9	2.1	71.2	214.2	0.99	23.8	1.5	3.2	3.2
63	32	1	4.7	2.0	71.9	192.3	0.81	15.0	1.8	2.8	2.8
64	32	2	5.0	3.0	75.0	194.7	0.87	20.0	2.0	3.6	2.4
65	33	1	6.4	0.2	66.8	212.6	0.95	7.0	1.7	2.7	3.0
66	33	2	4.0	3.2	74.1	213.6	0.92	13.0	1.8	2.9	2.9
67	34	1	6.5	1.0	70.9	220.1	1.04	6.0	1.8	3.2	2.9
68	34	2	9.4	0.6	72.2	246.8	1.04	5.2	1.5	1.9	3.9
69	35	1	5.4	4.4	78.0	225.7	0.69	18.4	2.0	3.2	3.8
70	35	2	7.6	2.7	79.2	231.7	0.89	12.5	1.7	2.6	4.0
71	36	1	6.2	2.4	71.9	213.9	0.78	37.5	2.2	3.1	3.7
72	36	2	7.6	2.0	75.3	217.6	0.91	10.9	2.0	3.0	3.9
73	37	1	5.8	2.7	72.3	203.0	0.99	27.0	2.0	3.2	2.7
74	37	2	6.1	2.2	75.4	238.4	0.90	17.1	2.0	3.0	3.8
75	38	1	7.0	0.9	72.9	245.2	0.99	20.7	2.0	3.6	4.1
76	38	2	6.8	1.7	77.7	254.0	0.80	9.4	1.7	2.3	4.3
77	39	1	5.9	1.5	70.2	205.3	0.90	13.2	1.8	3.0	2.5
78	39	2	6.4	3.5	74.9	184.0	0.93	20.8	2.0	3.0	2.7
79	40	1	5.1	1.4	71.6	218.6	0.96	27.2	2.0	3.1	3.6
80	40	2	6.3	1.2	76.5	231.8	0.86	18.3	1.8	2.7	3.8
81	41	1	6.7	0.9	74.0	252.8	1.09	21.9	1.5	2.5	4.2
82	41	2	9.7	1.1	78.6	241.5	1.04	5.9	1.8	2.2	4.0
83	42	1	6.9	2.8	76.5	239.2	0.76	21.2	2.0	2.7	4.3
84	42	2	5.0	1.8	81.8	222.1	0.83	22.5	1.7	2.9	4.1
85	43	1	4.4	3.3	72.4	205.4	0.88	23.1	1.8	3.7	2.9
86	43	2	3.4	3.4	74.4	196.6	0.82	28.2	1.6	3.8	3.0
87	44	1	5.2	1.7	71.1	241.9	0.88	9.0	1.7	3.4	3.5
88	44	2	6.4	1.2	72.3	246.4	0.92	9.0	1.7	3.2	4.0
89	45	1	7.1	1.1	76.3	253.0	1.04	22.4	1.4	3.3	4.1
90	45	2	7.0	2.1	82.6	238.5	1.07	13.0	1.4	2.7	3.5
91	46	1	7.1	5.5	77.5	233.6	0.92	9.1	1.8	3.4	3.4
92	46	2	4.4	5.3	82.1	229.8	0.77	30.1	1.7	3.5	3.5
classical commercial hybrid checks											
93	WH403	.	7.6	2.1	77.3	238.8	0.92	17.9	1.5	2.6	3.5
94	H513	.	4.2	4.2	75.3	207.9	0.90	25.4	1.5	3.3	3.5
95	DUMA43	.	3.7	1.7	68.4	232.3	0.89	34.5	1.5	3.5	3.1
96	DK8031	.	4.5	3.4	73.5	221.7	0.85	22.5	2.0	3.9	3.7
Trial mean			**5.9**	**1.9**	**68.8**	**221.4**	**0.90**	**18.7**	**1.8**	**3.1**	**3.4**
Max			**9.71**	**5.5**	**82.6**	**262.7**	**1.09**	**92.1**	**2.2**	**4.0**	**4.3**
Min			**3.38**	**-0.9**	**66.8**	**174.4**	**0.60**	**3.8**	**1.4**	**1.9**	**2.3**
CV			**16.37**	**60.5**	**2.2**	**6.1**	**10.79**	**71.2**	**13.9**	**13.0**	**12.5**
LSD (0.05)			**1.54**	**2.0**	**2.8**	**24.7**	**0.18**	**25.9**	**0.5**	**0.8**	**0.8**

Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum blight

Appendix 4. 9: **Mean for traits of DH hybrids evaluated at Bulindi under optimal conditions**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	EPP #	ER %	ASI day	DTS day	PH cm	ET 1-5	PA 1-5
1	1	1	3.5	1.1	0.0	0.6	68.4	154.6	4.7	3.5
2	1	2	5.1	1.0	0.0	2.1	69.1	215.5	4.1	3.2
3	2	1	4.6	0.9	0.0	-0.2	66.2	195.4	4.7	2.9
4	2	2	5.4	1.1	0.0	0.3	69.3	182.8	3.7	3.2
5	3	1	2.9	0.9	0.0	1.1	66.8	207.6	4.9	3.8
6	3	2	3.8	1.0	0.0	0.9	69.6	182.7	5.0	3.3
7	4	1	3.8	1.0	0.0	0.5	61.8	185.6	4.5	2.9
8	4	2	2.8	1.0	0.0	-0.9	65.8	181.3	4.4	3.3
9	5	1	5.4	1.1	1.5	0.4	64.2	196.8	3.0	2.4
10	5	2	6.9	1.0	1.5	1.1	66.6	215.3	3.6	2.9
11	6	1	3.8	0.9	0.0	0.6	66.0	159.9	4.1	3.3
12	6	2	3.5	1.1	0.0	1.3	66.2	192.7	4.4	3.5
13	7	1	3.2	1.0	0.0	1.0	63.2	173.2	4.1	4.0
14	7	2	3.2	1.0	1.5	1.0	67.3	159.2	4.9	4.3
15	8	1	3.6	1.0	0.0	3.0	65.6	185.0	4.5	3.5
16	8	2	2.8	0.8	0.0	0.3	66.0	176.8	5.0	3.7
17	9	1	2.8	1.0	0.0	1.3	65.2	193.8	4.5	3.4
18	9	2	3.2	1.2	0.0	2.3	66.8	166.8	4.9	4.0
19	10	1	5.0	0.9	0.0	0.0	66.8	186.8	3.7	2.9
20	10	2	3.3	1.2	0.0	0.6	66.9	183.1	5.0	3.5
21	11	1	2.1	1.1	0.0	-0.3	62.6	175.4	4.9	5.0
22	11	2	3.1	1.1	0.0	1.1	66.9	179.7	4.9	4.0
23	12	1	5.2	1.2	0.0	1.5	66.1	210.9	3.9	3.4
24	12	2	3.3	1.0	1.5	0.5	65.2	175.2	3.4	2.8
25	13	1	1.6	0.9	0.0	0.7	64.9	164.3	5.0	5.0
26	13	2	4.0	1.0	0.0	0.4	65.1	190.9	5.1	3.6
27	14	1	2.2	0.9	0.0	0.4	65.6	188.8	5.2	4.5
28	14	2	4.4	1.0	0.0	0.6	64.5	204.0	4.5	3.4
29	15	1	2.1	0.9	0.0	0.5	62.2	197.3	5.0	4.7
30	15	2	4.0	1.0	0.0	0.8	65.3	199.8	5.1	3.6
31	16	1	2.5	1.0	0.0	1.4	70.9	176.8	4.9	3.5
32	16	2	4.5	1.0	2.5	1.1	69.7	208.6	4.0	3.0
33	17	1	4.4	1.1	0.0	-0.4	65.3	211.9	4.3	3.5
34	17	2	3.2	0.9	2.5	-0.5	65.7	203.2	4.0	3.5
35	18	1	3.3	1.1	2.0	0.8	66.6	210.0	4.9	3.5
36	18	2	2.9	1.0	0.0	2.4	67.8	176.5	4.2	3.7
37	19	1	3.8	1.1	0.0	0.5	67.1	175.1	4.8	3.5
38	19	2	4.1	1.2	0.0	0.1	69.2	192.7	4.6	3.1
39	20	1	2.9	0.9	0.0	0.2	65.7	190.3	5.2	3.7
40	20	2	2.9	1.1	0.0	6.0	69.4	220.9	5.1	3.6
41	21	1	4.4	0.9	0.0	0.5	67.3	181.7	4.8	3.5
42	21	2	4.4	1.2	0.0	-0.1	69.4	160.2	4.5	3.9
43	22	1	2.4	1.0	0.0	0.7	61.8	191.9	5.1	4.2
44	22	2	3.5	1.0	0.0	0.5	64.2	172.9	4.9	3.9
45	23	1	1.7	1.1	0.0	2.1	64.8	173.0	5.1	5.0
46	23	2	3.4	1.1	0.0	0.1	65.1	202.5	4.8	3.3
47	24	1	2.1	0.8	0.0	2.3	66.6	189.8	4.9	4.1
48	24	2	4.6	1.0	0.0	1.1	66.5	213.5	4.9	3.4
49	25	1	4.9	1.1	0.0	0.1	65.8	185.3	3.4	3.2
50	25	2	3.1	0.9	0.0	2.1	69.9	170.3	4.6	3.4
51	26	1	2.9	1.1	0.0	0.8	61.7	171.8	5.2	3.7

