PERFORMANCE OF DOUBLED HAPLOID MAIZE INBRED LINES IN F_1 HYBRIDS UNDER STRESS AND NON-STRESS CONDITIONS

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DECLARATION

I hereby declare that this thesis is my original research and has neither in whole nor part been presented for award of a degree in any other university.

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DEDICATION

I dedicate this work to my aunt and guardian Dr. Milcah Ajuoga for her passion to mentor and educate me up to this level and to my mother Grace Odiyo for her love, care and encouragement throughout this walk of education.

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ACRONYMS

AATF	-	African Agricultural Technology Foundation
ANOVA	-	Analysis of Variance
ASAL	-	Arid and Semi-arid lands
CA	-	Combining ability
CV	-	Coefficient of Variation
CIMMYT	-	International Maize and Wheat Improvement Center
CML	-	CIMMYT maize inbred line
ESA	-	Eastern and Southern Africa
DH	-	Doubled haploids
GCA	-	General Combining Ability
KARI	-	Kenya Agricultural Research Institute
LSD	-	Least Significance Difference
SAS	-	Statistical Analysis Software
SCA	-	Specific Combining Ability
SC	-	Single cross hybrids
TWC	-	Three Way Cross hybrids
WEMA	-	Water Efficient Maize for Africa

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ABSTRACT

Drought, which is a major constraint to maize production in Kenya, is a difficult trait to breed for in this crop. Conventionally, it takes 10-15 years of breeding to develop homozygous and homogeneous inbred lines. Additionally, heavy funding and inputs are required to develop new varieties. Doubled haploid (DH) technology which requires only 1-2 years to reach homozygosity, is gaining rapid adoption in modern maize breeding programs. DH germplasm is available in eastern and southern Africa awaiting commercial exploitation by the National Agricultural Research Systems. This study was designed to i) evaluate the performance of maize DH inbred lines under stress and non-stress conditions, ii) classify the DH lines into respective heterotic groups iii) estimate combining abilities, heritability and correlation coefficients for grain yield and yield associated traits in DH hybrids made from these lines and iv) assess stability of performance of three-way DH hybrids. One hundred DH lines obtained from International Maize and Wheat Improvement Center (CIMMYT) gene pool were test-crossed to two single cross parents (CML312/CML442) and (CML395/CML444) in a North Carolina design II fashion to generate 200 DH hybrids. Screening for good agronomic traits reduced these harvested testcrosses to 160. An alpha-lattice design of 15x11 with two replications was used to evaluate the 160 DH hybrids together with three commercial checks and two local checks across 6 locations in Kenya under optimum, nanaged drought and random drought conditions during 2012-2013 growing seasons. Each two-row plot measured 5 m long spaced at 0.75 m between rows and 0.25 m between hills. Data were collected on grain yield, days to anthesis, ear and plant heights, ear and plant aspects, number of ears per plant, foliar diseases and grain moisture at harvest and analyzed using SAS software. Ten DH inbred lines L_{36}, L_4, L_{13}, L_{11}, L_5, L_{71}, L_9, L_{65}, L_{64} and L_{51} had positive and significant ($p<0.001$; 0.05) GCA effects for grain yield while best

SCA estimates for grain yield were observed in thirteen DH testcross hybrids. The top ten DH hybrids yielded 16 % higher grain than the best commercial check (7.7 t/ha) under non-stress conditions, while under drought stress these hybrids out yielded the best commercial check (3.43 t/ha) by 62 %; a highly significant ($p<0.001$) amount. Outstanding DH hybrids across various moisture regimes included entries 91, 116, 120, 26 and 23. Significant location, genotype and genotype x location effects were observed for grain yield, days to anthesis and anthesis-silking interval (ASI) under well-watered conditions. Although high heritability estimates were observed under optimum conditions, heritability was greatly reduced under drought. However, selection under drought could be greatly enhanced by using the secondary traits. The two single cross testers successfully classified 24 DH inbred lines into heterotic group A, 47 to heterotic group B and nine (9) to HGA/B. It was concluded from these studies that DH lines have ability to produce high grain yield and acceptable agronomic traits for commercial use. Further, the identified best ten DH lines offer good parental sources for improved yield in hybrids under drought conditions for commercial exploitation. It was therefore recommended that these lines should be introduced into Kenyan breeding programs.

CHAPTER ONE

1.0 GENERAL INTRODUTION

Maize (*Zea mays* L.) originated through domestication of the wild grass teosinte (*Zea mexicana*) which is native to Mexico, Guatemala and Honduras (Wilkes, 1967). However, one form of teosinte, known as *Z. mays* ssp. *parviglumis*, shares a particularly close genetic relationship with maize; suggesting that it is the direct ancestor of maize (Matsuoka *et al.,* 2002). The United States has dominated world maize production, but China, the nations of the Mercado Commun Sudamericano (MERCOSUR), and the European Union (EU) are also major producers (Pingali and Pandey, 2001). Maize was introduced into Africa through the explorers of the 16th and 17th centuries (Doebley, 1990) and has since become one of Africa's dominant food crops. It is the most important cereal crop in sub-Saharan Africa (SSA) being a staple food for more than 1.2 billion people in SSA and Latin America (FAO, 2011). The grains, which are rich in vitamins A, C and E, carbohydrates, proteins (9 %), essential minerals and dietary fiber, are a good source of energy accounting for over 50 % of the total daily calories of people in rural and urban areas of ESA (Bänziger and Diallo, 2001). In industrialized countries, maize is largely used as livestock feed and as a raw material for industrial products. It accounts for 30 – 50 % of low-income household expenditures in Eastern and Southern Africa (ESA).

Maize is the third most traded cereal after wheat and rice. However, it ranks top in grain yield per unit area of land (CIMMYT, 2000). Global production of maize was 785 million tons by 2008 with the largest producer being United States of America producing 42 % while Africa produced 6.5 %. Consumption per capita of maize is more than 116 million tons worldwide, with Africa consuming 30 % and SSA 21 % (FAOSTAT, 2011). Currently, maize is the world's most widely grown cereal because of its versatility, varied varieties and ability to grow in all sorts of edaphic, altitudinal and fertility conditions. The trend in global cereal demand in the next decade is projected to increase rapidly. The demand for maize is expected to surpass that of wheat and rice by 2020. This shift will be reflected in a 50 % increase in global maize demand in industrialized and developing countries from 558 million tons in 1995 to 837 million tons by 2020 (Pingali and Pandey, 2001). In developing countries alone, maize requirement will increase from 282 million tons in 1995 to 504 million tons by 2020 (IFPRI, 2000). A greater portion of this increase is expected to come from the developing countries which contribute 96 million hectares out of the total 140 million hectares of maize grown worldwide (CIMMYT, 2000). The increased demand for maize in recent years has largely been driven by rising incomes and the consequent growth in meat and poultry consumption.

In Kenya, maize is among the most important crops. It contributes more than 20 % of total agricultural production, 78 % of total cereal consumption, 25 % of employment, 44 % of total energy and 32 % of the total protein consumed by Kenyans (Hassan, 1998). It is grown over a wide range of agro-ecological zones (AEZs) from sea level to over 2100 metres above sea level, with average rainfall varying from 250 to 2000 mm per season. Kenya Agricultural Research Institute (KARI) in collaboration with CIMMYT through a Maize Improvement Programme has identified six maize growing AEZs with relatively homogenous biotic and abiotic stresses, cropping systems requirements and consumer preferences. The three key environmental determinants of these AEZs are elevation, rainfall and temperature. In all the tropical maize growing ecologies in Kenya, totaling about 1.6 million hectares (Bradford *et al.,* 1995), maize is produced under rain-fed conditions. A larger proportion of this production comes from small-holder farms ranging in size from 0.2 to 8 hectares. This accounts for nearly 80 percent of the total maize crop and corresponds to the high number of 3.5 million small-scale farmers involved in maize production largely for home consumption. The remaining 20 percent is borne by large scale farms which are estimated to be managed by about 1000 farmers. The annual maize production is estimated at 3.3 million metric tons giving a national average yield of 2 metric tons per hectare (MT/ha). The yields range from 8 MT/ha in the high potential areas to less than 1 MT/ha in the marginal areas (Nyoro, 2002). The crop is optimally produced in the highlands and mid-altitude regions but the current high demand for the crop has driven communities in marginalized regions to grow it. CIMMYT (2002) reported a 3 % or more increase in maize demand each year for East Africa due to its rapidly expanding population. For example, Kenya's population is estimated at 38.6 million people (Kenya Census, 2009) with a monthly maize requirement of 3.5 million 90 Kg bags (Owuor and Höffler, 2010) and with the expanding numbers, pressure on food availability is bound to increase.

On top of the increasing population pressure, constraints to maize production comprising an array of biotic, abiotic and socioeconomic factors also lead to tremendous decline in maize productivity. Among the abiotic stresses, soil water deficits and soil infertility (low nitrogen and phosphorous) are the most important; drought being the most limiting of these stresses especially in ESA (Araus *et al*., 2002; Bänziger and Diallo, 2004). For example, drought occurring shortly before flowering causes an estimated yield loss of 21-50 % (Denmead and Shaw, 1960) while drought during flowering and grain filling can cause between 17-37 % crop losses (Bänziger *et al*., 1999). Moreover, climatic change, which putatively leads to increased temperatures and decreased rainfall is expected to accelerate aridity in most parts of many developing countries of Africa and Asia (Rijsberman, 2006; Lobell *et al.,* 2008) leading to failure of major crops that are crucial to large food-insecure populations. To moderate the negative impacts of climate change, it is imperative to get maize germplasm with improved tolerance to drought, high yielding and adapted to other stresses present in the farmers' fields (Araus *et al.,* 2008; Golbashy *et al.,* 2010). Mugo *et al.* (2005) reported that such varieties have the ability to withstand drought stress and have better harvests under harsh environments and thus contribute to increased food production.

Cassman *et al.* (2003) projected that due to the growing populations, encroachment of arid and semi-arid lands (ASALs) and limited area of arable land for expansion, improved and innovative breeding techniques are critical to ensure agricultural sustainability; implying that the relative importance of plant breeding to raise crop yield potential and adaptiveness to various stresses is now greater than in the past (Slafer *et al*., 2005; Araus *et al*., 2002). Through different regional breeding programs at CIMMYT, inbred lines and populations tolerant to drought and low nitrogen stress (Bänziger, 2000) and resistant to insect pests (Tadele *et al.,*2011a; 2011b) are now available for commercial exploitation within SSA. However, it is important to know the relationship between elite lines from different programs used as testers to produce experimental hybrids, and to gain an understanding of how this facilitates flow of materials and strategies for hybrid production. Furthermore, the germplasm available as inbred lines can be used to develop either single- or three-way cross hybrids.

The development of homozygous lines is an important part of maize breeding. In classical breeding methods such as pedigree selection or single seed descent (SSD), 96.9 % homozygous lines are obtained after 6 to 10 generations of selfing heterozygous material (Allard, 1960; Hallauer *et al.,* 2010), a time consuming and expensive process. Advances in technologies such as doubled haploid (DH) breeding have added efficiencies to modern commercial maize breeding. Instead of several generations of selfing accompanied by pedigree selection, potential homozygous varietal parents are rapidly produced within 1-2 generations and can be evaluated for their breeding value with regard to their line *per se* and/or testcross performance and combining abilities. Information on the combining ability of parental germplasm is greatly beneficial to the breeders in defining a breeding strategy. This can be achieved by combining lines from different heterotic groupings so as to transfer traits of interest to their progenies (Ricci *et al.,* 2007). Haploid breeding technology has enabled for rapid identification of lines and introgression of desirable genes allowing scientists to make more informed decisions around specific genetic combinations to improve genetic gain. For instance, CIMMYT has developed drought-tolerant doubled haploid (DH) inbred lines for commercial exploitation in Kenya and other developing countries in ESA (Beyene *et al.,* 2013). Over the last decade, inbred line development by DH technology has been adopted as a routine method in many commercial hybrid maize breeding programs in Europe (Schmidt, 2003), North America (Seitz, 2005) and more recently in China (Chen *et al.,* 2009). Nevertheless, maize breeding institutions in several tropical maize growing countries in Latin America, SSA and Asia have lagged behind in adopting the DH technology (Prasanna *et al.,* 2010; Kebede *et al.,* 2011) yet these regions have the top most research priority as development of new high yielding and drought tolerant cultivars. To this effect, most maize breeding programmes are geared towards developing drought tolerant maize germplasm, an objective that has recently gained more importance. This is done through critical evaluation of homozygous breeding material by determining the existing genetic variability, heritability, correlation and inter-relationship among grain yield and its components.

This study was part of the efforts of the Water Efficient Maize for Africa (WEMA) project. WEMA is a public-private partnership to develop and deploy drought-tolerant white maize varieties royalty-free in selected countries of Africa namely: Kenya, Tanzania, Uganda, Mozambique, and South Africa, to increase maize yields and reduce risk under drought conditions through a combination of conventional breeding, marker-assisted breeding and transgenes. The project is jointly being implemented by CIMMYT; the African Agricultural Technology Foundation (AATF); Monsanto and the National Agricultural Research Systems in Kenya, Uganda, Tanzania, Mozambique and South Africa.