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum leaf blight

Appendix 4. 9 continued: **Mean for traits of DH hybrids evaluated at Bulindi under optimal conditions**

Entry No.	Line No.	Tester No.	GY t ha^{-1}	EPP #	ER %	ASI day	DTS day	PH cm	ET 1-5	PA 1-5
52	26	2	2.9	1.1	0.0	0.5	66.5	183.5	4.1	3.4
53	27	1	3.4	1.0	0.0	1.2	66.0	187.1	4.7	3.4
54	27	2	5.1	1.1	0.0	1.6	67.6	193.4	4.3	3.5
55	28	1	5.9	1.1	0.0	0.8	66.9	216.0	3.9	2.7
56	28	2	4.0	1.0	0.0	0.0	71.0	221.7	3.5	3.0
57	29	1	4.4	0.9	0.0	1.0	68.9	176.0	2.7	3.0
58	29	2	6.3	1.0	1.5	0.8	69.7	194.0	3.8	2.9
59	30	1	4.1	1.2	3.0	0.6	64.4	170.3	4.2	3.4
60	30	2	3.8	1.1	0.0	0.5	66.4	215.7	4.5	3.1
61	31	1	3.4	0.9	0.0	1.5	64.1	175.1	5.1	3.8
62	31	2	3.3	0.9	0.0	1.0	64.2	175.4	3.7	3.0
63	32	1	3.5	1.1	0.0	2.3	68.2	179.0	5.1	4.0
64	32	2	5.6	1.1	0.0	1.1	68.7	186.7	4.4	3.1
65	33	1	4.0	1.0	1.5	0.1	64.3	137.4	4.9	3.7
66	33	2	4.6	1.1	0.0	0.0	64.2	187.0	3.6	3.1
67	34	1	4.1	1.1	0.0	1.0	65.6	177.4	4.4	3.6
68	34	2	5.1	1.1	0.0	-0.6	69.6	203.0	2.8	3.0
69	35	1	4.5	0.9	0.0	0.2	68.7	188.9	4.2	2.9
70	35	2	4.5	1.0	0.0	3.0	70.0	190.7	3.8	3.0
71	36	1	6.7	1.1	0.0	1.6	67.0	195.0	3.0	2.7
72	36	2	3.2	1.0	0.0	1.1	71.3	196.7	4.4	3.3
73	37	1	5.1	1.0	0.0	1.0	67.8	173.6	3.8	2.8
74	37	2	3.9	1.1	0.0	0.9	66.7	187.7	4.3	3.1
75	38	1	3.8	0.9	0.0	0.2	66.5	207.1	4.5	2.7
76	38	2	5.1	1.0	0.0	0.6	70.3	210.8	4.7	4.1
77	39	1	5.4	1.0	0.0	1.0	67.1	168.7	3.2	2.9
78	39	2	4.3	0.9	0.0	1.2	69.0	178.3	3.9	3.1
79	40	1	2.8	1.0	2.0	1.5	67.9	180.7	5.1	3.9
80	40	2	5.1	1.0	0.0	1.7	70.8	204.1	3.9	3.1
81	41	1	4.7	1.0	1.5	1.1	69.8	206.5	2.6	3.0
82	41	2	5.7	1.2	1.5	0.1	66.6	230.4	3.7	3.1
83	42	1	3.1	1.0	0.0	1.1	72.3	176.7	4.4	3.5
84	42	2	3.5	0.8	2.0	1.6	69.3	198.6	4.6	3.3
85	43	1	3.5	1.0	0.0	0.5	62.1	174.2	5.0	4.2
86	43	2	2.7	1.1	0.0	1.3	64.5	187.0	5.1	3.5
87	44	1	2.7	0.9	0.0	1.7	63.5	194.6	5.0	4.4
88	44	2	3.3	1.2	0.0	1.1	65.0	187.9	5.0	4.2
89	45	1	6.3	1.1	0.0	0.5	68.5	216.9	3.7	2.9
90	45	2	3.1	1.0	0.0	0.3	69.3	196.6	4.9	4.2
91	46	1	6.4	1.0	0.0	1.6	69.0	215.6	2.7	2.6
92	46	2	3.0	1.4	0.0	1.0	71.7	192.9	3.2	3.4
classical commercial hybrid checks										
93	WH403	.	4.9	0.9	0.0	1.0	69.1	199.0	4.8	3.7
94	H513	.	4.5	1.0	1.5	0.0	68.8	210.9	3.6	3.3
95	DUMA43	.	6.3	1.1	0.0	1.0	61.0	209.4	2.7	2.9
96	DK8031	.	4.9	1.1	0.0	0.0	62.5	199.3	2.7	2.9
Trial Mean			**3.9**	**1.0**	**0.3**	**0.9**	**66.8**	**189.1**	**4.4**	**3.5**
Min			**1.6**	**0.8**	**0.0**	**-0.9**	**61.0**	**137.4**	**2.6**	**2.4**
Max			**6.9**	**1.4**	**3.0**	**6.0**	**72.3**	**230.4**	**5.2**	**5.0**
LSD (0.05)			**2.0**	**0.3**	**1.9**	**2.4**	**3.1**	**39.7**	**1.4**	**0.9**
CV			**26.1**	**14.3**	**337.1**	**131.3**	**2.3**	**10.5**	**15.9**	**12.5**

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum leaf blight

Appendix 4. 10: **Mean for traits of DH hybrids evaluated at Arusha under optimal conditions**