1.1 Problem statement and justification

"Maize is life" to more than 300 million vulnerable people in Africa but its production has been declining since the last decade as a result of scanty and very erratic rainfall largely caused by negative climate change. In Kenya, the adversely changing weather patterns coupled with continuous cropping using unadapted local maize varieties has led to poor maize productivity (Ngaira, 2009) leaving approximately 10 million people faced with starvation. Since the last bumper harvest of 2006/07, Kenya has experienced perennial maize crop shortages. Its production has been deteriorating in the last four consecutive years with the main reason being the unreliable rainfall and high temperatures which are accelerated by climate change. Recurrent incidence of droughts in SSA is one of the most important constraints for improving maize production and productivity, and the livelihoods of the smallholders. The government, the private sector and the farmers have attempted for many means to avert the dwindling production levels albeit with very little success. Government interventions constitute a move towards the right direction but the country can be more food secure if and when the interventions are accompanied with development and utilization of germplasm adapted to various stresses present in farmers' fields. In particular to drought stress, drought tolerant maize germplasm developed through classical breeding methods is available for commercial exploitation in Kenya's mid- and low-altitude agro-ecological zones. This has drastically strengthened the food security outlook in most parts of the country. But more recently, research institutions such as CIMMYT, have adopted the doubled haploid (DH) technology to increase the rate of progress in hybrid maize breeding. This is because the DH technology provides additional opportunities to increase breeding efficiency. It allows breeders to rapidly generate homozygous progeny that provide material for testing and for selection that is both more reliable and more predictive than segregating progeny. This enables the efficiency and precision of field based selection to be improved. Additionally, it can also be used to facilitate access to parental germplasm using threshold values with computer simulations and molecular marker data in subsequent cycles of selection. This enables recombination of DH progeny that have high and complementary contributions from a parental line. The newly developed cultivars need to be tested in multi-environments over space and time to determine their performance and adaptability before commercial release. This helps in minimizing the inconsistent genotypic responses to environmental factors such as temperature, soil moisture and soil fertility level from location to location and year to year. The heterotic patterns to which the DH lines belong should also be identified for fuller utilization in hybrid combination. Bolaños and Edmeades (1993) ascertained that breeding for maize cultivars with high and stable yields under drought conditions remains the only feasible option to boost maize productivity for many small-scale farmers. Therefore, there is need to exploit the already available drought tolerant DH materials to curtail issues of food insecurity. In order to achieve this, potentially suitable parents and superior combinations must be identified in terms of adaptation and performance in different maize growing ecologies. This study evaluated the DH lines within CIMMYT's gene pool to determine their performance, combining abilities and adaptability under stress and non-stress conditions. Grouping the DH lines into respective heterotic groups is recommended for fuller utilization in developing best hybrid combinations. The testcross hybrids which exhibit good performance for grain yield and other agronomic traits under stress and non-stress conditions are to be further evaluated in advance yield trials for commercial exploitation.

1.2 Objectives

1.2.1 General objective

To evaluate the potential of doubled haploid maize inbred lines for commercial exploitation under drought and well-watered conditions.

1.2.2 Specific objectives

i) To estimate combining abilities, heritability and correlation coefficients for grain yield and yield associated traits in doubled haploid hybrids derived from the DH lines.

ii) To assess genotype x environment interaction of doubled haploid test-cross hybrids.

iii) To classify the doubled haploid lines into respective heterotic groups.

1.3 Hypotheses

1. Doubled haploid test-cross hybrids perform poorly under well-watered and drought conditions and they are not stable across different maize growing ecologies.
2. Doubled haploid test-crosses and lines *per se* have poor combining abilities and high heritability for grain yield and other agronomic traits.

CHAPTER TWO

LITERATURE REVIEW

2.0 Production of doubled haploid lines in maize

A doubled haploid (DH) genotype is formed when haploid *(n)* cells undergo either artificial or spontaneous chromosome doubling producing two gene sets which are exactly identical (Mohan *et al*., 1996; Prasanna *et al.,* 2012). Barnabás *et al.* (1999) and Maluszynski *et al.* (2003) reported that DHs can be produced artificially through *in vivo* or *in vitro* techniques under different frequencies. The *in vivo* approach is focused on parthenogenesis and pseudogamy (chromosome elimination after wide crossing). The haploid embryo is then rescued, cultured and chromosome-doubled to produce doubled haploids. The *in vitro* procedure focuses on gynogenesis (ovary and flower culture) and androgenesis (anther and microspore culture). Genetic analyses generated by several workers have shown that *in vitro* androgenetic response is under complex multifactorial control. Thus, despite good results with specific genotypes, the technique has not yet become a routine tool in maize breeding. In contrast, *in vivo* procedures have been widely applied during the last two decades since they can be improved considerably. *In vivo* induction of paternal haploids based on the 'indeterminate gametophyte' mutant has become a standard technique for transferring elite seed parent lines into cytoplasms that condition male sterility. Similarly, the induction of maternal haploids by pollination with specific inducer genotypes has become a routine procedure for large-scale DH line production. *In vivo* techniques are much less affected by donor genotypes than *in vitro* procedures (Geiger, 2009).

Chase (1952) proposed the first method to produce DHs in maize using monoploids. He reported that haploids occur spontaneously at a rate of about 10^{-3} and about 10 % of these are successfully selfed progenies. According to Rokka *et al.* (1995), anther culture of diploid plants can lead to the production of haploids but success has been limited by low induction of spontaneous chromosome doubling (Mohammadi *et al.,* 2007) coupled with poor plant regeneration and low anther response frequencies (Nägeli *et al.,* 1999). Improvement in maize anther culture can be obtained by selecting for highly responsive genotypes (Dieu and Beckert, 1986) and transfer of genetic aptitude through *in vitro* crossing androgenesis (Petolino and Thompson, 1987).

Haploid plants must be treated with a chromosome doubling agent (mitotic inhibitor) since spontaneous duplication of chromosomes occurs at a very slow rate (Chase 1969; Deimling *et al.,* 1997). They are then self-pollinated to form completely homozygous plants also known as DH lines (Bordes *et al*., 2007; Geiger and Gordillo 2009). Several institutions currently use colchicine as a chromosome doubling agent but herbicides such as pronamid, trifularin and oryzalin (Häntzschel and Weber, 2010) and nitrous oxide gas (Kato, 2002) can also be used. Colchicine disrupts mitotic cell division. It inhibits the formation of spindle fibers and polar migration of chromosomes but treatment with colchicine is not always completely effective and sectoral diploidization of male or female inflorescences can occur.

Regeneration of DH plants can be done using two methods: Method I as proposed by Gayen *et al.* (1994) and Method II as proposed by Deimling *et al.* (1997). In Method I, the tips of haploid plants are cut-off when the coleoptiles are at least 1 cm long then the seedlings are immersed into a concoction of 0.06 % colchicine solution plus 0.5 % dimethyl sulfoxide (DMSO) for 12 hours at 18°C. The generated DH seedlings are then washed in running water for 20 minutes and then planted in the field. In Method II, haploid seedlings are grown until 3 to 4 leaf stage then injected with a mixture of 0.125 % colchicine and 0.5 % DMSO, 3 to 5 mm above the apex to double the haploid cells. The immersed seedlings are then placed in the dark, carefully washed in water and subsequently grown in the greenhouse to the 6-leaf stage under high humidity. Afterwards, the treated plants are transferred to the field. Method II increased the efficacy of Method I. The success of the treatments in both methods is determined by several anthers with fertile pollen appearing on the tassel of a haploid plant.

Colchicine treatment of maize seedlings doubles the chromosome number in the tassel or the ear, but often not in both, which makes self-pollination impossible (Wan *et al*., 1989). High mortality and abnormal plant development can also be observed in colchicine-treated plant populations. This could explain the low efficiency of doubled haploid production in maize after colchicine treatment of regenerated haploid plantlets. A doubling rate of 49 % was reported by Eder and Chalyk (2002) when they applied method II to a broad range of donor genotypes. About 50-60 % of the successfully treated plants shed pollen and could be selfed. Wan *et al*. (1989) and Wan and Widholm (1995) also reported the recovery of genetically stable doubled-haploid maize plants at high frequency through the colchicine treatment of embryogenic, microspore-derived haploid calli. In other experiments conducted by Antoine-Michard and Beckert (1997) and Mohammadi *et al.* (2007), the application of colchicine treatment together with a 7-days cold shock to cultured maize anthers resulted in a considerable increase in chromosome doubling in microspore derived plants.

Haploid plants are smaller and less vigorous than corresponding diploid homozygous lines (Chase, 1952; Auger *et al*., 2004). Most haploids display a certain level of female fertility (Geiger *et al.*, 2006) but in general haploids lack male fertility (Chalyk, 1994). However, certain donor genotypes were detected that provided haploid plants producing traces of pollen which could successfully be used for selfing (Chalyk, 1994). Zabirova *et al.* (1993), identified a donor genotype from which one third of the induced haploids were male fertile. The donor resulted from four cycles of selection for that trait.

2.1.1 Genetics of male inducer lines and haploid induction rates

In maize, some genotypes produce pollen capable of inducing *in vivo* gynogenesis that results in maternal haploids originating wholly from the female plant. Chase (1952) observed spontaneous haploids in US Corn-Belt germplasm at a rate of about 0.1 %. This value was too low for any commercial application. Coe (1959) later described the Stock6 inbred line with an induction rate of up to 2.3 %. More recently, Röber *et al.* (2005) described the RWS line with the highest induction rate of 8.1 % reported up to the present time. These lines are extensively used to produce doubled haploid lines (Eder and Chalyk, 2002; Röber *et al.,* 2005; Bordes *et al.,* 2007) but they can also be considered as original mutant lines for the analysis of double fertilization mechanisms. Scientists have grouped the inducer lines into those adapted for temperate regions and those for tropicalized regions. Examples of temperate haploid inducers are PK6 (Barret *et al.,* 2008), HZI1, derived from stock6 (Zhang *et al.,* 2008) and WS14, developed from a cross between lines W23*ig* and stock6 (Lashermes and Beckert, 1988) with induction rates of 3 to 5 %. Röber *et al.*, 2005 reported observing significant induction rate differences between donor genotypes. However, Büter (1997) and Spitkó *et al*. (2006) reported small variations compared with that for *in vitro* culture techniques. Since 2007, CIMMYT Global Maize Program in partnership with University of Hohenheim, Germany, has been intensively engaged in over optimization of the DH technology especially for the tropical and sub-tropical maize growing environments. They have been able to successfully develop tropically adapted inducer lines (TAILs) with induction rates of 8 to 10 %. The TAILs were developed from segregating populations from crosses between temperate inducers (RWS, UH400 and RWS x RWK) as pollinators and three tropical CIMMYT inbred lines CML494, CML451 and CL02450 as females (Prigge *et al.,* 2011; Prasanna *et al.,* 2010). The haploid-inducing capacity of an inducer line can be increased by selection (Sarkar *et al.,* 1972), environmental factors (Röber *et al*., 2005) and method and time of pollination (Rotarenco *et al.,* 2009) to obtain inducers with higher rates of haploid induction.

2.1.2 *In vivo* induction of maternal haploids

In maize, two modes of *in vivo* haploid induction are recognized; maternal and paternal haploids (Röber *et al.,* 2005; Zhang *et al.,* 2008). The genomes of maternal haploids originate exclusively from the maternal seed parent plant. In this case, haploid induction is caused by the pollinator parent (paternal parent) serving as the inducer. To induce maternal haploids, the genome donor plant is pollinated by a specific maize stock either a line, a single cross, or a population called inducer. In many instances, one of the two inducer sperm cells is not fully functional yet fuses with the egg cell. During subsequent cell divisions, a degeneration process starts and the chromosomes get fragmented and finally are eliminated from the primordial cells leaving only maternal chromosomes. The second sperm cell fuses with the central cell leading to a regular triploid endosperm and a normal-sized functional seed (F_1 kernels) and a certain proportion of kernels with a haploid maternal embryo which displays a normal germination rate and lead to viable haploid seedlings (Röber *et al*., 2005; Geiger, 2009). Increased maternal haploid induction frequencies have been achieved through the identification and selection of haploid inducing pollinators (Coe, 1959) enhancing large production of maternal haploid plants.

Progress in selection of pollen parents with high induction rates has led to precise and improved *in vivo* haploid induction, which is now established as a routine method for maize breeding (Bordes *et al.,* 1997; Röber, 1999). All present commercial DH-line breeding programs are based on *in vivo* induction of maternal haploids (Seitz, 2005; Barret *et al.,* 2008; Rotarenco *et al.,* 2009) since it involves only ordinary breeding operations except for the special treatment of plants required for chromosome doubling. Once established, the method allows production of doubled haploid lines in large numbers at low costs (Melchinger, *et al.,* 2005). A key issue in applying the *in vivo* haploid induction technique is an efficient screening system for separating the kernels with a haploid embryo from those with a regular diploid F_1 embryo. At present this is accomplished by a combination of dominant kernel, embryo and stem markers (Röber, 1999; Eder and Chalyk, 2002). Progress achieved in the induction of maternal haploids pertains to the induction rate, easily screenable markers for haploid identification, chromosome doubling procedures and handling of seedlings which survive chromosome doubling.