Entry No.	**Line No.**	**Tester No.**	**GY** t ha^{-1}	**DTS** day	**ASI** day	**PH** cm	**EPP** #	**ET** 1-5	**EA** 1-5	**PA** 1-5
1	1	1	5.0	76.8	4.0	182.3	0.9	2.5	2.8	2.1
2	1	2	4.9	79.4	3.5	178.6	1.0	2.7	2.7	2.4
3	2	1	5.2	74.9	3.5	164.0	1.0	3.0	2.2	2.4
4	2	2	4.4	79.0	3.0	162.8	0.9	3.2	1.5	2.3
5	3	1	4.4	75.4	3.0	187.8	1.0	2.9	1.7	2.1
6	3	2	4.6	78.5	3.5	196.6	1.0	3.0	1.5	2.5
7	4	1	5.7	70.0	3.0	174.4	1.0	3.5	1.8	2.0
8	4	2	5.1	71.4	2.9	171.0	1.0	3.8	2.0	2.0
9	5	1	4.4	73.7	3.0	175.3	1.1	3.2	2.8	2.0
10	5	2	3.7	76.7	3.5	154.8	0.9	3.3	2.8	2.2
11	6	1	4.9	70.5	3.0	173.8	1.0	3.0	2.7	1.9
12	6	2	6.3	73.5	4.0	180.5	1.0	3.1	1.3	2.3
13	7	1	6.9	71.5	3.0	176.1	1.0	3.2	2.0	2.0
14	7	2	4.9	72.5	3.0	191.4	1.1	3.2	2.2	1.9
15	8	1	5.6	69.4	3.0	168.8	1.0	3.2	2.2	2.4
16	8	2	4.1	73.3	3.5	170.2	0.9	3.2	3.3	2.4
17	9	1	5.8	70.6	3.0	186.6	1.0	3.3	2.2	2.0
18	9	2	4.7	74.4	3.5	189.5	1.0	3.0	2.2	2.0
19	10	1	5.8	73.0	3.0	208.1	1.0	3.0	1.8	2.3
20	10	2	5.6	71.9	3.6	175.3	1.0	2.9	1.7	1.9
21	11	1	4.5	70.4	3.0	169.9	1.0	3.4	2.7	2.6
22	11	2	5.3	71.5	2.0	176.0	1.0	3.1	1.7	2.0
23	12	1	4.4	72.4	3.5	174.9	1.0	3.2	2.3	2.6
24	12	2	3.6	73.3	4.0	179.5	1.0	3.4	3.2	2.4
25	13	1	4.7	75.4	3.5	142.6	1.0	2.9	2.2	3.0
26	13	2	3.4	74.3	1.5	182.6	1.1	3.0	2.8	2.7
27	14	1	5.3	71.2	3.0	163.4	1.0	3.4	2.8	2.3
28	14	2	4.6	74.6	3.0	164.0	1.0	3.1	3.2	2.7
29	15	1	4.6	71.1	3.1	173.8	1.0	3.6	2.7	2.4
30	15	2	4.2	72.0	2.9	186.0	1.2	3.2	1.5	2.3
31	16	1	4.1	76.4	3.0	172.3	1.0	3.3	2.7	2.0
32	16	2	6.0	74.4	3.5	175.2	1.0	2.8	1.2	2.1
33	17	1	5.0	71.7	3.5	157.5	1.0	3.4	2.5	2.7
34	17	2	3.8	72.5	3.0	176.7	1.2	3.4	3.2	2.9
35	18	1	5.1	74.0	3.0	173.1	1.0	3.3	1.8	2.3
36	18	2	4.3	75.1	2.5	169.6	1.0	3.3	2.5	2.7
37	19	1	6.0	74.8	3.0	178.3	1.0	2.8	1.5	2.1
38	19	2	4.6	78.5	3.1	165.5	1.0	3.1	2.2	3.3
39	20	1	5.2	72.4	3.0	198.0	0.8	3.3	1.8	2.1
40	20	2	4.4	72.6	3.0	155.6	1.0	3.3	2.3	2.5
41	21	1	2.8	79.6	3.5	153.1	1.0	2.3	3.0	3.2
42	21	2	5.1	74.3	3.0	175.7	1.0	2.3	1.8	2.3
43	22	1	4.7	70.1	2.9	162.4	1.0	3.5	2.5	2.5
44	22	2	4.8	73.1	-2.0	166.4	1.0	3.0	2.5	2.7
45	23	1	3.7	70.6	3.0	153.2	1.0	3.2	2.3	2.3
46	23	2	4.4	72.8	3.0	186.1	1.0	3.8	2.3	2.6
47	24	1	5.5	75.5	3.6	176.1	1.0	3.0	1.5	2.3
48	24	2	5.0	74.6	3.4	196.4	1.0	3.0	1.7	2.2
49	25	1	5.6	71.4	3.5	171.6	1.0	3.2	1.2	2.3
50	25	2	4.7	76.2	3.0	171.0	0.9	2.7	2.0	2.2
51	26	1	5.6	71.5	3.0	175.5	0.9	3.5	2.8	2.3

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum leaf blight

Appendix 4. 10 continued: **Mean for traits of DH hybrids evaluated at Arusha under optimal conditions**

Entry No.	Line No.	Tester No.	GY $t\ ha^{-1}$	DTS day	ASI day	PH cm	EPP #	ET 1-5	EA 1-5	PA 1-5
52	26	2	6.6	72.4	3.0	183.2	1.0	3.3	2.0	2.4
53	27	1	4.2	71.8	3.5	164.1	1.0	3.4	2.7	2.7
54	27	2	4.1	73.9	4.0	160.1	0.9	3.3	2.3	2.0
55	28	1	4.7	74.1	3.5	169.1	1.0	2.3	2.0	2.0
56	28	2	5.6	79.4	3.5	175.2	1.0	2.2	1.2	2.3
57	29	1	5.5	77.5	3.0	168.1	1.0	2.3	1.8	2.1
58	29	2	5.5	76.3	2.5	175.6	1.0	2.2	1.5	1.8
59	30	1	4.9	72.6	5.0	173.3	1.0	2.8	2.3	2.1
60	30	2	5.0	70.9	3.0	157.6	0.8	3.5	2.3	2.3
61	31	1	4.2	73.7	3.0	160.4	1.0	3.2	1.8	2.5
62	31	2	4.6	71.2	3.0	181.9	1.2	3.3	2.0	2.3
63	32	1	5.1	72.0	4.0	162.0	1.1	3.2	1.5	2.9
64	32	2	4.6	74.9	3.0	146.8	1.0	2.5	2.0	2.0
65	33	1	4.1	71.9	3.0	153.9	1.0	3.0	2.5	2.7
66	33	2	4.0	74.0	3.1	169.5	1.0	3.5	2.5	2.2
67	34	1	5.3	75.8	3.5	183.5	1.0	3.0	2.0	2.0
68	34	2	5.9	76.2	3.0	192.7	1.0	2.8	1.5	2.3
69	35	1	5.0	78.5	3.0	205.0	0.9	2.8	1.8	2.0
70	35	2	3.6	80.8	3.5	174.5	1.0	2.8	2.8	2.0
71	36	1	5.3	76.1	2.5	180.0	0.9	2.7	1.5	2.1
72	36	2	3.0	76.1	2.5	159.2	1.0	3.0	3.5	3.0
73	37	1	4.3	75.2	3.0	178.7	1.0	2.8	1.8	2.1
74	37	2	4.1	79.5	2.0	200.1	1.1	2.8	2.5	2.6
75	38	1	4.1	76.5	3.0	169.9	1.2	2.7	2.5	1.9
76	38	2	4.6	80.2	3.5	167.8	1.1	2.6	2.3	2.1
77	39	1	6.0	71.2	3.0	181.2	1.0	2.7	2.3	2.1
78	39	2	3.7	74.3	3.1	165.6	1.0	2.8	2.3	2.2
79	40	1	4.3	76.3	3.0	179.2	1.0	2.5	2.3	2.0
80	40	2	6.0	77.8	4.0	157.7	1.0	3.0	2.3	2.4
81	41	1	3.9	77.3	4.0	138.8	0.9	3.0	2.7	2.4
82	41	2	4.1	80.8	2.5	175.7	1.1	2.0	2.3	2.3
83	42	1	4.8	79.5	3.0	194.7	1.0	2.8	1.5	2.2
84	42	2	3.2	80.7	3.0	181.2	0.8	2.1	3.5	2.4
85	43	1	3.5	71.1	2.9	193.4	1.2	3.5	2.7	2.2
86	43	2	4.2	70.8	1.5	179.1	1.0	3.5	3.0	2.5
87	44	1	4.1	73.0	3.0	178.2	1.0	3.5	3.0	2.8
88	44	2	5.8	74.9	3.6	204.0	1.0	3.0	2.0	2.5
89	45	1	4.3	75.5	3.5	188.9	1.0	2.7	2.5	2.2
90	45	2	4.2	79.3	2.6	178.9	1.0	2.5	2.0	1.9
91	46	1	4.2	76.2	3.5	183.3	1.2	2.9	2.0	2.2
92	46	2	3.2	80.1	3.5	167.7	1.4	2.8	2.8	2.5
Commercial classical hybrids checks										
93	WH403		4.0	79.9	3.9	176.1	1.2	2.7	2.0	2.5
94	H513		4.4	75.4	3.5	182.3	0.9	3.1	2.2	2.4
95	DUMA43		4.2	72.8	3.5	182.7	1.0	3.0	2.3	2.3
96	DK8031		2.7	75.8	4.9	165.7	1.3	3.4	2.2	2.7
Trial mean			**4.7**	**74.5**	**3.1**	**174.5**	**1.0**	**3.0**	**2.2**	**2.3**
Min			**2.8**	**69.4**	**2.0**	**138.8**	**0.8**	**2.0**	**1.2**	**1.8**
Max			**6.9**	**80.8**	**5.0**	**208.1**	**1.4**	**3.8**	**3.5**	**3.3**
LSD (0.05)			**1.9**	**3.9**	**2.0**	**36.7**	**0.2**	**0.7**	**1.2**	**0.8**
CV			**20.2**	**2.6**	**31.4**	**10.5**	**12.2**	**11.8**	**27.9**	**16.5**

† Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect; ET=turcicum leaf blight

Appendix 4. 11: **Mean yields of DH hybrids and classical hybrid checks evaluated at 7 locations**

Entry No.	LxT	KB-MDS	Entry No.	LxT	KIB-LNS	Entry No.	LxT	SHK-OPT	Entry No.	LxT	KK-OPT	Entry No.	LxT	BUL-OPT	Entry No.	LxT	EBU-OPT	Entry No.	LxT	ARU-OPT
Ten top yielding DH hybrids																				
19	10x1	4.6	35	18X1	4.0	13	7x1	7.9	81	41x1	10.0	10	5x2	6.9	82	41x2	9.7	13	7X1	6.9
25	13x1	3.7	27	14X1	3.9	77	39x1	7.7	13	7x1	9.5	71	36x1	6.7	68	34x2	9.4	52	26X2	6.6
58	29x2	3.7	26	13X2	3.9	69	35x1	7.4	89	45x1	9.5	91	46x1	6.4	6	3x2	9.0	12	6X2	6.3
29	15x1	3.5	30	15X2	3.8	81	41x1	7.4	14	7x2	9.4	58	29x2	6.3	33	17x1	7.7	37	19X1	6.0
30	15x2	3.4	57	29X1	3.7	71	36x1	7.3	74	37x2	9.1	89	45x1	6.3	2	1x2	7.7	77	39X1	6.0
54	27x2	3.4	33	17X1	3.7	2	1x2	6.8	49	25x1	9.0	55	28x1	5.9	70	35x2	7.6	32	16X2	6.0
20	10x2	3.2	62	31X2	3.7	14	7x2	6.6	78	39x2	8.8	82	41x2	5.7	72	36x2	7.6	80	40X2	6.0
55	28x1	3.2	45	23X1	3.6	3	2x1	6.5	77	39x1	8.7	64	32x2	5.6	5	3x1	7.5	68	34X2	5.9
44	22x2	3.1	16	8X2	3.5	67	34x1	6.3	68	34x2	8.7	4	2x2	5.4	54	27x2	7.5	17	9X1	5.8
52	26x2	3.1	23	12X1	3.4	58	29x2	6.3	83	42x1	8.6	77	39x1	5.4	53	27x1	7.4	88	44X2	5.8
Ten mid yielding DH hybrids																				
75	38x1	2.2	39.0	20X1	2.9	53	27x1	4.4	87	44X1	5.7	6	3X2	3.8	74	37X2	6.1	55	28x1	4.7
80	40x2	2.1	44.0	22X2	2.9	87	44x1	4.3	6	3X2	5.7	75	38X1	3.8	13	7X1	6.1	43	22x1	4.7
60	30x2	2.1	83.0	42X1	2.8	34	17x2	4.2	57	29X1	5.7	60	30X2	3.8	39	20X1	6.1	18	9x2	4.7
17	9x1	2.1	65.0	33X1	2.8	10	5x2	4.2	16	8X2	5.7	11	6X1	3.8	10	5X2	6.0	50	25x2	4.7
62	31x2	2.1	71.0	36X1	2.8	64	32x2	4.2	34	17X2	5.6	37	19X1	3.8	21	11X1	6.0	25	13x1	4.7
81	41x1	2.1	59.0	30X1	2.8	54	27x2	4.2	41	21X1	5.4	7	4X1	3.8	77	39X1	5.9	6	3x2	4.6
1	1x1	2.0	88.0	44X2	2.8	32	16x2	4.2	37	19X1	5.4	15	8X1	3.6	58	29X2	5.9	29	15x1	4.6
79	40x1	2.0	34.0	17X2	2.8	23	12x1	4.1	84	42X1	5.4	44	22X2	3.5	3	2X1	5.9	38	19x2	4.6
82	41x2	2.0	2.0	1X2	2.7	66	33x2	4.1	23	12X1	5.4	63	32X1	3.5	41	21X1	5.8	64	32x2	4.6
86	43x2	2.0	13.0	7X1	2.7	20	10x2	3.9	92	46X2	5.3	84	42X2	3.5	26	13X2	5.8	28	14x2	4.6
Ten least yielding DH hybrids																				
31	16x1	1.1	9	5X1	2.0	46	23x2	2.2	86	43x2	3.8	86	43x2	2.7	12	6x2	4.5	10	5x2	3.7
6	3x2	1.0	52	26X2	1.8	30	15x2	2.1	47	24x1	3.7	87	44x1	2.7	92	46x2	4.4	78	39x2	3.7
90	45x2	1.0	86	43X2	1.6	44	22x2	2.1	30	15x2	3.6	31	16x1	2.5	85	43x1	4.4	24	12x2	3.6
65	33x1	1.0	40	20X2	1.6	85	43x1	2.1	51	26x1	3.3	43	22x1	2.4	24	12x2	4.4	70	35x2	3.6
89	45x1	0.7	25	13X1	1.5	35	18x1	2.0	60	30x2	3.3	27	14x1	2.2	17	9x1	4.3	85	43x1	3.5
87	44x1	0.7	89	45X1	1.5	86	43x2	1.8	45	23x1	3.2	21	11x1	2.1	66	33x2	4.0	26	13x2	3.4
10	5x2	0.6	50	25X2	1.3	29	15x1	1.2	29	15x1	3.0	29	15x1	2.1	62	31x2	3.9	84	42x2	3.2
91	46x1	0.5	38	19X2	1.3	26	13x2	1.1	8	4x2	3.0	47	24x1	2.1	8	4x2	3.8	92	46x2	3.2
69	35x1	0.4	84	42X2	1.1	45	23x1	0.7	52	26x2	2.9	45	23x1	1.7	16	8x2	3.8	72	36x2	3.0
92	46x2	0.3	21	11X1	1.0	25	13x1	0.6	25	13x1	2.1	25	13x1	1.6	86	43x2	3.4	41	21x1	2.8
Commercial classical hybrids checks																				
93	WH403	1.2	93		1.8	93		7.2	93		7.7	93		4.9	93		7.6	93		4.0
94	H513	1.8	94		1.9	94		5.3	94		5.3	94		4.5	94		4.2	94		4.4
95	DUMA43	0.9	95		2.2	95		4.9	95		5.9	95		6.3	95		3.7	95		4.2
96	DK8031	1.5	96		3.4	96		4.7	96		6.9	96		4.9	96		4.5	96		2.7
Trial mean		**2.0**			**2.7**			**3.7**			**5.4**			**3.9**			**6.0**			**4.7**
Top 10		**3.5**			**3.7**			**7.0**			**9.1**			**6.1**			**8.1**			**6.2**
Mid 10		**2.1**			**2.8**			**4.2**			**5.5**			**3.7**			**6.0**			**4.7**
Bottom 10		**0.7**			**1.5**			**1.6**			**3.2**			**2.2**			**4.1**			**3.4**
LSD (0.05)		**1.2**			**1.6**			**2.0**			**1.5**			**2.0**			**1.5**			**1.9**
% CV		**29.4**			**30.2**			**23.9**			**13.3**			**26.1**			**16.4**			**20.2**

TC=hybrids; MDS= managed drought stress, LNS=low nitrogen stress; RD=random drought stress; OPT=optimal conditions; KIB= Kiboko; KK=Kakamega; SHK=Shikusa; ARU=Arusha; EBU=Embu

Appendix 4. 12: **GCA effects of 46 DH lines evaluated under optimal conditions at Arusha**