2.1.3 Haploid plants identification

Maize breeders commonly use color markers to differentiate kernels resulting from regular fertilization and those generated by haploid induction. Five different methods have been identified to differentiate haploid from diploid kernels. Chase (1969) identified a phenotypic marker system based on anthocyanin coloration encoded by the dominant variant allele *R1-nj (R1-navajo)* of the *R1* locus. Integration of anthocyanin markers in haploid inducer lines facilitates haploid identification at the seed level and also during other stages of plant growth. The marker expresses well in dent materials but in flint germplasm, it does so after earlier cycles of selection. "False positives" can be identified by morphological markers such as anthocyanin coloration of the stalk. In the presence of the dominant pigmentation genes *A1, A2* and *C2*, *R1-nj* conditions deep pigmentation of the aleurone layer (endosperm tissue) in the crown and scutellum (embryo tissue) of the kernel. Pigmentation varies in degree and intensity depending on the genetic background of the donor genotype (Geiger and Gordillo, 2009).

Coe (1994) reported that anthocyanin production was hindered by inhibitor genes at a much higher rate in flint maize than in dent maize hence it was complex selecting haploids from flint maize. In contrast, Eder and Chalyk (2002) obtained haploids from all maternal dent and flint genotypes, with flint genotypes having better expression of the *R1-nj* gene in embryos than the dent genotypes. Nanda and Chase (1966) and Greenblatt and Bock (1967) were the first to use the red crown mutant as a selectable marker in haploid induction experiments. They reported that to be effective, the donor parent has to have colorless seeds and the inducer line needs to be homozygous for *R1-nj* and the above-mentioned dominant pigmentation genes. Pollination of maternal haploid by an inducer liner results in regular F_1 kernels, a regular triploid endosperm and haploid kernels (maternal embryo). A kernel resulting from haploid induction then has a red crown (regular triploid endosperm) and a colorless scutellum, whereas a regular F_1 kernel displays pigmentation of both the aleurone and scutellum (Geiger, 2009). In an attempt to isolate haploids from flint genotypes, difficulties exist due to the dominant genes (*A1, A2* and *C2*) that exist in maize. These inhibit anthocyanin synthesis of the marker for the selection of haploids (Coe, 1994). Genes that inhibit anthocyanin synthesis in dent maize are rare, hence anthocyanin marker genes are mostly well expressed (Röber, 1999).

Red crown marker does not work if the donor genome is homozygous for *R1* or for dominant anthocyanin inhibitor genes such as *C1-I, C2-Idf* and *In1*-D. These genes occur quite frequently in European flint and tropical materials (Belicuas *et al.*, 2007). In such cases, haploid identification is possible in the early seedling stage if the inducer is homozygous for the genes *B1* and *Pl1* which in conjunction condition light-independent pigmentation of the coleoptile and root of the F_1 seedlings. The haploid kernels display a normal germination rate and lead to viable haploid seedlings (Rober *et al.,* 2005; Geiger, 2009). In addition, Rotarenco *et al.* (2007) proposed a method of identifying haploid kernels based on kernel oil content using nuclear magnetic resonance. They observed that F_1 kernels with haploid embryos had lower oil concentration than those with diploid embryos. Li *et al.* (2009) developed an inducer line CAUHOI derived from stock6 that allows identification of haploids based on both lack of *R1-nj* conferred scutellum coloration as well as low embryo oil content. Jones *et al.* (2012) explored the utility of Near Infrared Reflectance (NIR) transmission spectroscopy to differentiate haploids from hybrid maize kernels after the maternal haploid induction. Haploid plants can be distinguished from diploid plants by their growth characteristics like erect leaves, poor vigor and sterility. Distinguishing haploids from diploids at seed level is critical for adapting DH technology on a commercial scale since it saves on costs involved in chromosome doubling, green house, field space and labor involved (Prasanna *et al.,* 2012).

2.1.4 Haploid technology in modern hybrid maize breeding

The doubled haploid (DH) approach provides additional opportunities to increase breeding efficiency. This is because it allows breeders to rapidly generate homozygous progeny that provide material for testing and for selection that is both more reliable and more predictive than segregating progeny (Forster and Thomas, 2005). This feature is particularly significant to many agronomically important traits that are prone to effects of genotype by environment interaction. Consequently, the DH approach enables the efficiency and precision of field based selection to be improved (Choo *et al.,* 1985; Bonnet *et al.,* 2005).

The DH approach can also be used to facilitate access to parental germplasm using threshold values with computer simulations (Heckenberger *et al.*, 2005). The DH-derived inbred lines undergo less recombination and segregation compared with those developed using successive generations of self-pollination (Frisch and Melchinger, 2007). Bernardo and Kahler (2001) speculated that reduced recombination resulting from the use of DHs could facilitate the selection of progeny that extend closer in genotypic similarity to either parent than would be the case for progeny selected after several selfing events. Frisch and Melchinger (2007) showed by simulation that in maize, for the 0.95 quantile of the parental genome distribution, contribution was 0.65 for F_2-single seed descent lines of maize compared to 0.67 for lines derived as doubled haploids. The DH technology thus offers a means to facilitate access to the germplasm present within either the female or the male parental lines for hybrid formation. Such an application could be especially facilitated by the concerted use of molecular marker data in subsequent cycles of selection to recombine DH progeny that have high and complementary contributions from a parental line.

Studies conducted by Friedt *et al.* (1986) and Winzeler *et al.* (1987) concluded that DHs are comparable to the inbred lines from pedigree breeding. Thus, in general, DH technology dramatically increases the speed of the inbred line development process by trimming off several time-intensive generations of inbreeding, while making phenotyping and genotyping more predictive (Curran, 2008; Geiger and Gordillo, 2009; Chang and Coe, 2009); it allows for increased options for *per se* selection and integration of key desirable agronomic traits; it offers optimal aptitude for marker applications and it also ensures increased efficiency of the breeding programs while reducing developmental costs (Geiger and Gordillo, 2009). These advantages allow breeders to do more testing in the same amount of time to increase the rate of genetic gain per cycle and ensure that the products being advanced are the best possible choices for farmers.

Protocols for producing doubled haploid plants in other plant genera of over 250 species (Maluszynski *et al.,* 2003) is now available. This provides greater efficiency to plant breeding. Various DH line-based breeding schemes have been suggested and computer softwares have been developed for optimizing the dimensioning of the schemes and for determining the relative merits of alternative breeding strategies. In summary, DH inbred lines feature important advantages regarding quantitative genetics, operational, logistic and economic aspects. In research, DH lines are mainly being used for mapping purposes and in breeding they are progressively replacing conventional inbred lines. The DH-line technology can therefore be considered as one of the most effective tools in modern maize genetics and breeding.

2.2 Drought stress breeding

According to estimates by CIMMYT (1997) regarding abiotic stresses, the most significant causes of yield loss on farmers' fields are drought followed by low soil fertility (nitrogen and phosphorous deficiency) and less important, by plant competition related to low planting densities, weeds and intercrops (Edmeades and Deutsch, 1994). From an agricultural context, drought is the inadequacy of water availability in forms of precipitation and soil-moisture storage capacity both in quantity and distribution during the life cycle of a crop plant (Zhu, 2002). This limits the expression of the full genetic potential of the plant and the determined theoretical maximum yield (Begg and Turner, 1976).

Drought occurs due to infrequent and poorly distributed rains in an area causing depletion of moisture in the soil (Wang *et al.,* 2005). The water deficit leads to a decrease of water potential in plant tissues (Kramer, 1980) disrupting physiological and biochemical processes within the plant (Lawlor, 2002). This influences production and quality of many crops worldwide and with the increasing population and global climate change, the situation is worsening (Hongbo *et al.,* 2005). An understanding of genetic basis of drought resistance in crop plants is a pre-requisite for a maize breeder to evolve superior genotype. Levitt (1972) grouped the mechanisms of drought resistance into three categories: drought escape, drought avoidance and drought tolerance. *Drought escape* is the ability of a plant to complete its life cycle before the start of severe soil and plant water deficits. This mechanism involves rapid phenological development (early flowering and early maturity), developmental plasticity (variation in duration of growth period depending on the extent of water-deficit) and remobilization of pre-anthesis assimilates to grain (Turner, 1979). *Drought avoidance* on the other hand is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil-moisture. Plants confer drought avoidance by active water uptake through the roots, storing it in the cell and reducing its loss through evapotranspiration. Drought avoidance is achieved in plants by maintenance of turgor through efficient root system with increased hydraulic conductance and by reduction of water loss through reduced epidermal (stomatal and lenticular) conductance, increased rooting depth, reduced absorption of radiation by leaf rolling or folding (Begg, 1980) and reduced leaf area (Turner, 1986). Plants survive drought stress by balancing turgor pressure maintenance and water loss reduction (Shashidhar *et al.,* 2000). Finally, *drought tolerance* is the ability of a crop to withstand water-deficit with low tissue water potential. It involves numerous changes including reduced growth, transcriptional activation/inactivation of specific genes, transient increases in ABA levels, accumulation of compatible solutes and protective enzymes, increased levels of antioxidants and suppression of energy-consuming pathways (Waseem *et al.,* 2011).

Considerable efforts have been devoted to breeding for improved drought tolerance in cultivars of major crops such as maize but with little progress. Drought resistance response in plants is complex since it interacts with factors such as high temperature and nutrient uptake (McWilliam, 1989) making selection difficult. Turner (1986) developed a cluster analysis classifying drought stress into six groups namely: early drought, mid-season drought, late-season drought, drought with relief near harvest, progressive moderate drought and progressive severe drought. It is therefore necessary to identify the type of drought that the crop is likely to encounter when breeding for drought tolerance.

2.2.1 Physiological basis of yield reduction in maize under drought stress

Drought affects maize grain yield to some degree at almost all growth stages (Bänziger *et al.,* 2000b). However, the magnitude in reduction of grain yield under drought depends on the developmental stage of the crop, severity and duration of the stress and susceptibility of a particular genotype to stress (Lorens *et al.,* 1987). Grain yield is highly correlated with kernel number per plant rather than with weight per kernel (Bolaños and Edmeades, 1996; Edmeades *et al.,* 1998). Therefore, moisture deficiency at any growth stage of maize development affects its productivity (Saini and Westgate, 2000; Vasal *et al.,* 1997; Denmead and Shaw, 1960) but the most susceptible stage is during flowering. Several workers have reported that extreme sensitivity occurs at two weeks bracketing flowering; -2 to 22 days after silking with a peak at 7 days after silking (Grant *et al.,* 1989).

Early reproductive development is the most vulnerable stage to water deficits because reduction in grain yield is irreversible if drought stress coincides with flowering (Boyer, 1992; Bolanos and Edmeades, 1993) due to abnormal floral, kernel and ear development (Edmeades *et al.,* 1999; Zinselmeier *et al.,* 2002). Drought stress during the reproductive stage reduces the green leaf area of a plant to accelerated senescence and from radiation use efficiency (Dwyer *et al*., 1992). These directly affects photosynthesis process by reducing sink strength and kernel development since assimilates are distributed to the tassel resulting in barrenness, kernel abortion, shriveled grains or poor seed set (Vasal *et al.,* 1997) thereby reducing the harvest index (HI). Drought stress prior to anthesis inhibited silk growth more than the ear growth (Westgate, 1997; Bolanos and Edmeades 1993). The authors also indicated that the difference between days to silking and days to pollen shed caused an increase in anthesis-silking interval (ASI) resulting into barren or poorly developed ears. However, water deficit occurring during anthesis did not affect pollen viability (Herrero and Johnson, 1981; Boyer and Westgate, 2004) but it could cause a decline in silk receptivity if pollination was delayed (Bassetti and Westgate, 1993). Even if pollen was not limiting and gamete and floral development proceed normally, kernel number could be reduced by only a few days of dehydration at flowering (Schoper *et al.,* 1986). DuPlessis and Djikhuis (1967) found an 82 % decline in grain yield as ASI increased from zero to 28 days. Bolanos and Edmeades (1993) working on 'Tuxpeno Sequia' maize inbred line reported a reduction in grain yield by 90 % as ASI increased from 0 to 10 days. A long ASI is generally associated with drought susceptibility, slow ear growth, barrenness and low HI (Edmeades *et al.,* 1998).

Drought during seedling establishment causes a decrease in crop leaf area and percent radiation interception (Andrade *et al*., 1996) reducing photosynthetic rate to nearly zero (Zinselmeier *et al.,* 1999). During vegetative growth, drought stress leads to reduction in size of leaves, stems and roots thereby affecting the expansion of the assimilatory structures. This lowers assimilation of a plant at the time of ear development since dry matter accumulation is dependent on the size of assimilatory surface (Denmead and Shaw, 1960). They therefore reported a 25 %, 50 % and 21 % grain yield reduction during vegetative, silking and ear development stages respectively. In agreement, Grant *et al.* (1989), Rhoades and Bennett (1990) and Kiniry and Ritchie (1985) reported a reduction of 2 to 3 times more than the afore-mentioned scholars when drought coincided with flowering stage compared to other growth stages since during flowering, crops respond by abortion of ovaries, kernels and entire ears. Herrero and Johnson (1981) reported visible symptoms of midday wilting and leaf senescence. Sobrado (1987) indicated that leaf rolling, which occurs as a result of low leaf water status, reduced leaf area exposed to radiation.

Bruce *et al.* (2002) concluded that water deficits in a maize plant lead to a decline in photosynthetic rate due to reduction in light interception as leaf expansion is reduced or as leaves senesce, and to reduction in carbon fixation per unit leaf area as stomates close or as photo-oxidation damages the photosynthetic mechanism. The accumulation of abscisic acid (ABA) was found to enhance plant survival under drought stress but it reduced the overall crop productivity (Mugo *et al.* 2000). Retrospective studies have been conducted comparing genotypes released in different eras as a result of drought tolerance breeding programs. Results show improvement in performance under drought, averaging 126 kg/ha per cycle (Bruce *et al.,* 2002; Sanguineti *et al*., 2006). Screening under managed stress levels has led to more maize hybrids with superior and stable performance across a wide range of growing environments in ESA (Bänziger *et al.,* 2000a). To minimize yield reductions in arid and semi-arid tropics, farmers need to deploy effective production strategies such as escaping periods of low moisture availability through the manipulation of genotype maturity and planting date (Abrecht and Carberry, 1993) and cultivate drought-tolerant and nitrogen-use efficient maize varieties (Bolaños and Edmeades, 1993).

2.2.2 Drought selection indices in maize

Drought selection indices provide a measure of drought based on yield loss under drought stress conditions in comparison to well-watered conditions (Mitra, 2001). These indices have been used for screening drought-tolerant genotypes. A number of scholars have proposed drought selection indices used to effect precise selection of drought tolerant varieties. These indices are based on a mathematical relationship used to evaluate response of plant genotypes to drought stress (Clarke *et al.,* 1992; Sio-Se Mardeh *et al.,* 2006). They include:

i) *Stress Susceptibility Index (SSI):* (Fischer and Maurer, 1978)

$$SSI = \{1 - (Y_{si}/Y_{pi})\}/SI$$

ii) *Stress Tolerance Index (STI):* (Fernandez, 1992)

$$STI = (Y_{pi} \text{ x } Y_{si})/Y_p^2$$

iii) *Tolerance Index (TOL):* (Rosielle and Hamblin, 1981)

$$TOL = Y_{pi} - Y_{si}$$

iv) *Geometric Mean Productivity (GMP):* (Fernandez, 1992)

$$GMP = (Y_{pi} \text{ x } Y_{si})^{0.5}$$

v) *Yield Stability Index (YSI):* (Bouslama and Schapaugh, 1984)

$$YSI = Y_{si}/Y_{pi}$$

Where:

Stress intensity (SI) = 1- (Y_s/Y_p)

Y_{si} = yield of cultivar in stress condition

Y_{pi} = yield of cultivar in normal condition

Y_s = total mean yield in stress condition

Y_p = total mean yield in normal condition

Genetic increases in yield potential are best expressed in optimum environments, but they are also associated with enhanced yields under drought (Slafer and Araus, 2007). These yield gains are especially relevant given that further large increases in the area under irrigation are not expected, and land deterioration associated with intensive agriculture threatens areas under irrigation (Araus, 2004). In studying the yield of genotypes in two contrasting environments; stressed and non-stressed, Fernandez (1992) classified plants according to their performance in to four groups: genotypes with high yield in both environments (group A); genotypes with high yield only in non-stress environments (group B); genotypes with high yield in stress environments (group C); and genotypes with low yield in both environments (group D).

2.3 Combining ability and gene action

Combining ability (CA) is the capacity of parents to combine amongst each other during the process of hybridization such that favorable traits are transferred to their progenies (Panhwar *et al.,* 2008). Rawlings and Thompson (1962) adduced that CA is important in designing plant breeding programs, especially in testing procedures for studying and comparing the performance of lines in hybrid combinations.

Sprague and Tatum (1942) formulated two types of CA used in quantitative genetics: general combining ability (GCA) and specific combining ability (SCA). The term GCA refers to the average performance of an individual in a particular series of crosses. SCA is the deviation in the performance of hybrids from the expected productivity, based upon the average performance of lines involved in the hybrid combination (Miranda Filho and Gorgulho, 2001). GCA is due to additive genetic variance and additive gene interaction while SCA is due to the genes with dominance genetic variance or epistatic effects. Information on CA effects helps the breeder in choosing the parents with high GCA effects and progenies (hybrids) with high SCA effects (Dillen, 1975). Estimates of the variances due to GCA and SCA provide an appropriate diagnosis of the predominant role of additive or non-additive gene actions for a given character. If a ratio of GCA to SCA is greater than one (>1; unity), it implies that additive variance dominates the expression of that particular trait whereas a ratio less than one (<1) indicates the importance of non-additive variance in controlling the expression of that particular trait (Gardner, 1963).

Ojo *et al.* (2007) reported that the GCA mean squares were highly significant for grain yield and ear diameter. Meanwhile, the GCA/SCA ratio was larger than unity for all the studied traits except grain yield, indicating that the GCA was more important than SCA in the inheritance of these traits. Shashidhara (2008) in a study of early generation testing for combining ability in maize noticed a higher magnitude of SCA and GCA variance for the characters under study, the ratio of additive to dominance variance was lower than one for all the traits, indicating a higher dominance variance than additive variance. A study conducted by Gichuru *et al.* (2011) on combining ability of grain yield and agronomic traits in diverse maize lines with maize streak virus resistance for eastern Africa region, concluded that GCA effects interacted highly with the environments of production while SCA effects were much more stable. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects of parents. It aides in selecting desirable parents and crosses for the exploitation of heterosis. Crosses with high SCA should be used to generate genetic variability to permit selection in maize segregating generations.

2.3.1 North Carolina design II

The North Carolina Design II (factorial) mating design which was modified from North Carolina I by Comstock and Robinson (1948) is a factorial experiment that measures the variance of male and female main effects and the male x female interaction effects. It involves different sets of parents used as males and females. One female can be crossed to *n* number of males in all possible combinations creating female half-sibs (HS) groups as well as male HS groups (Kearsey and Pooni, 1996; Dabholkar, 1992). The statistical analysis of NCII is the two-way factorial analysis of variance. Appropriate F-tests can be made to test for the differences among males and among females and for the interactions of males and females.

Table 1: North Carolina II mating design for the possible crosses among parents

Parents (females)	Parents (males)			
	1	2	3	4
5	x_{15}	x_{25}	x_{35}	x_{45}
6	x_{16}	x_{26}	x_{36}	x_{46}
7	x_{17}	x_{27}	x_{37}	x_{47}
8	x_{18}	x_{28}	x_{38}	x_{48}

Advantages of using NC II for mating purposes are i) it gives two independent estimates for the GCA effects for the males and females. The independent estimates allow determination of maternal effects and calculation of heritability based on the male variance, which is free from maternal effects (Stuber, 1980); ii) it can handle more parents and produce fewer crosses; iii) it provides a distinct estimation of the dominance variance directly from the mean squares of parents and F_1 hybrids and iv) crossing of parents in sets can increase the sample size to be tested (Hallauer and Miranda, 1988).

2.3.2 Line x Tester mating design

Line x tester mating design was developed by Kempthorne (1957). It provides reliable information on the combining ability effects of parents and their hybrid combinations (Rashid *et al.*, 2007; Sarker *et al.,* 2002) and estimates of other genetic parameters (Saleem *et al.,* 2009), for the full exploitation of heterosis and evaluation of breeding values of genotypes for population improvement (Hallauer and Miranda, 1988). This is useful in deciding the relative ability of female and male lines to produce desirable hybrid combinations. It also provides information on various types of gene actions governing transfer of desirable traits thus enabling breeders to choose appropriate breeding methods for hybrid variety or cultivar development programmes.

The mating pattern involves lines and tester(s) crossed to each other producing full-sib progenies. Most often, the lines are used as female parents while the testers are used as male parents (Sharma, 1998). Matzinger (1953) and Hallauer (1975) defined a 'desirable tester' as one that combines the greatest simplicity in use and provides maximum information on performance to be expected from the tested lines when used in other combinations. Rawlings and Thompson (1962) defined a 'good tester' as one that classifies correctly relative performance of lines and discriminates efficiently among lines under test. Allison and Curnow (1966) defined the 'best tester' as one that maximizes the expected mean yield of the population produced from random mating of selected genotypes. The resulting testcross hybrids and parents are then evaluated over environments, in replicated trials to obtain estimates of genetic parameters unbiased by environmental effects. This provides guidelines in developing breeding programs and to predict future gain from selection (Hallauer and Miranda, 1988).

The use of testers in a maize recurrent selection program has been well documented by several workers (Horner *et al.*, 1976; Ali and Tepora, 1986; Beyene *et al.,* 2011a; Fan *et al.,* 2010). Testers can be developed from open-pollinated variety, a three-way cross hybrid, a single cross hybrid a synthetic variety and an inbred line. The line x tester mating design has been widely used in maize breeding (Joshi *et al.,* 2002; Sharma *et al.,* 2004) and continues to be applied in quantitative genetic studies in maize due to its significance. Newly-developed maize cultivars need to be tested in many locations for several years to determine their performance and adaptability before commercial release.

2.4 Heritability and correlation coefficients

The degree of correspondence between phenotypic and genotypic values enables breeders to measure and change the characteristics of a population (Dabholkar, 1992). This degree of correspondence is presented by a quantitative measure known as heritability. Heritability is a measure of the phenotypic variance among individuals in a population attributable to genetic causes and has predictive function in plant breeding (Nyquist, 1991). It provides information on the extent to which a particular morphogenetic character can be transmitted to successive generations. It is divided into broad-sense and narrow-sense. Broad-sense heritability is defined as the ratio of genetic variance to phenotypic variance; designated as $H^2 = V_G/V_P$. It captures the proportion of phenotypic variation due to genetic values that includes additive, dominant and epistatic effects. Narrow-sense heritability is defined as the ratio of additive variance to phenotypic variance; designated as $h^2 = V_A/V_P$. It captures only that proportion of genetic variation that is due to additive genetic values (Falconer and Mackay, 1995). Heritability in the narrow sense is the most important aspect in plant selection programs. It determines the breeding value of a population since response to artificial and natural selection depends on additive genetic variance (Hill *et al.,* 2008). Ramanujam and Thirumalachar (1967) reported the limitation of estimating heritability in narrow sense as inclusion of both additive and epistatic gene effects simultaneously thus, heritability estimates in the broad sense would be reliable if accompanied by a high genetic advancement.

Estimation of heritability in populations depends on the partitioning of observed variation into components that reflect unobserved genetic and environmental factors as well as empirical data on the observed and expected resemblance between relatives (Wray and Visscher, 2008). Knowledge of heritability influences the choice of selection techniques used by the plant breeder to decide which selection procedures would be most useful to improve a given character, to predict selection gain and to determine the relative importance of genetic effects in controlling that particular trait (Kashiani *et al.,* 2010; Laghari *et al.,* 2010). Characters with high heritability can easily be fixed with simple selection resulting in quick progress. Najeeb *et al.* (2009) highlighted that heritability alone had no practical importance without genetic advance. Genetic advance shows the degree of gain obtained in a character under a given selection pressure. High genetic advance coupled with high heritability estimates offers the most suitable condition for selection. A number of researchers (Rafiq *et al.,* 2010; Rafique *et al.,* 2004; Akbar *et al.,* 2008) have reported high heritability and high genetic advance for different yield controlling traits in maize. Therefore, availability of good knowledge of these genetic parameters existing in yield associated characters and the relative proportion of this genetic information in various quantitative traits is a pre-requisite for effective crop improvement.

Grain yield is the primary and most important trait during selection breeding (Edmeades *et al.,* 1997). However, yield is a complex character governed by several interacting intrinsic and extrinsic factors. In addition, heritability of yield under drought is low because the genetic variance for grain yield decreases more rapidly than the environment variance among plots, with increasing stress. In this regard, breeders utilize secondary traits associated with grain yield to increase selection efficiency (Bolaños and Edmeades, 1996). Most of the yield related traits are less complex, simply inherited and less influenced by the environmental deviations. Grafius (1960) suggested that selection based on component characters is more effective than on yield *per se*. To assess the phenotypic traits that may help step-up drought tolerance breeding, breeders express yield as combination of distinct independent processes; either agronomical or physiological yield components (Araus *et al*., 2002; Reynolds and Tuberosa, 2008). Bänziger *et al.* (2000b) identified secondary traits normally used in selecting for drought tolerance based on grain yield. They include ears per plant, anthesis-silking interval (ASI), leaf senescence, tassel size and leaf rolling. For a secondary trait to have maximum utility in selection, it must comply with several requirements (Bänziger *et al.,* 2000b; Lafitte *et al.,* 2003; Royo *et al.,* 2005): it must be genetically correlated with grain yield in a desired direction under stress; highly heritable with less genotype by environment interaction; an estimator of yield potential before harvest; cheap, fast to measure and non-destructive; stable over the measurement period; observed before or at flowering; not associated with yield loss in unstressed environments and gives actual measurement rather than a subjective score during quantitative trait loci analysis.