Line No.	GY (t ha^{-1})	EPP (#)	EA (1-5)	ASI (d)	DTS (d)	PH (cm)	ER (%)	ET (1-5)	PA(1-5)
1	0.25	-0.04	0.77*	0.66	3.49***	4.22	0.23	-0.36	-0.62
2	0.08	-0.06	0.64*	0.16	2.74**	-12.03	-0.67	0.11	-0.52
3	-0.20	-0.01	0.52	0.16	2.49*	14.22	0.73	-0.01	-1.22
4	0.70	-0.01	0.52	-0.09	-4.01***	-2.03	1.75	0.61**	0.3
5	-0.70	-0.04	0.27	0.16	0.49	-9.53	-0.67	0.24	0.6
6	0.90	-0.04	0.02	0.41	-2.01*	1.72	-0.67	-0.01	-0.9
7	1.2*	0.04	-0.11	-0.09	-2.26*	7.97	-0.67	0.24	-0.27
8	0.08	-0.09	-0.11	0.16	-2.51*	-5.78	0.15	0.24	-0.92
9	0.53	-0.01	-0.23	0.16	-2.26*	12.97	-0.67	0.11	-1.4*
10	0.98*	-0.01	-0.36	0.16	-2.26*	17.97	-0.67	-0.01	-0.95
11	0.18	-0.01	-0.48	-0.59	-3.76***	-3.28	-0.67	0.24	-0.15
12	-0.72	-0.01	0.27	0.66	-1.51	-0.78	-0.67	0.36*	1.38*
13	-0.70	0.04	0.27	-0.59	0.74	-14.53	2.35	-0.14	0.98
14	0.20	-0.01	0.14	-0.09	-1.51	-10.78	-0.67	0.24	1.68*
15	-0.30	0.09	0.14	-0.09	-3.01**	4.22	-0.02	0.36*	-0.15
16	0.33	0.01	0.02	0.16	1.24	0.47	0.13	-0.01	-0.05
17	-0.35	0.06	-0.23	0.16	-2.01*	-10.78	-0.67	0.49**	0.65
18	-0.02	0.01	-0.36	-0.34	-0.26	-3.78	0.08	0.24	-0.07
19	0.63	0.01	-0.61	-0.09	1.99	-0.78	-0.67	-0.14	-0.17
20	0.10	-0.09	-0.61	-0.09	-2.51*	1.72	0.25	0.24	-0.02
21	-0.75	-0.01	-0.61	0.16	2.24*	-9.53	0.05	-0.76***	0.35
22	0.00	-0.01	-0.61	-2.59***	-3.26**	-8.28	-0.67	0.24	-0.2
23	-0.67	-0.01	0.27	-0.09	-2.76**	-3.28	1.25	0.49**	4.33***
24	0.55	-0.01	0.27	0.41	-0.26	12.97	-0.67	-0.01	-0.6
25	0.45	-0.06	0.14	0.16	-0.76	-2.03	0.1	-0.01	-0.3
26	1.35**	-0.04	0.02	-0.09	-3.51***	2.97	-0.67	0.36*	0.43
27	-0.62	-0.06	0.02	0.66	-1.26	-10.78	-0.67	0.36*	-0.5
28	0.48	0.01	0.02	0.41	2.74**	1.72	-0.67	-0.76***	-1.5*
29	0.75	-0.01	-0.11	-0.34	2.49*	-3.28	-0.67	-0.76***	-1.55*
30	0.23	-0.11	-0.36	0.91	-2.76**	-5.78	-0.67	0.11	-0.17
31	-0.30	0.14*	-0.48	-0.09	-2.26*	-3.28	-0.67	0.24	0.65
32	0.13	0.04	-0.48	0.41	-1.76	-18.28	-0.67	-0.14	-0.72
33	-0.70	-0.01	-0.61	-0.09	-1.51	-9.53	-0.67	0.24	0.58
34	0.85	-0.01	0.64*	0.16	1.49	14.22	-0.67	-0.14	-1.45*
35	-0.45	-0.04	0.27	0.16	5.49***	15.47	-0.67	-0.26	0.48
36	-0.60	-0.04	0.27	-0.59	1.49	-4.53	0.33	-0.14	0.3
37	-0.52	0.04	0.27	-0.59	2.99**	14.22	-0.67	-0.26	0.18
38	-0.37	0.11	0.14	0.16	4.24***	-4.53	0.95	-0.39*	-0.07
39	0.15	-0.01	0.02	-0.09	-1.76	2.97	-0.67	-0.26	-0.35
40	0.43	0.01	0.02	0.41	2.49*	-4.53	1.53	-0.26	-0.27
41	-0.70	-0.04	-0.36	0.16	4.99***	-17.03	0.23	-0.51**	-0.57
42	-0.67	-0.11	0.52	-0.09	5.99***	10.47	-0.67	-0.51**	-0.07
43	-0.87	0.09	-0.23	-0.84	-3.51***	10.47	0.53	0.49**	1.15
44	0.25	-0.01	-0.11	0.16	-0.76	20.47*	0.08	0.24	0.68
45	-0.47	-0.01	0.52	-0.09	2.74**	7.97	5.85***	-0.39*	0.05
46	-1.02*	0.28***	0.02	0.41	3.49***	-0.78	1.0	-0.14	0.85

Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect.

Appendix 4. 13: **GCA effects of 46 DH lines evaluated under optimal conditions at Bulindi**

Line No.	GY (t ha^{-1})	EPP (#)	EA (1-5)	ASI (d)	DTS (d)	PH (cm)	ER (%)	ET (1-5)	PA(1-5)
1	0.44	0.05	0.00	0.33	2.70***	-2.55	-0.28	0.01	-0.1
2	0.94	-0.05	0.00	-0.67	0.95	-4.05	-0.28	-0.11	-0.35
3	-0.66	-0.07	0.00	0.08	1.95*	1.95	-0.28	0.64	0.15
4	-0.41	-0.05	0.00	-1.17	-3.55***	0.2	-0.28	0.14	-0.47*
5	1.96***	0.05	-0.38	-0.17	-1.55*	14.95	1.22*	-0.99**	-0.72**
6	-0.21	-0.05	-0.38	0.08	-0.8	-13.55	-0.28	-0.11	-0.1
7	-0.76	-0.02	-0.75***	0.08	-1.3	-20.8	0.49	0.14	0.65**
8	-0.51	-0.15*	0.5*	0.83	-1.55*	-5.55	-0.28	0.39	0.15
9	-1.14*	0.08	0.37	1.08	-0.8	-17.05	-0.28	0.39	0.28
10	0.14	0.03	0.37	-0.67	0.2	-3.3	-0.28	0.01	-0.22
11	-1.41**	0.03	0.37	-0.42	-1.8*	-14.55	-0.28	0.64	1.03***
12	0.21	0.08	0.25	0.08	-1.05	-1.55	0.57	-0.74*	-0.35
13	-1.01	-0.10	0.25	-0.17	-1.3	-8.55	-0.28	0.64	0.78***
14	-0.49	-0.10	-0.75***	-0.42	-1.3	12.45	-0.28	0.39	0.4
15	-0.89	-0.05	-0.75***	-0.42	-3.05***	10.7	-0.28	0.64	0.65**
16	-0.34	-0.05	-0.13	0.33	3.2***	3.95	1.04*	0.01	-0.22
17	-0.16	-0.05	0.00	-1.42*	-2.05**	13.45	0.84	-0.11	0.03
18	-0.89	0.00	0.37	0.83	0.2	2.7	0.64	0.26	0.15
19	0.14	0.08	0.37	-0.67	0.95	-0.55	-0.28	0.39	-0.1
20	-0.84	0.00	0.37	2.08**	0.7	19.7	-0.28	0.64	0.03
21	0.29	0.00	-0.38	-0.67	1.7*	-24.55*	-0.28	0.26	0.28
22	-0.86	0.00	0.12	-0.17	-3.8***	-2.8	-0.28	0.64	0.65**
23	-1.16*	0.05	0.25	0.08	-2.8***	2.95	-0.28	0.64	0.65**
24	-0.61	-0.15*	0.87***	0.83	-0.8	12.7	-0.28	0.64	0.15
25	0.19	-0.07	0.25	0.08	1.7*	-10.3	-0.28	-0.49	-0.1
26	-1.14*	0.05	0.5*	-0.17	-2.3**	-14.8	-0.28	0.14	0.15
27	0.29	0.00	-0.13	0.33	-0.55	-3.8	-0.28	0.26	0.03
28	1.01	0.03	0.37	-0.42	2.2**	26.7*	-0.28	-0.61	-0.6**
29	1.61**	-0.02	0.37	-0.17	2.2**	-1.3	0.54	-1.11**	-0.6**
30	0.06	0.15*	-0.13	-0.42	-1.3	2.45	1.17*	0.01	-0.1
31	-0.56	-0.10	-0.13	0.33	-2.3**	-12.55	-0.28	-0.11	-0.1
32	0.86	0.03	0.12	0.58	0.45	-2.8	-0.28	0.39	0.03
33	0.24	0.05	0.37	-0.92	-2.3**	-32.3**	0.44	-0.24	-0.1
34	0.69	0.10	0.5*	-0.67	1.2	-3.3	-0.28	-0.74*	-0.1
35	0.64	-0.07	0.12	0.83	2.70***	-3.55	-0.28	-0.36	-0.47*
36	1.21*	0.00	-0.13	0.33	1.95*	9.95	-0.28	-0.61	-0.47*
37	0.74	0.03	-0.13	0.08	1.2	-0.3	-0.28	-0.36	-0.6**
38	0.59	-0.07	-0.25	-0.42	1.95*	17.2	-0.28	0.14	-0.1
39	1.06*	-0.05	-0.38	0.08	0.95	-10.3	-0.28	-0.86*	-0.6**
40	0.21	-0.02	-0.75***	0.58	2.45**	9.7	0.79	0.14	-0.1
41	1.49**	0.13	0.12	-0.42	1.2	38.95***	1.17*	-1.11**	-0.47*
42	-0.66	-0.15*	0.00	0.33	3.45***	-3.8	0.67	0.26	-0.1
43	-0.91	0.05	-0.5*	0.08	-3.05***	-13.05	-0.28	0.64	0.4
44	-1.14*	0.05	-0.5*	0.33	-1.8*	-4.8	-0.28	0.64	0.9***
45	0.61	0.00	-0.38	-0.42	2.70***	14.2	-0.28	0.01	0.15
46	1.06*	0.23**	-0.25	0.33	2.45**	21.7*	-0.28	-1.36***	-0.6**

Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect.

Appendix 4. 14: **GCA effects of 46 DH lines evaluated under optimal conditions at Embu**

Line No.	GY (t ha^{-1})	EPP (#)	EA (1-5)	ASI (d)	DTS (d)	PH (cm)	ER (%)	ET(1-5)	PA(1-5)
1	-1.6*	-0.03	0.27	0.71	2.91***	4.76	-6.4	-0.02	0.12
2	-0.51	0.04	-0.73***	-0.29	1.41*	-18.87**	-5.27	0.11	-0.26
3	1.20	0.02	-0.23	2.46***	2.66***	10.76	-5.2	-0.02	0.37
4	1.10	-0.06	0.77***	0.21	-3.59***	-24.87***	6.95	0.23*	-0.76***
5	1.10	0.02	-0.48*	0.96	-2.09**	1.13	-6.87	0.11	-0.13
6	0.40	-0.01	0.02	-0.29	-1.84*	-9.99	8.78	0.23*	-0.26
7	0.60	-0.01	-0.48*	-1.79**	0.41	12.13	-2.87	-0.14	0.74***
8	-0.98	-0.03	0.4*	-0.04	-0.84	-17.24**	5.6	-0.02	-0.38
9	0.90	-0.21	0.4*	-0.54	-3.09***	-5.24	11.65**	-0.02	-0.38
10	0.04	-0.03	-0.10	-1.29*	-1.09	-7.99	-4.72	-0.02	-0.38
11	1.20	0.04	-0.23	-0.79	-3.34***	-15.24*	-11.52*	-0.27*	-0.26
12	1.40	-0.01	0.15	-0.29	-1.09	9.88	7.38	-0.27*	-0.13
13	1.00	-0.06	0.15	-0.04	0.16	28.51***	7.28	-0.14	0.49*
14	0.70	-0.06	0.02	-1.04	-2.09**	16.76**	6.18	-0.14	-0.13
15	0.24	-0.03	0.4*	-0.79	-2.59***	-9.74	4.0	-0.14	-0.38
16	-0.13	0.02	0.15	0.46	1.16	-5.74	1.7	-0.02	0.12
17	-1.18	0.07	0.15	-0.04	-1.09	24.63***	-0.05	0.11	0.49*
18	1.00	-0.03	0.27	-0.79	-0.84	-7.24	1.28	-0.14	-0.38
19	0.90	-0.01	0.02	-2.04***	-0.59	-9.99	-6.87	0.11	-0.13
20	0.50	-0.03	0.4*	-0.54	-2.09**	21.76***	-1.3	0.11	0.37
21	0.80	-0.01	0.02	-1.29*	1.41*	16.38*	3.2	-0.02	0.49*
22	0.90	0.02	0.27	0.21	-4.59***	-17.37**	-2.2	-0.14	-0.76***
23	-0.46	0.02	0.65***	0.71	-1.59*	-38.99***	0.3	-0.02	-0.63**
24	-0.56	-0.01	-0.10	2.46***	1.16	-10.49	4.65	0.11	-0.01
25	-0.11	0.04	-0.35	-0.04	-2.59***	-5.12	-7.77	-0.02	-0.01
26	-0.41	0.09	0.15	-0.29	-1.34	-17.74**	-0.67	-0.02	-0.38
27	-0.26	0.02	-0.6**	-1.29*	-3.09***	4.76	-6.45	0.11	-0.13
28	1.10	0.04	-0.48*	-0.79	3.41***	26.13***	-1.77	-0.14	0.74***
29	0.60	0.04	0.15	-1.04	-0.59	-5.37	-0.9	0.23*	-0.01
30	-0.28	0.04	0.15	1.46**	-0.59	1.13	6.8	0.11	-0.01
31	-0.81	0.04	0.15	0.21	-2.84***	-10.99	3.15	-0.27*	-0.38
32	-0.53	-0.06	0.02	0.96	0.66	-29.24***	-0.8	0.11	-0.88***
33	-2.1**	0.02	-0.35	-0.04	-3.09***	-4.24	-7.77	-0.02	-0.38
34	-0.88	0.14**	-0.6**	-0.79	-1.09	9.76	-12.82**	-0.14	-0.01
35	0.80	-0.08	-0.10	2.21***	6.41***	0.26	-1.6	0.11	0.37
36	0.02	-0.08	-0.10	-0.04	-0.09	-3.74	5.53	0.36**	0.49*
37	0.42	0.04	0.02	1.21*	1.66*	-2.12	4.03	0.23*	-0.13
38	0.29	-0.03	0.02	-0.79	1.91**	31.88***	-1.15	0.11	0.87***
39	-1.6*	0.02	-0.10	0.96	-0.34	-25.74***	-1.27	0.11	-0.76***
40	-1.26	0.02	-0.10	-0.54	0.91	7.76	5.88	0.11	0.49*
41	-2.1**	0.12*	-0.73***	-1.29*	2.66***	26.63***	-3.62	-0.14	0.74***
42	-0.08	-0.13	-0.35	0.21	6.16***	10.38	4.03	0.11	0.74***
43	-0.53	-0.06	0.65***	1.46**	0.91	-19.99**	8.55	-0.14	-0.38
44	0.70	0.04	0.15	-1.04	-1.84*	26.63***	-7.75	-0.02	0.62**
45	-0.26	0.14**	-0.10	-0.54	6.41***	24.63***	0.23	-0.27*	0.49*
46	-1.6*	-0.03	0.4*	3.71***	7.41***	6.76	0.45	-0.02	-0.01

Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect;

Appendix 4. 15: **GCA effects of 46 DH lines evaluated under optimal conditions at Shikusa**