To end up with superior genotypes, the knowledge of inter-relationship of yield and yield related traits in a particular situation is a prerequisite. The extent of this character association between the desirable traits can be studied through correlation coefficients. Phenotypic correlation is the association between two characters while genotypic correlation expresses the extent to which two traits are genetically associated. Information on genotypic and phenotypic correlation coefficients among and between various plant traits aid in developing suitable maize selection criterion for a wide range of environments and to ascertain the degree to which these traits are associated with economic productivity. Olakojo and Olaoye (2011) concluded that genotypic and phenotypic correlation coefficients as well as heritability estimates were suitable as models for yield improvement and selection for *Striga lutea* tolerant genotypes in maize.

2.5 Heterotic grouping in maize

The term ‘heterosis’ was coined by Shull (1908). It is expressed as per cent increase or decrease of F_1 hybrid over mid-parent (average or relative heterosis), better parent (heterobeltiosis) and the best commercial check (standard heterosis). Several workers have proposed that heterosis is as a result of dominant effects (Bruce, 1910; Keeble and Pellow, 1910) and over-dominance effects (Shull, 1911; East and Hayes, 1912) while Carena and Hallauer (2001) and Swanson-Wagner *et al*. (2006) observed that expression of heterosis involves all modes of gene action and is extensively exploited to produce hybrids with superior performance (Troyer, 2004). To systematically exploit heterosis in hybrid breeding, it is necessary to acknowledge the concept of heterotic groups and patterns. This is because the correlation between the performance of the inbred lines *per se* and their hybrid progenies for most of the agronomic traits especially grain yield is normally weak (Hallauer, 2007). In addition, to broaden the genetic base of a breeding programme, the best alternative is to incorporate the exotic lines in to the already established heterotic groupings (Preciado-Ortiz and Johnson, 2004). Melchinger and Gumber (1998) defined a heterotic group as “a group of related or unrelated genotypes from the same or different populations, which display similar combining ability effects and heterotic response when crossed with genotypes from other genetically distinct germplasm groups.” By comparison, Carena (2008) defined the term heterotic pattern as a specific pair of two heterotic groups, which express high hybrid performance in their cross. In conclusion, Melchinger and Gumber, (1998) asserted that heterotic patterns have a strong impact in crop improvement because they pre-determine to a large extent the type of germplasm used in a hybrid breeding program over a long period of time.

Heterotic patterns were empirically created by breeders to facilitate the management of the germplasm within their programs (Tracy and Chandler, 2006). Conventionally, a breeder makes crosses between selected maize lines based on pedigree information (Smith *et al*., 1997). This provides insufficiencies in maize breeding because pedigree information alone is not enough in deciding which materials are to be included in crosses. Assigning of maize genotypes into heterotic groups has been the key to the economic success of the crop because it allows for the full exploitation of heterosis (Troyer, 2006) particularly for grain yield. Fan *et al.* (2009) observed that crossing maize lines from different heterotic groups would offer a breeder better chances of obtaining potentially good hybrids. Adequate characterization of germplasm, assignment of genotypes into heterotic groups, and extensive testing has facilitated the utilization of heterosis by breeders (Reif *et al*., 2005). It has been validated by Ricci *et al.* (2007) that combination of lines from different heterotic groups results in hybrids with higher chances of expression of hybrid vigor. A series of combining ability studies have been done by several breeders (Beck *et al*., 1990; Vasal *et al*., 1992) to establish heterotic patterns among several maize populations and gene pools, and to maximize their yield for hybrid development.

Tropical maize germplasm often belong to two main heterotic groups A and B (Vasal *et al.,* 1999). These groups enable breeders to classify maize lines into different clusters depending on the source of material and the ultimate goal. Globally, there are three methods used in classification maize germplasm into heterotic groups. First, use of genotypes' specific and general combining ability (HSGCA) as designed by Fan *et al.* (2009). This method defines the combining ability between a representative tester from a known heterotic group and a new maize line. The hypothesis behind this classification is that positive SCA effects between inbred lines indicate that lines are in opposite heterotic groups and lines in the same heterotic group exhibited negative SCA effects when crossed. Secondly, is the specific combining ability and line pedigree (SCA_PY). This method is based on on the information of the hybrid yield in the field (Bhatnagar *et al.,* 2004). Thirdly, is by use of molecular markers to compute genetic distance among the maize inbred lines in the crosses (Barata and Carena, 2006). Molecular markers can detect the DNA polymorphism at any stage of plant development and they are not influenced by the environment (Aguiar *et al.,* 2008). Once maize lines have been grouped into their different heterotic groups, crosses can then be made to develop hybrids. This can ideally be done by crossing inbred lines that are unrelated. The best combinations of hybrids result from a cross between lines from different heterotic groups (López Anido *et al.,* 2004). For example, in CIMMYT breeding programs, maize germplasm classified under heterotic group A are N3, tuxpeńo, Kitale and red types while those under heterotic group B includes Eto, Blanco Equador and Lancaster types (Vasal *et al.,* 1999). Studies done by CIMMYT workers have identified single crosses CML312/CML442, CML395/CML444, CML202/CML395 and CML505/CML509 as suitable testers for use within SSA since they are widely adapted for tropical environments (Sebastian, 2007).

CHAPTER THREE

3.1 MATERIALS AND METHODS

3.1.1 Germplasm selection

The doubled haploid (DH) lines were derived from BC_1F_1 of nine tropical maize backcross populations (Table 2) by means of *in vivo* haploid induction at the Monsanto facility in Mexico. The nine source populations were obtained by crossing four drought tolerant (DT) donor lines with four recurrent parents (CML312SR, CML395, CML444 and CML488). Three of the DT donor lines were extracted from La Posta Seq C7, a drought- tolerant population developed at CIMMYT Mexico through recurrent selection among full sib/S_1 families (Edmeades *et al.,* 1999). The fourth donor parent was developed from M37W, a temperate high yielding line. The recurrent parents were drought tolerant lines, have good combining abilities and were adapted across several environments in SSA (Magorokosho *et al.,* 2008).

The developed 250 BC_1F_1 seeds from each of the nine populations were submitted for DH induction. After *in vivo* induction, treatment with colchicine and selfing, a total of 806 DH lines were received from Monsanto. The DH lines were grown at Kenya Agricultural Research Institute (KARI) - Kiboko, during the 2009/2010 short rains season. Based on the results of *per se* evaluation using germination and good stand establishment, plant type, low ear placement, and well-filled ears, the best 100 DH lines were selected for this study.

Table 2: CIMMYT backcross populations used for DH lines production

Parent	Source population
1.	La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395
2.	La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444
3.	La Posta Seq C7-F96-1-2-1-1-B-B-B/CML488/CML488
4.	La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS [MSR/312]-117-2-2-1-2-B-4-B-B-B-B/CML312SR
5.	La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395
6.	La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444
7.	La Posta Seq C7-F71-1-2-1-2-B-B-B/CML488/CML488
8.	CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV- 03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395
9.	CML395/La Posta Seq C7-F102-1-3-1-2-B-B-B/CML395

Table 3: Pedigree of parents used in developing the DH testcross hybrids in the nursery.

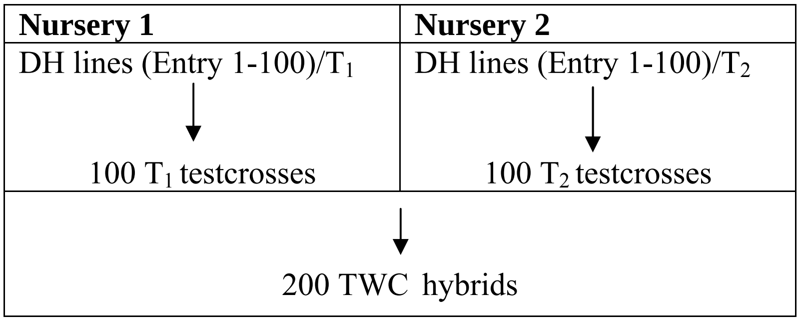
Parent	No. of lines extracted	Pedigree
1	13	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-8-B-B-B
2	14	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-11-B-B
3	3	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML488/CML488) DH-7-B-B
4	9	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B-4-B-B-B-B/CML312SR) DH-8-B-B-B
5	16	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-4-B-B-B
6	32	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-2-B-B-B
7	3	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML488/CML488) DH-4-B-B
8	6	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395) DH-8-B-B
9	4	(CML395/La Posta Seq C7-F102-1-3-1-2-B-B-B/CML395) DH-1-B-B
Tester 1 CML395/CML444		**CML395:** 90323(B)-1-B-1-B-4 **CML444:** P43C9-1-1-1-1-1-BBBB
Tester 2 CML312/CML442		**CML312:** S89500F2-2-2-1-1-B-5 **CML442:** [M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BBB

# denotes sibbing

3.2 Methodology

3.2.1 Formation of DH testcrosses

The nursery was laid out at KARI-Kiboko field station in November 2011. Two sets of nurseries were designed, one for each tester group. Each DH line (female parent) was crossed to each single cross tester (male parent) in a North Carolina II mating design (Comstock and Robinson, 1948) to form 200 three-way cross (TWC) hybrids.



Where:

Tester 1 (T_1) - CML395/CML444

Tester 2 (T_2) - CML312/CML442

Figure 1: Mating between the female and males parents in the nursery blocks

The experimental unit for each male parent was 100 rows of 5 m long spaced at 0.25 m between plants and by 0.75 m between rows. The male plots were staggered three times (-5 days, 0 days and +5 days) to effect nicking with female plants at pollination. The first male rows were planted five days prior to planting the female rows (-5 days), the second male rows were planted five days later; on the same day as the female rows (0 days) while the third male rows were planted five days after planting the female rows (+5 days). One seed per hill was sown in each plot of 21 hills. In the female plots, each DH line was sown in five rows with the same spacing as the male plots giving a total of 500 rows per nursery. Two seeds were sown per hill and later thinned to one plant per hill after emergence.

Agronomic practices were carried out as required. Di-ammonium phosphate (D.A.P) was applied at the rate of 24 Kg N and 60 Kg P_2O_5 ha^{-1} at planting. Calcium Ammonium Nitrate (C.A.N) at the rate of 40 Kg N ha^{-1} was used for topdressing one month after planting. Irrigation was applied throughout the growth period to supplement the rain water and ensure good growth and development of plants. Stem borers were controlled in all rows and plants at 6-leaf stage and at 10-leaf stage using Bulldock® (5 % Cyfluthrin) pesticide. In the female plots, clean plants i.e. free from diseases and other defects, were selected to make maximum number of crosses possible within the plot. First ear shoots in all plants were covered with shoot bags as they emerged to control pollination. Pollen was harvested daily from at least 10 plants in the male rows when 20 % of the males had started shedding pollen. This was bulked and used to pollinate as many plants in the female rows as possible. This was done to ensure a large seed set sufficient for all the planned field evaluations. At harvest, ears from the female plots that were rotten or with any kind of contamination were discarded. The remaining ears were bulked per entry, dried, shelled and treated with Murtano® (20 % Lindane and 26 % Thiram) against storage pests for use in the field evaluations.

3.2.2 Field evaluations of the DH testcrosses

Out of the 200 DH testcross hybrids harvested, 160 hybrids with enough seed were used for field evaluations. The experimental material for the field evaluations therefore comprised of 160 DH testcrosses, three commercial check hybrids (DK-8053, H513 and PH3253) and two local checks (resistant and susceptible to drought stress) according to each trial site specification (Table 4).

Table 4: Experimental materials used in field evaluations across eleven locations in Kenya during 2012-2013 seasons

ENTRY	LINE	TESTER	CROSS	PEDIGREE
1	1	1	1x1	CKDHL0007//(CML395/CML444)
2	2	1	2x1	CKDHL0020//(CML395/CML444)
3	3	1	3x1	CKDHL0021//(CML395/CML444)
4	4	1	4x1	CKDHL0023//(CML395/CML444)
5	5	1	5x1	CKDHL0032//(CML395/CML444)
6	6	1	6x1	CKDHL0043//(CML395/CML444)
7	7	1	7x1	CKDHL0048//(CML395/CML444)
8	8	1	8x1	CKDHL0053//(CML395/CML444)
9	9	1	9x1	CKDHL0056//(CML395/CML444)
10	10	1	10x1	CKDHL0058//(CML395/CML444)
11	11	1	11x1	CKDHL0063//(CML395/CML444)
12	12	1	12x1	CKDHL0065//(CML395/CML444)
13	13	1	13x1	CKDHL0076//(CML395/CML444)
14	14	1	14x1	CKDHL0086//(CML395/CML444)
15	15	1	15x1	CKDHL0110//(CML395/CML444)
16	16	1	16x1	CKDHL0114//(CML395/CML444)
17	17	1	17x1	CKDHL0121//(CML395/CML444)
18	18	1	18x1	CKDHL0130//(CML395/CML444)
19	19	1	19x1	CKDHL0134//(CML395/CML444)
20	20	1	20x1	CKDHL0140//(CML395/CML444)
21	21	1	21x1	CKDHL0172//(CML395/CML444)
22	22	1	22x1	CKDHL0225//(CML395/CML444)
23	23	1	23x1	CKDHL0235//(CML395/CML444)
24	24	1	24x1	CKDHL0237//(CML395/CML444)
25	25	1	25x1	CKDHL0241//(CML395/CML444)
26	26	1	26x1	CKDHL0248//(CML395/CML444)
27	27	1	27x1	CKDHL0254//(CML395/CML444)
28	28	1	28x1	CKDHL0266//(CML395/CML444)
29	29	1	29x1	CKDHL0267//(CML395/CML444)
30	30	1	30x1	CKDHL0283//(CML395/CML444)
31	31	1	31x1	CKDHL0284//(CML395/CML444)
32	32	1	32x1	CKDHL0298//(CML395/CML444)
33	33	1	33x1	CKDHL0299//(CML395/CML444)
34	34	1	34x1	CKDHL0313//(CML395/CML444)
35	35	1	35x1	CKDHL0324//(CML395/CML444)
36	36	1	36x1	CKDHL0331//(CML395/CML444)
37	37	1	37x1	CKDHL0340//(CML395/CML444)
38	38	1	38x1	CKDHL0345//(CML395/CML444)
39	39	1	39x1	CKDHL0356//(CML395/CML444)
40	40	1	40x1	CKDHL0364//(CML395/CML444)
41	41	1	41x1	CKDHL0369//(CML395/CML444)
42	42	1	42x1	CKDHL0380//(CML395/CML444)
43	43	1	43x1	CKDHL0386//(CML395/CML444)
44	44	1	44x1	CKDHL0399//(CML395/CML444)
45	45	1	45x1	CKDHL0416//(CML395/CML444)
46	46	1	46x1	CKDHL0430//(CML395/CML444)
47	47	1	47x1	CKDHL0439//(CML395/CML444)
48	48	1	48x1	CKDHL0441//(CML395/CML444)
49	49	1	49x1	CKDHL0443//(CML395/CML444)
50	50	1	50x1	CKDHL0448//(CML395/CML444)
51	51	1	51x1	CKDHL0460//(CML395/CML444)
52	52	1	52x1	CKDHL0470//(CML395/CML444)
53	53	1	53x1	CKDHL0471//(CML395/CML444)
54	54	1	54x1	CKDHL0474//(CML395/CML444)
55	55	1	55x1	CKDHL0475//(CML395/CML444)
56	56	1	56x1	CKDHL0476//(CML395/CML444)
57	57	1	57x1	CKDHL0482//(CML395/CML444)
58	58	1	58x1	CKDHL0484//(CML395/CML444)
59	59	1	59x1	CKDHL0493//(CML395/CML444)
60	60	1	60x1	CKDHL0494//(CML395/CML444)
61	61	1	61x1	CKDHL0497//(CML395/CML444)
62	62	1	62x1	CKDHL0498//(CML395/CML444)
63	63	1	63x1	CKDHL0500//(CML395/CML444)
64	64	1	64x1	CKDHL0501//(CML395/CML444)
65	65	1	65x1	CKDHL0505//(CML395/CML444)
66	66	1	66x1	CKDHL0509//(CML395/CML444)
67	67	1	67x1	CKDHL0513//(CML395/CML444)
68	68	1	68x1	CKDHL0526//(CML395/CML444)
69	69	1	69x1	CKDHL0556//(CML395/CML444)
70	70	1	70x1	CKDHL0561//(CML395/CML444)
71	71	1	71x1	CKDHL0574//(CML395/CML444)
72	72	1	72x1	CKDHL0585//(CML395/CML444)
73	73	1	73x1	CKDHL0588//(CML395/CML444)
74	74	1	74x1	CKDHL0591//(CML395/CML444)
75	75	1	75x1	CKDHL0608//(CML395/CML444)
76	76	1	76x1	CKDHL0610//(CML395/CML444)
77	77	1	77x1	CKDHL0624//(CML395/CML444)
78	78	1	78x1	CKDHL0625//(CML395/CML444)
79	79	1	79x1	CKDHL0631//(CML395/CML444)
80	80	1	80x1	CKDHL0634//(CML395/CML444)
81	1	2	1x2	CKDHL0007//(CML312/CML442)
82	2	2	2x2	CKDHL0020//(CML312/CML442)
83	3	2	3x2	CKDHL0021//(CML312/CML442)
84	4	2	4x2	CKDHL0023//(CML312/CML442)
85	5	2	5x2	CKDHL0032//(CML312/CML442)
86	6	2	6x2	CKDHL0043//(CML312/CML442)
87	7	2	7x2	CKDHL0048//(CML312/CML442)
88	8	2	8x2	CKDHL0053//(CML312/CML442)
89	9	2	9x2	CKDHL0056//(CML312/CML442)
90	10	2	10x2	CKDHL0058//(CML312/CML442)
91	11	2	11x2	CKDHL0063//(CML312/CML442)
92	12	2	12x2	CKDHL0065//(CML312/CML442)
93	13	2	13x2	CKDHL0076//(CML312/CML442)
94	14	2	14x2	CKDHL0086//(CML312/CML442)
95	15	2	15x2	CKDHL0110//(CML312/CML442)
96	16	2	16x2	CKDHL0114//(CML312/CML442)
97	17	2	17x2	CKDHL0121//(CML312/CML442)
98	18	2	18x2	CKDHL0130//(CML312/CML442)
99	19	2	19x2	CKDHL0134//(CML312/CML442)
100	20	2	20x2	CKDHL0140//(CML312/CML442)
101	21	2	21x2	CKDHL0172//(CML312/CML442)
102	22	2	22x2	CKDHL0225//(CML312/CML442)
103	23	2	23x2	CKDHL0235//(CML312/CML442)
104	24	2	24x2	CKDHL0237//(CML312/CML442)
105	25	2	25x2	CKDHL0241//(CML312/CML442)
106	26	2	26x2	CKDHL0248//(CML312/CML442)
107	27	2	27x2	CKDHL0254//(CML312/CML442)
108	28	2	28x2	CKDHL0266//(CML312/CML442)
109	29	2	29x2	CKDHL0267//(CML312/CML442)
110	30	2	30x2	CKDHL0283//(CML312/CML442)
111	31	2	31x2	CKDHL0284//(CML312/CML442)
112	32	2	32x2	CKDHL0298//(CML312/CML442)
113	33	2	33x2	CKDHL0299//(CML312/CML442)
114	34	2	34x2	CKDHL0313//(CML312/CML442)
115	35	2	35x2	CKDHL0324//(CML312/CML442)
116	36	2	36x2	CKDHL0331//(CML312/CML442)
117	37	2	37x2	CKDHL0340//(CML312/CML442)
118	38	2	38x2	CKDHL0345//(CML312/CML442)

ENTRY	LINE	TESTER	CROSS	PEDIGREE
119	39	2	39x2	CKDHL0356//(CML312/CML442)
120	40	2	40x2	CKDHL0364//(CML312/CML442)
121	41	2	41x2	CKDHL0369//(CML312/CML442)
122	42	2	42x2	CKDHL0380//(CML312/CML442)
123	43	2	43x1	CKDHL0386//(CML312/CML442)
124	44	2	44x2	CKDHL0399//(CML312/CML442)
125	45	2	45x2	CKDHL0416//(CML312/CML442)
126	46	2	46x2	CKDHL0430//(CML312/CML442)
127	47	2	47x2	CKDHL0439//(CML312/CML442)
128	48	2	48x2	CKDHL0441//(CML312/CML442)
129	49	2	49x2	CKDHL0443//(CML312/CML442)
130	50	2	50x2	CKDHL0448//(CML312/CML442)
131	51	2	51x2	CKDHL0460//(CML312/CML442)
132	52	2	52x2	CKDHL0470//(CML312/CML442)
133	53	2	53x2	CKDHL0471//(CML312/CML442)
134	54	2	54x2	CKDHL0474//(CML312/CML442)
135	55	2	55x2	CKDHL0475//(CML312/CML442)
136	56	2	56x2	CKDHL0476//(CML312/CML442)
137	57	2	57x2	CKDHL0482//(CML312/CML442)
138	58	2	58x2	CKDHL0484//(CML312/CML442)
139	59	2	59x2	CKDHL0493//(CML312/CML442)
140	60	2	60x2	CKDHL0494//(CML312/CML442)
141	61	2	61x2	CKDHL0497//(CML312/CML442)
142	62	2	62x2	CKDHL0498//(CML312/CML442)
143	63	2	63x2	CKDHL0500//(CML312/CML442)
144	64	2	64x2	CKDHL0501//(CML312/CML442)
145	65	2	65x2	CKDHL0505//(CML312/CML442)
146	66	2	66x2	CKDHL0509//(CML312/CML442)
147	67	2	67x2	CKDHL0513//(CML312/CML442)
148	68	2	68x1	CKDHL0526//(CML312/CML442)
149	69	2	69x2	CKDHL0556//(CML312/CML442)
150	70	2	70x2	CKDHL0561//(CML312/CML442)
151	71	2	71x2	CKDHL0574//(CML312/CML442)
152	72	2	72x2	CKDHL0585//(CML312/CML442)
153	73	2	73x2	CKDHL0588//(CML312/CML442)
154	74	2	74x2	CKDHL0591//(CML312/CML442)
155	75	2	75x2	CKDHL0608//(CML312/CML442)
156	76	2	76x2	CKDHL0610//(CML312/CML442)
157	77	2	77x2	CKDHL0624//(CML312/CML442)
158	78	2	78x2	CKDHL0625//(CML312/CML442)
159	79	2	79x2	CKDHL0631//(CML312/CML442)
160	80	2	80x2	CKDHL0634//(CML312/CML442)
161	Commercial check			DK-8053
162	Commercial check			H513
163	Commercial check			PH3253
164	Local check 1 (Resistant to drought)			
165	Local check 2 (Susceptible to drought)			

The trials were conducted across six locations in Kenya under different moisture regimes (well-watered, managed drought and random drought conditions) at Kiboko, Embu, Kakamega, Mtwapa, Kirinyaga Technical Institute (KTI) and Homabay.

Table 5: Agro-climatic description of trial sites

Site	Longitude	Latitude	Elevation (masl)	Rainfall (mm/yr)	Temperature (0^oC) Min	Max	Mega Environment
Kiboko	37° 75'E	2° 15'S	975	530	14.3	35.1	Dry Mid-Altitude
Embu	37° 42'E	0° 49'S	1510	1200	14.1	25.0	Wet Lower Mid-Altitude
Kakamega	34° 45'E	0° 16'N	1585	1916	12.8	28.6	Wet Upper Mid-Altitude
Mtwapa	39° 44'E	3° 50'S	15	1200	22.0	30.0	Low land coastal tropic
KTI	37° 19'E	0° 34'S	1282	1500	18.0	24.0	Wet Lower Mid-Altitude
Homabay	34° 27'E	0° 31'S	1751	700	17.1	34.8	Dry Mid-Altitude

In season I (April - August 2012), trials were grown under well-watered conditions at Kiboko, Embu, KTI and Kakamega where standard agronomic practices recommended in maize production were applied. In season II (June - October 2012), trials were grown under managed drought stress at Kiboko and Homabay during a rain-free period. Irrigation was done at the beginning of the season to establish a good plant stand but later on withdrawn at 43 to 57 days after planting (averagely 50 days before anthesis) to induce stress at flowering. The crops completed their growth cycle without any further irrigation or rain. In season III (November 2012 - March 2013), trials were grown under random drought at Embu, Kiboko, Mtwapa, KTI and Kakamega. There ought to have been a protracted period of deficient rainfall during the growing season but instead, the rainfall intensity and duration was high during the short rains season. As a result, data collected was more or less not as had been expected thus were not regarded as under random drought conditions.

An alpha lattice design of 15 x 11 with two replications was used. Each entry was planted in two-row plots of 5 m long spaced at 0. 25 m between hills and 0.75 m between rows. Two seeds were sown per hill and three weeks after emergence thinned to one plant per hill to give a plant population of 53,333 plants per hectare but compensating by leaving two plants in the adjacent hill whenever a hill had both plants missing. Di-ammonium phosphate (D.A.P) fertilizer was applied at the rate of 24 kg N and 60 kg P_2O_5 ha^{-1} as recommended for the area. Nitrogen in form of Calcium Ammonium Nitrate (C.A.N) at the rate of 40 Kg N ha^{-1} was given in two split applications: at planting and six weeks after emergence. Irrigation was applied to supplement the rain water and ensure good growth and development of plants. Stem borers were controlled in all rows and plants at 6-leaf stage and at 10-leaf stage using Bulldock® 0.05 GR granule, which is a systemic insecticide; a synthetic pyrethroid with β-cyfluthrin 0.5 g/Kg as the active ingredient.

Data collection

Data was collected on the following traits based on protocol by Bänziger *et al.* (2000b):

***Anthesis date* (AD):** Number of days after planting when 50 % of the plants per plot had shed pollen.

***Days to silking* (SD):** Number of days after planting when 50 % of the plants per plot showed silks.

***Anthesis to silking interval* (ASI):** Determined as the difference between days to silking and anthesis.

***Plant height* (PH):** Determined by measuring representative of 10 plants (in cm) from the base to the insertion of the first tassel branch of the same plant.