Line No.	GY (t ha^{-1})	EPP (#)	EA (1-5)	ASI (d)	DTS (d)	PH (cm)	ER (%)	ET(1-5)	PA(1-5)
1	-0.25	0.08	0.22	0.55	-1.35	-2.4	-7.2	-0.21	0.00
2	0.29	0.08	0.09	0.05	0.65	0.22	-1.1	-0.08	-0.13
3	0.70	0.05	-0.41*	0.3	0.4	4.15	-6.35	-0.58***	-0.25
4	-0.06	0.05	0.09	1.3	-2.1	5.95	5.85	-0.08	0.13
5	0.24	0.03	0.09	0.8	-0.35	-3.58	5.85	-0.08	-0.13
6	1.20	-0.02	0.09	-0.2	1.65	-1.18	-4.9	0.04	0.13
7	-0.64	0.03	0.09	-0.2	-0.35	-1.8	-6.13	0.17	-0.38
8	0.60	0.00	0.09	0.05	-1.1	-3.55	-11.08	-0.08	0.38
9	-2.6**	-0.15	0.34	2.05*	-1.35	-0.63	6.47	0.29	0.38
10	-1.56	-0.17	0.34	0.05	-1.1	-3.6	-1.38	-0.21	-0.25
11	0.70	-0.02	-0.53*	0.3	-0.35	0.9	3.97	-0.08	0.00
12	0.39	-0.05	0.09	-0.45	0.9	7.12	-2.08	0.04	0.13
13	-1.36	-0.07	0.34	-0.2	-0.6	-2.98	0.55	-0.46**	0.13
14	-0.59	0.03	-0.16	1.55	-1.1	3.65	9.32	0.04	-0.25
15	1.00	0.03	-0.28	-0.45	2.65*	-1.8	-8.63	0.29	0.13
16	-0.41	-0.02	0.09	0.8	-1.1	7.15	9.72	0.04	-0.13
17	0.90	0.18*	-0.28	-0.7	2.9*	2.07	-4.95	0.04	-0.25
18	0.70	-0.05	-0.03	-1.2	1.15	-6.55	-13.65	0.17	0.13
19	-0.31	-0.17	0.09	-0.45	0.65	-1.8	1.12	0.17	0.00
20	-0.21	-0.10	0.09	-0.2	-0.85	-4.75	-3.88	-0.08	0.00
21	-0.66	0.03	0.09	0.8	-0.6	-2.25	-2.68	0.29	0.00
22	0.34	-0.07	-0.16	0.8	-1.6	3.55	5.45	0.17	0.00
23	-0.21	0.00	0.22	0.3	-1.85	-0.58	3.12	0.04	0.38
24	0.50	0.15	0.09	-0.2	1.15	11.3*	0.7	0.04	0.00
25	0.50	0.00	-0.16	0.3	0.4	2.35	-4.48	0.29	-0.13
26	1.40	0.10	-0.41*	0.55	-0.85	-1.18	-2.8	0.17	-0.25
27	0.90	0.18*	0.09	0.3	-1.35	-5.95	-0.08	-0.08	-0.13
28	0.29	0.00	0.09	-1.7*	2.4	8.35	5.75	-0.08	0.00
29	0.29	-0.05	-0.28	1.55	-0.6	-2.4	-6.48	-0.21	-0.13
30	-0.06	0.03	-0.16	-0.7	0.9	2.37	0.07	0.04	0.00
31	0.70	0.00	0.09	0.3	-0.6	2.97	0.87	0.04	0.00
32	-0.44	-0.10	0.09	-0.7	-0.35	-2.4	6.45	0.17	-0.13
33	0.36	0.05	-0.16	0.55	-0.1	-7.13	2.87	0.17	0.00
34	-0.66	0.08	-0.16	0.05	0.15	5.32	-1.63	0.04	0.13
35	0.60	0.03	0.09	-1.45	5.15***	-5.35	7.37	-0.08	0.00
36	1.20	0.03	-0.41*	-0.45	-0.1	6.55	-5.85	-0.46**	0.25
37	-0.94	-0.02	0.22	-0.2	-1.1	-3.6	-1.55	-0.33	-0.13
38	0.70	0.05	0.09	-0.2	-1.35	-7.15	5.82	0.04	0.13
39	-0.34	-0.05	0.22	-0.7	0.65	-0.6	11.35	0.17	0.00
40	-0.91	-0.12	0.22	-1.95*	3.65**	-5.38	3.87	0.29	0.13
41	0.39	0.08	-0.03	0.3	-0.1	-1.78	-2.28	0.04	0.38
42	-1.9*	-0.17	0.09	-0.95	-0.6	7.12	5.72	-0.08	0.25
43	-0.19	0.10	-0.16	0.55	-3.6**	1.80	-1.45	-0.08	-0.13
44	-0.11	-0.05	-0.16	0.55	-2.1	-1.78	-5.45	-0.08	-0.25
45	-0.64	-0.05	0.22	-0.7	0.4	-2.40	6.97	0.17	-0.13
46	0.26	0.05	-0.16	-0.7	2.65*	1.80	-3.10	-0.08	0.02

Traits are: GY= grain yield; DTS= days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect;

Appendix 4. 16: **GCA effects of 46 DH lines evaluated under optimal conditions at Kakamega**

Line No.	GY (t ha^{-1})	EPP (#)	EA (1-5)	ASI (d)	DTS (d)	PH (cm)	ER (%)	ET(1-5)	PA(1-5)
1	0.50	-0.03	-0.34*	-0.18	1.77	12.31	-8.86	-0.37	0.07
2	0.02	0.05	-0.46**	-0.43	0.27	-17.69	-0.76	-0.62**	-0.18
3	0.35	0.02	-0.09	0.82	2.77*	4.81	0.77	0.88***	0.19
4	-1.65	-0.03	0.54***	-0.18	-3.98**	-17.69	3.42	-0.49**	0.32
5	-0.28	0.02	-0.46**	1.32	0.77	2.31	-5.88	-0.24	-0.06
6	-1.30	0.02	-0.34*	1.32	-2.73*	-15.19	-9.18*	-0.49**	-0.06
7	-1.70	-0.05	-0.71***	-0.18	1.77	-2.69	-15.13**	-0.99***	-0.56**
8	2.00**	-0.08	0.29*	-0.18	-4.23***	3.56	1.92	0.13	-0.06
9	-0.38	-0.03	0.04	-1.18	-2.98*	-12.69	3.04	0.13	0.07
10	0.90	0.07	0.16	-1.43	-1.73	-5.19	4.54	0.26	0.07
11	-0.60	-0.03	0.29*	-1.18	-5.48***	-7.69	9.39	0.63***	0.32
12	0.60	0.05	0.16	1.82	1.02	-0.19	-3.98	0.01	0.19
13	-0.40	-0.08	1.04***	1.32	0.77	7.31	20.89***	1.76***	0.57**
14	-0.25	-0.03	0.29*	-0.93	-1.73	21.06*	1.24	1.26***	0.44**
15	-0.65	-0.13	0.54***	0.07	-0.48	-1.44	16.14***	1.38***	0.57**
16	-0.28	0.05	0.29*	1.07	3.52**	-2.69	2.74	0.38*	0.07
17	0.60	-0.05	-0.09	0.32	-2.23	-3.94	3.57	-0.12	-0.06
18	-0.25	0.05	0.29*	-1.93*	-1.98	4.81	7.52	0.63***	0.19
19	-0.68	-0.05	0.16	-0.43	1.77	9.81	4.04	-0.74***	0.07
20	0.00	-0.03	0.29*	-0.68	-1.48	8.56	4.67	0.88***	0.19
21	1.10	0.02	0.16	-0.43	1.77	24.81*	6.49	0.13	-0.18
22	-0.38	-0.05	0.41**	0.57	-3.23**	-32.69**	14.12**	0.13	0.32
23	0.50	-0.08	0.79***	-0.43	-3.48**	-0.19	23.04***	1.13***	0.19
24	0.05	-0.05	0.29*	1.57	-1.23	7.31	-0.86	1.01***	0.32
25	2.50**	-0.03	-0.46**	0.07	-1.48	-5.19	-7.36	-0.74***	-0.31
26	-1.30	-0.03	0.66***	-0.68	0.02	-27.69**	8.59	0.13	0.57**
27	1.90*	0.00	-0.46**	0.57	2.02	-11.44	-9.13*	0.51**	-0.18
28	-1.73	0.02	-0.09	-0.43	3.02*	17.31	-9.36*	-0.12	-0.31
29	-0.98	-0.03	0.16	-0.93	1.52	6.06	-6.01	-0.87***	-0.43*
30	-1.33	-0.05	0.16	2.07*	0.27	-12.69	3.92	0.51**	0.19
31	-0.88	0.10*	0.04	-0.43	-2.23	-2.69	10.74*	-0.24	0.19
32	-0.43	-0.03	0.04	0.57	-0.48	-22.69*	13.62**	0.26	-0.18
33	0.15	-0.03	-0.59***	-0.43	-3.98**	-7.69	-12.48**	-0.87***	-0.43*
34	0.22	0.12**	-0.59***	-0.18	1.02	-5.19	-4.41	-0.74***	-0.56**
35	-0.33	-0.03	-0.34*	-0.18	3.02*	9.81	-9.48*	-0.62**	-0.31
36	-0.90	-0.03	-0.21	0.07	1.77	16.06	-2.23	-0.37	-0.31
37	-0.23	0.05	-0.21	-0.18	2.27	-0.19	-4.26	-0.74***	-0.56**
38	0.60	-0.03	-0.21	-0.18	2.52*	22.31*	-7.01	-0.24	-0.06
39	0.02	0.10*	-0.71***	-0.18	-1.48	-2.69	-16.78***	-0.99***	-0.56**
40	1.70*	0.05	0.41**	0.07	1.77	17.31	-0.28	0.76***	-0.06
41	1.30	0.07	-0.84***	-0.68	2.77*	-0.19	-11.28*	-0.74***	0.07
42	-0.83	0.07	0.04	0.57	2.27	24.81*	0.94	-0.24	0.32
43	0.27	0.02	0.41**	0.07	-1.98	-5.19	-1.23	0.51**	0.19
44	0.90	0.10*	-0.38**	-1.18	-0.23	-3.94	-5.93	0.13	-0.06
45	1.10	0.05	-0.34*	0.57	5.27***	9.81	-7.91	-0.87***	-0.31
46	0.32	0.00	-0.09	0.82	3.27**	-2.69	-5.51	-0.99***	0.07