***Ear height* (EH):** Determined by measuring representative of 10 plants (in cm) from the base to the insertion of the top ear of the same plant.

***Ear aspect* (EA):** This was scored using a scale of 1-5. One indicated clean, uniform and large cobs with the preferred texture in the area whereas 5 indicated small non-uniform and diseased cobs with an undesirable texture.

***Plant aspect* (PA):** This was scored using a scale of 1 to 5. One indicated plants with uniform height, low and uniform ear placement and free of diseases whereas 5 indicated tall plants with high and irregular ear placement and are affected by diseases.

***Root lodging* (RL):** Percentage of plants that were inclined by more than 35º before harvest.

***Stem lodging* (SL):** Percentage of plants whose stems were broken below the ear.

***Leaf Senescence* (SEN):** Scores were taken on a scale of 1-10 during grain-filling stage by estimating the percentage of dead leaf area and dividing it by 10 (Figure 1).

1 = 10 % dead leaf area, 2 = 20 % dead leaf area, 3 = 30 % dead leaf area, 4 = 40 % dead leaf area, 5 = 50 % dead leaf area, 6 = 60 % dePad leaf area, 7 = 70 % dead leaf area, 8 = 80 % dead leaf area 9 = 90 % dead leaf area and 10 =100 % dead leaf area.

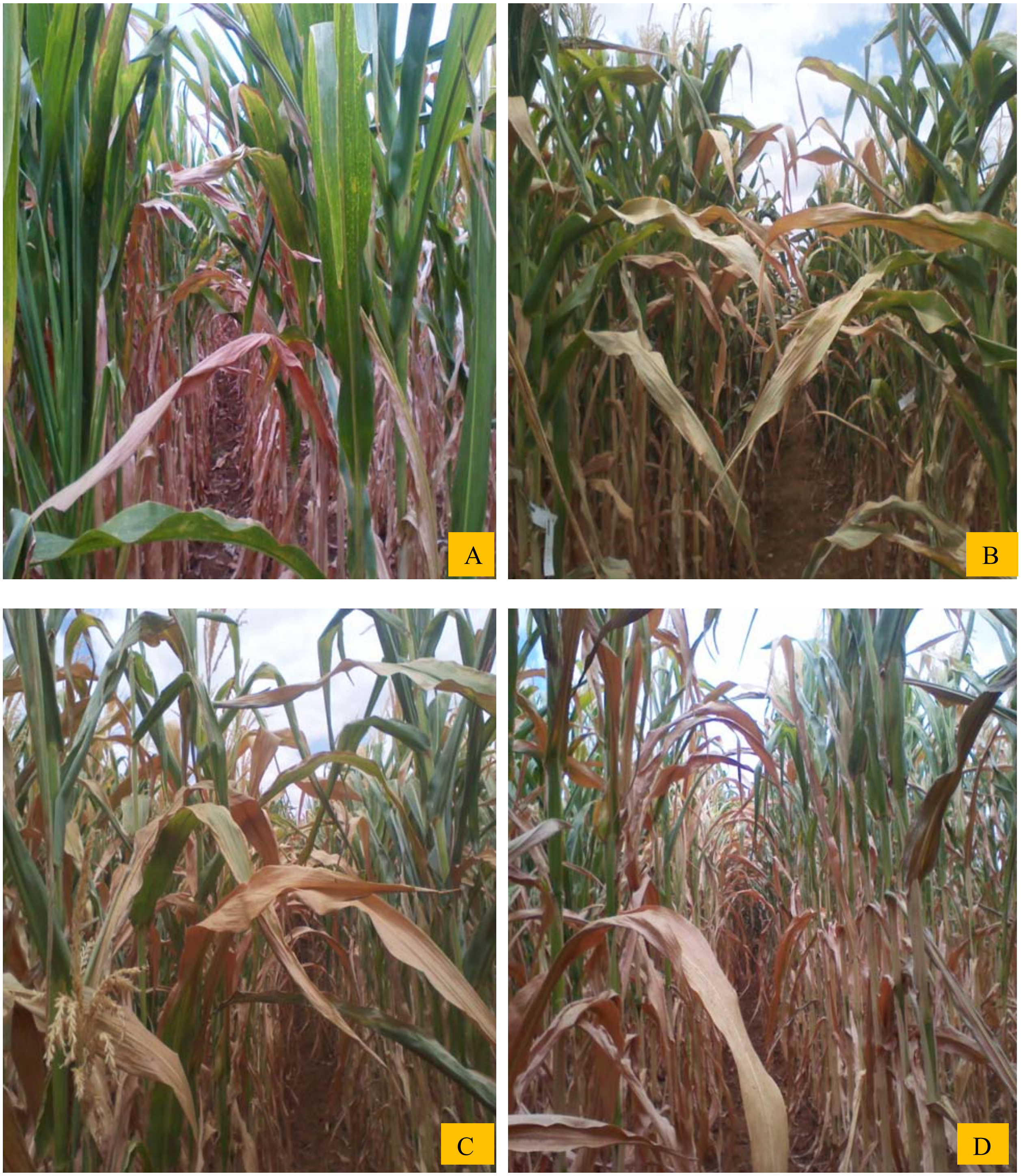


Plate 1: Pictorial presentation of scores for leaf senescence under drought stress using a scale of 1-10 for different DH genotypes 14 weeks after planting (A) Drought tolerant (score-3); (B) score – 4; (C) score – 6; (D) Drought susceptible (score – 8).

***Number of plants at harvest* (NP):** These were plants that survived to complete maturity. A count was taken before harvesting after having removed the plants of the first hill on each side of the row.

***Number of ears per plant* (EPP):** The ear of the plants of the first hill on each side of the plot was removed before harvesting because of the border effects. Number of ears with at least one fully developed grain were then counted and divided by the number of harvested plants.

Foliar diseases: Natural infestation of **Gray leaf spot** (*Cercospora zea-maydis)* (GLS), **Northern leaf blight** (*Exerohilum turcicum)* (ET), **Maize leaf rust** *(Puccinia sorghii)* (PS), **Maize streak virus** (MSV) were visually scored on a scale of 1 to 5 (1 = resistance; 5 = susceptible) by assessing the severity of the symptoms on plants in the entire plot. Diseases were scored twice during the growth period of crops, with the first scores taken when there were perceivable differences between plots for the severity of disease symptoms. **Ear rot** was scored on a scale of 1 (clean, no rot) to 5 (completely rotten). All ears, including the rotten ones were kept for measuring field and grain weights.

***Grain moisture* (MOI):** Percent water content of grain as measured at harvest.

***Field weight* (GYF):** This was the weight of the ears per plot taken directly after harvest after removal of husks, but before shelling was done.

***Grain yield* (GYG):** this was measured as the weight of grains only, after shelling had been done. It was calculated using shelled grain weight adjusted to 12.5 % moisture content.

3.3 Statistical analysis

Data collected were entered into MS excel sheet (Fieldbook). Cleaning and preliminary analyses were done using Fieldbook (Vivek *et al.*, 2007) which is built on MS excel software to compute mean performance of all the studied traits, genetic variances, entry and location variances and heritability estimates on plot mean basis. Analysis of variance (ANOVA) was carried out for individual as well as for combined environments, considering environments as random effects and genotypes as fixed effects. General Linear Model procedure (PROC GLM) in Statistical Analysis System 9.2 (SAS, 2003) was used to compute general combining ability effects for the DH inbred lines and testers, specific combining ability effects for cross combinations, standard errors and phenotypic and genotypic correlations. Adjusted means for individual sites were calculated using the mixed procedure (PROC MIXED) of SAS and mean separation was done using the least significant difference (LSD) method of Snedecor and Cochran (1967).

CHAPTER FOUR

4.1 RESULTS AND DISCUSSION

The analyzed data from well-watered, managed drought and random drought conditions were presented in individual site basis and also combined across test sites per treatment, respectively. Only the top 10 best, last 5 DH testcross hybrids and commercial checks were reported on for this work, the rest of the data is presented in the appendices for reference. The meteorological data on weather elements such as rainfall, temperature and relative humidity at the time of evaluations is presented in Table 6. This data was used to classify the treatments as optimum, managed drought and random conditions.

Table 6: Meteorological data for various weather elements at various trial sites at the time of field evaluations.

	Mtwapa		**Kiboko**		**Embu/KTI**		**Kakamega**	
	2011	**2012**	**2011**	**2012**	**2011**	**2012**	**2011**	**2012**
Maximum temperature (0^oC)	30.66	30.23	32.52	32.14	25.36	24.60	25.63	28.60
Minimum temperature (0^oC)	23.44	23.48	17.08	16.71	14.70	14.40	12.80	14.20
Relative humidity (%)	74.22	74.92	81.20	68.73	80.12	78.64	84.80	81.53
Rainfall (mm)	1204.86	1500.04	322.41	530.22	1236.40	1549.30	1562.60	1729.70

4.1.1 Well-watered environments

4.1.1.1 Performance of the DH testcrosses in individual sites

The mean performances of the experimental materials for all the studied traits were calculated for each site as presented in Tables 7-10. Variation in mean grain yield was observed across different trial sites (Figure 2). The hybrids performed best in Kakamega (4.99 to 11.75 t ha^{-1}) followed by Kiboko (4.73 to 9.58 t ha^{-1}), Embu (2.65 to 8.83 t ha^{-1}) and KTI (2.24 to 8.83 t ha^{-1}) with a mean grain yield of 8.79 t ha^{-1} in Kakamega, 7.17 t ha^{-1} in Kiboko, 6.05 t ha^{-1} in Embu and 5.85 t ha^{-1} in KTI.

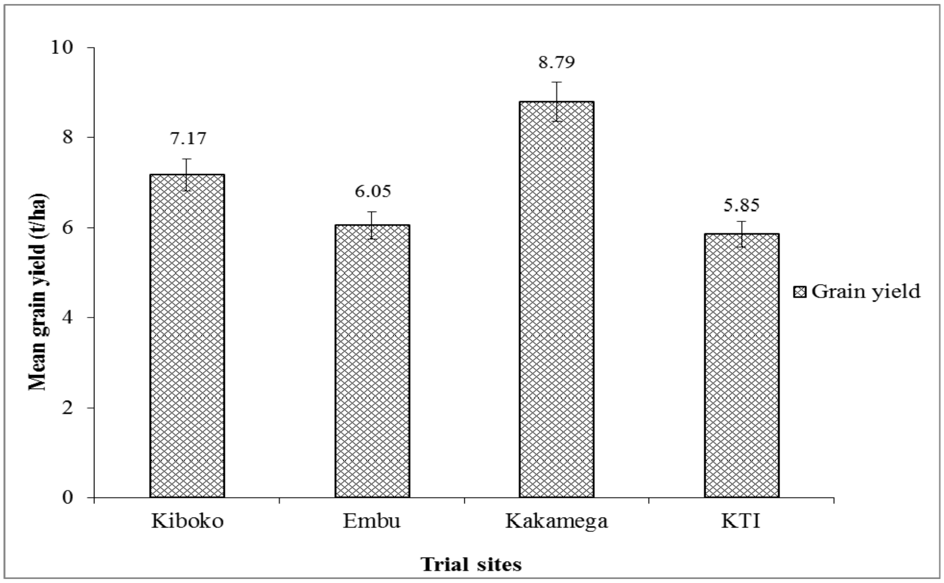


Figure 2: A graph showing the mean performance for grain yield of the doubled haploid maize testcross hybrids evaluated across four locations in Kenya under well-watered conditions during 2012 season.

Nine DH hybrids yielded higher than the best check hybrid (DK-8053) in Kiboko, 16 DH hybrids yielded higher than the best check hybrid (Duma 43) in Embu, nine hybrids yielded higher than the best check hybrid (H624) in Kakamega while 16 DH hybrids yielded higher than the best check hybrid (H513) in KTI (Table 7-10). This meant that some of the DH hybrids were superior relative to the best commercial hybrids available to farmers in various agro-zones. DH lines therefore present useful sources for improving yield in maize growing areas in Kenya. Similar results were observed by Beyene *et al.* (2011a) while studying the testcross performance of 75 DH hybrids. They observed high yielding potential of the experimental hybrids at Embu, Kakamega, KTI and Kiboko with 47.8 %, 61.5 %, 36.5 % and 180 % above the best commercial check WH505, respectively. The best performing DH hybrids in two or three locations were $L_{36}xT_1$, $L_{11}xT_2$, $L_{40}xT_2$, $L_{29}xT_1$, $L_{22}xT_1$ and $L_{34}xT_2$. In agreement, L_{36}, L_{11} and L_{40} were among the best general combiners for grain yield (Table 14) under well-watered conditions. These observations are indicative of the presence of good genetic materials in the DH inbred lines that can be used to form hybrid combinations for improved yield.

The experimental hybrids took fewer days to tassel in Kiboko (54 to 65 days) and longer in Kakamega (69 to 82 days). This could be attributed to environmental variations at Kiboko and Kakamega with respect to temperature, rainfall and altitude (Table 5). Early flowering of plants is desirable in maize breeding programs because the plants are able to grow and physiologically mature before any form of stress sets in. The lowest mean grain yield observed in KTI compared to other well-watered sites might be due to more days to pollen shed (70 days) and reduced rainfall during grain filling stage (Table 10). This led to the significant ($p<0.05$) lower yields due to late maturity and poor grain filling of ears. High yield of DH testcrosses observed in Kakamega (Table 9) could be attributed to high rainfall experienced during the season providing optimal growth conditions for the hybrids.