Traits are: GY= grain yield; DTS=days from planting to emergence of silks in 50 % of plants; ASI= anthesis-silking interval; EPP=ears per plant; EA= ear aspect; ER= ear rot; PH= plant height; PA= plant aspect.

Appendix 4. 17: **SCA effects for grain yields of DH lines at 5 optimal conditions**

	Kakamega		Shikusa		Bulindi		Arusha		Embu	
Line No.	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
1	-1.5	1.5	-1.0	1.0	-0.7	0.7	-0.1	0.1	0.1	-0.1
2	1.4	-1.4	0.6	-0.6	-0.3	0.3	0.3	-0.3	0.2	-0.2
3	0.9	-0.9	-1.1	1.1	-0.5	0.5	-0.2	0.2	0.9	-0.9
4	-0.2	0.2	0.6	-0.6	0.4	-0.4	0.2	-0.2	0.1	-0.1
5	0.2	-0.2	-1.0	1.0	-0.7	0.7	0.2	-0.2	-0.6	0.6
6	-0.6	0.6	0.6	-0.6	0.2	-0.2	-0.8	0.8	0.4	-0.4
7	0.1	-0.1	0.5	-0.5	0.1	-0.1	0.9	-0.9	-0.2	0.2
8	-1.5	1.5	-0.3	0.3	0.7	-0.7	0.6	-0.6	-0.7	0.7
9	-0.8	0.8	0.6	-0.6	-0.1	0.1	0.4	-0.4	-0.7	0.7
10	-0.8	0.8	-0.1	0.1	0.8	-0.8	0.0	0.0	-0.5	0.5
11	0.9	-0.9	0.2	-0.2	-0.3	0.3	-0.5	0.5	0.6	-0.6
12	-1.1	1.1	-0.6	0.6	0.9	-0.9	0.3	-0.3	-0.3	0.3
13	-1.3	1.3	-0.5	0.5	-1.1*	1.1*	0.5	-0.5	0.4	-0.4
14	-0.5	0.5	-0.8	0.8	-0.8	0.8	0.2	-0.2	0.3	-0.3
15	1.0	-1.0	-1.9*	1.9*	-0.9	0.9	0.1	-0.1	-0.3	0.3
16	0.3	-0.3	-0.2	0.2	-0.8	0.8	-1.1*	1.1*	-0.4	0.4
17	0.4	-0.4	-0.6	0.6	0.8	-0.8	0.5	-0.5	0.2	-0.2
18	0.3	-0.3	-0.9	0.9	0.1	-0.1	0.3	-0.3	0.5	-0.5
19	-0.5	0.5	1.2	-1.2	0.0	0.0	0.6	-0.6	-0.3	0.3
20	0.6	-0.6	-0.3	0.3	0.1	-0.1	0.3	-0.3	-0.9	0.9
21	1.2	-1.2	-1.0	1.0	0.2	-0.2	-1.3**	1.3**	-0.1	0.1
22	0.5	-0.5	-0.5	0.5	-0.3	0.3	-0.1	0.1	-0.6	0.6
23	1.3	-1.3	-1.0	1.0	-0.6	0.6	-0.4	0.4	-0.5	0.5
24	-1.2	1.2	-1.3	1.3	-1.0	1.0	0.2	-0.2	-0.3	0.3
25	-0.9	0.9	-0.7	0.7	0.9	-0.9	0.4	-0.4	-0.7	0.7
26	-0.3	0.3	0.7	-0.7	0.3	-0.3	-0.6	0.6	0.6	-0.6
27	-1.6	1.6	0.6	-0.6	-0.9	0.9	-0.1	0.1	1.1	-1.1
28	0.6	-0.6	1.1	-1.1	1.0	-1.0	-0.6	0.6	-0.3	0.3
29	0.9	-0.9	0.7	-0.7	-1.0	1.0	-0.1	0.1	0.2	-0.2
30	0.6	-0.6	-0.2	0.2	0.3	-0.3	-0.2	0.2	0.2	-0.2
31	-0.6	0.6	-1.0	1.0	0.3	-0.3	-0.3	0.3	-0.7	0.7
32	0.7	-0.7	1.0	-1.0	-1.2*	1.2*	0.1	-0.1	0.2	-0.2
33	0.9	-0.9	0.5	-0.5	-0.3	0.3	-0.1	0.1	0.3	-0.3
34	0.2	-0.2	0.1	-0.1	-0.6	0.6	-0.4	0.4	0.6	-0.6
35	1.5	-1.5	0.7	-0.7	0.1	-0.1	0.6	-0.6	0.0	0.0
36	-0.3	0.3	-1.2	1.2	1.8**	-1.8**	1.0*	-1.0*	0.6	-0.6
37	-0.8	0.8	1.6	-1.6	0.8	-0.8	0.0	0.0	-0.1	0.1
38	-0.1	0.1	1.9*	-1.9*	-0.4	0.4	-0.3	0.3	0.7	-0.7
39	0.5	-0.5	1.2	-1.2	0.7	-0.7	1.1*	-1.1*	0.6	-0.6
40	0.7	-0.7	-0.3	0.3	-1.0	1.0	-1.0*	1.0*	-0.4	0.4
41	0.6	-0.6	-0.1	0.1	-0.5	0.5	-0.2	0.2	-0.5	0.5
42	0.4	-0.4	1.0	-1.0	-0.2	0.2	0.7	-0.7	0.4	-0.4
43	-1.8*	1.8*	1.7	-1.7	0.4	-0.4	-0.4	0.4	-0.2	0.2
44	-1.1	1.1	-0.8	0.8	-0.2	0.2	-1.0*	1.0*	-0.6	0.6
45	1.0	-1.0	-0.3	0.3	1.7**	-1.7**	-0.1	0.1	0.8	-0.8
46	-0.2	0.2	0.5	-0.5	1.8***	-1.8***	0.4	-0.4	-0.1	0.1

T1= CML312/CML442 and it belongs to heterotic group A. T2 = CML395/CML444 and it belongs to heterotic group B