Table 7: Mean performance for grain yield and other agronomic traits of the top 10, last 5 DH hybrids and check hybrids evaluated at Kiboko, Kenya under well-watered conditions.

RANK	CROSS	GY $t\ ha^{-1}$	AD Days	ASI days	EH cm	PH cm	EPP #	EA 1-5	PA 1-5	MOI %	RL %	SL %
1	30x2	9.58	60	2.0	175	285	1.00	1.95	3.0	18.88	-0.02	7.27
2	36x1	9.45	62	1.0	166	266	1.04	2.01	3.0	19.59	0.04	27.79
3	4x1	9.20	61	0.5	169	278	1.00	2.03	2.5	18.54	3.21	5.04
4	17x2	9.06	60	0.0	157	274	1.08	2.45	2.0	17.23	-0.37	39.35
5	13x2	9.03	58	2.5	147	263	1.00	2.24	2.5	17.78	2.50	51.33
6	68x1	9.01	60	0.0	154	252	0.99	2.52	3.0	18.67	0.56	28.85
7	16x2	8.95	60	0.0	161	269	0.98	2.72	2.0	17.37	1.16	35.83
8	11x2	8.94	59	1.0	152	269	1.02	2.24	3.0	19.00	0.00	36.66
9	55x2	8.88	61	0.0	148	259	0.94	2.46	2.5	18.30	0.88	11.47
10	2x2	8.83	57	2.0	139	243	0.98	2.03	3.0	18.68	-0.43	25.66
156	15x1	5.19	64	-0.5	158	266	0.89	2.75	3.0	16.44	12.17	49.51
157	22x2	5.07	59	2.0	124	226	0.90	2.56	3.5	16.83	0.24	38.15
158	61x1	4.93	63	0.0	137	244	0.96	2.54	3.5	16.28	-0.41	21.09
159	26x2	4.77	58	-1.5	114	234	0.97	2.82	4.0	13.01	3.04	22.90
160	28x2	4.73	58	1.5	125	227	1.00	2.74	4.0	14.21	2.31	56.39
	DK-8053	8.86	58	3.0	122	241	0.97	1.98	2.0	18.17	2.95	13.73
	H513	7.62	57	2.5	152	270	0.95	2.33	3.5	17.42	1.63	17.59
	PH3253	6.18	58	2.5	142	265	1.05	2.75	3.5	14.57	0.10	10.29
	WH403	6.79	60	2.0	143	265	1.00	2.26	3.5	17.12	-0.02	47.10
	Duma 43	6.58	55	1.0	119	275	1.04	2.75	4.0	14.97	0.03	0.60
Grand mean of trial		**7.17**	**60**	**0.8**	**149**	**260**	**0.97**	**2.30**	**2.9**	**17.90**	**2.00**	**30.40**
CV %		**12.5**	**1.8**	**260.2**	**5.7**	**5.0**	**7.4**	**13.7**	**20**	**4.8**	**163.8**	**45.8**
Heritability		**0.74**	**0.91**	**0.74**	**0.81**	**0.68**	**0.06**	**0.69**	**0.50**	**0.84**	**0.04**	**0.57**
LSD (0.05)		**1.56**	**1.86**	**1.51**	**15.32**	**18.43**	**0.14**	**0.59**	**1.20**	**1.39**	**6.08**	**24.16**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; EA: Ear aspect; PA: Plant aspect; MOI: Grain moisture; RL: Root lodging; SL: Stem lodging.

Table 8: Mean performance for grain yield and other agronomic traits of the top 10, last 5 DH hybrids and check hybrids evaluated at Embu, Kenya under well-watered conditions.

RANK	CROSS	GY t ha	AD Days	ASI days	EA 1-5	PA 1-5	EH Cm	PH cm	EPP #	MOI %	RL %	SL %
1	40x2	8.83	78	2.0	1.46	2.52	122	231	0.95	25.04	0.44	0.00
2	16x2	8.36	77	1.0	1.34	1.86	126	237	0.98	23.43	3.35	0.00
3	64x2	8.29	75	0.0	1.19	2.85	116	231	1.00	23.57	-0.35	1.30
4	29x1	7.81	76	2.5	1.20	3.05	125	249	0.97	24.10	1.68	1.30
5	49x2	7.69	75	1.5	2.06	2.05	118	237	0.99	23.30	-0.52	0.00
6	22x1	7.67	76	2.0	1.29	2.55	130	244	0.93	25.42	0.90	0.00
7	72x2	7.66	73	2.5	1.07	2.57	115	229	0.98	23.04	3.97	1.30
8	34x2	7.66	77	4.5	1.44	1.97	111	218	0.94	26.84	2.03	0.00
9	12x2	7.64	73	2.0	1.49	2.96	128	238	0.98	23.81	3.25	4.10
10	23x1	7.63	79	1.0	1.50	2.38	124	249	0.97	22.80	1.53	1.30
156	49x1	3.60	87	4.0	2.21	3.00	101	210	0.89	23.72	7.40	0.00
157	28x2	3.51	73	3.0	2.85	2.57	85	184	0.94	24.17	3.43	0.00
158	24x2	3.47	66	1.5	2.50	3.55	95	211	0.89	20.05	12.34	14.7
159	1x1	2.95	89	4.0	3.20	3.40	114	209	0.61	24.59	5.50	1.35
160	79x1	2.65	77	3.0	2.50	4.06	98	213	0.81	20.25	7.79	0.00
	DK-8053	6.39	73	1.0	1.97	2.53	97	210	0.90	21.82	0.91	0.00
	H513	6.36	75	2.0	2.02	2.53	130	236	1.01	24.27	8.84	2.80
	PH3253	5.94	73	2.0	2.07	2.99	115	237	0.98	21.49	2.36	3.95
	DH04	4.12	70	4.5	2.67	4.33	111	246	0.80	19.81	9.60	0.00
	Duma 43	7.23	75	3.0	1.36	2.97	124	251	0.95	22.25	3.33	1.35
Grand mean of trial		**6.05**	**80**	**2.3**	**2.0**	**2.80**	**107**	**217**	**0.93**	**23.30**	**3.10**	**1.10**
CV (%)		**18.9**	**2.6**	**65.8**	**20.0**	**23.0**	**11.4**	**7.7**	**7.1**	**5.6**	**157.9**	**173.0**
Heritability (H^2)		**0.60**	**0.91**	**0.59**	**0.49**	**0.18**	**0.60**	**0.60**	**0.36**	**0.57**	**0.00**	**0.62**
LSD (0.05)		**1.98**	**3.86**	**2.97**	**0.76**	**1.24**	**20.90**	**26.10**	**0.13**	**2.49**	**8.70**	**3.84**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; EPP: Ears per plant; MOI: Grain moisture; RL: Root lodging; SL: Stem lodging

Table 9: Mean performance for grain yield and other agronomic traits of the top 10, last 5 DH hybrids and check hybrids evaluated at Kakamega, Kenya under well-watered conditions.

RANK	CROSS	GY t ha^{-1}	AD days	ASI days	EA 1-5	EH cm	PA 1-5	PH cm	EPP #	MOI %	RL %	SL %	GLS 1-5	ET 1-5	PS 1-5
1	28x1	11.75	74	-0.08	2.35	140	2.94	265	1.22	25.26	0.00	0.00	1.50	2.53	1.75
2	22x1	11.59	75	1.22	1.16	139	2.40	248	1.16	27.51	0.00	0.00	1.50	2.28	1.50
3	29x1	11.56	76	-0.14	2.22	144	2.38	273	1.16	24.43	0.00	0.00	1.50	2.25	1.50
4	34x2	11.52	75	0.88	1.94	141	2.02	267	1.07	26.11	0.00	0.00	1.50	2.50	1.50
5	71x1	11.43	74	0.56	1.91	139	1.92	263	1.16	24.20	0.00	1.40	1.50	2.00	1.50
6	36x2	11.35	76	0.82	1.90	149	2.57	272	1.04	28.10	1.30	1.30	1.50	2.21	1.75
7	13x2	11.34	73	0.98	2.25	142	2.58	257	1.25	23.14	0.00	1.45	1.50	2.53	1.50
8	36x1	11.27	80	-0.80	1.87	147	2.33	266	1.07	24.41	17.20	2.80	1.50	1.98	1.75
9	11x2	11.21	75	-0.56	2.27	140	3.10	266	1.13	27.11	1.40	0.00	1.50	2.29	1.50
10	46x2	10.97	76	0.03	2.49	143	2.09	265	1.05	26.56	0.00	0.00	1.50	2.28	1.50
156	18x2	6.17	77	-3.28	2.84	128	4.55	252	1.03	22.34	1.45	1.45	1.50	3.44	1.50
157	80x1	6.13	81	0.55	2.72	139	3.86	263	1.04	24.82	7.35	0.00	1.50	2.94	1.50
158	23x2	5.43	76	-0.50	3.73	129	3.86	244	1.06	24.52	0.00	1.45	1.50	2.97	1.50
159	24x2	5.17	79	-12.2	3.64	96	4.99	217	1.23	22.39	14.50	16.6	1.50	3.46	1.50
160	3x1	4.99	81	-0.10	3.12	151	4.93	271	1.06	25.70	1.45	1.45	1.50	3.18	1.50
	DK-8053	8.46	73	0.91	2.97	114	2.89	244	1.02	26.81	0.00	0.00	1.50	2.26	2.25
	H513	8.98	72	0.07	2.41	144	3.05	255	1.26	22.82	0.00	0.00	1.50	2.26	1.50
	PH3253	7.76	75	-0.61	2.66	127	3.13	253	1.08	22.20	3.95	0.00	1.50	1.97	1.50
	H624	11.20	77	0.69	1.51	182	3.10	288	1.06	25.32	1.40	0.00	1.50	2.03	1.50
	H520	7.87	71	0.46	2.46	142	3.46	258	1.16	20.21	2.80	0.00	1.75	2.48	1.50
Grand mean of trial		**8.79**	**77**	**-0.50**	**2.52**	**141**	**3.00**	**261**	**1.11**	**25.03**	**1.90**	**0.70**	**1.5**	**2.6**	**1.5**
CV (%)		**10.2**	**2.1**	**-305**	**12.5**	**6.1**	**17.0**	**4.1**	**9.4**	**7.0**	**196.0**	**271.5**	**4.1**	**9.4**	**7.6**
Heritability (H^2)		**0.84**	**0.86**	**0.56**	**0.66**	**0.77**	**0.16**	**0.69**	**0.53**	**0.51**	**0.64**	**0.46**	**0.00**	**0.75**	**0.49**
LSD (0.05)		**1.57**	**3.01**	**2.71**	**0.61**	**14.69**	**0.20**	**0.97**	**19.3**	**3.33**	**6.31**	**3.81**	**0.12**	**0.45**	**0.23**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; EH: Ear height; PA: Plant aspect; PH: Plant height; EPP: Ears per plant; MOI: Grain moisture; RL: Root lodging; SL: Stem lodging; GLS: Gray leaf spot; ET: *E. turcicum*; PS: *Puccinia sorghi* (leaf rust).

Table 10: Mean performance for grain yield and other agronomic traits of the top 10, last 5 DH hybrids and check hybrids evaluated at KTI, Kenya under well-watered conditions.

RANK	CROSS	GY t ha	AD Days	ASI Days	EA 1-5	PA 1-5	EH cm	PH Cm	ER %	EPP #	MOI %	RL %	SL %
1	26x1	8.83	68	-1.0	2.45	3.01	126	257	4.87	1.05	21.70	-0.87	3.28
2	5x2	8.50	68	0.5	3.35	2.52	108	225	10.34	0.87	22.39	1.97	0.59
3	21x2	8.30	68	-0.5	3.78	1.96	118	248	7.46	1.04	21.78	-0.27	-1.88
4	11x2	8.26	68	0.0	3.02	1.93	117	244	11.46	0.99	24.30	0.23	2.28
5	15x2	8.16	69	0.0	2.88	2.44	133	265	6.94	0.94	20.59	-0.22	-0.93
6	27x1	7.99	73	-0.5	2.73	1.97	152	277	3.71	1.12	25.51	0.25	1.82
7	57x1	7.92	69	-0.5	2.88	3.04	144	269	7.25	1.09	22.87	3.27	3.84
8	58x2	7.76	69	0.5	3.12	2.40	125	249	6.51	1.18	22.41	3.35	-1.33
9	18x2	7.64	65	-0.5	3.54	2.44	117	244	9.47	0.91	21.82	0.27	2.60
10	40x2	7.64	71	0.5	2.69	2.86	124	245	6.22	0.97	25.13	-0.31	0.19
156	47x1	3.74	74	-0.5	3.63	2.89	121	242	14.19	0.97	22.89	1.87	-1.24
157	43x1	3.66	78	1.0	2.95	3.00	111	226	1.29	1.04	21.66	9.76	12.25
158	42x1	3.61	73	2.0	2.55	3.43	112	231	2.28	0.97	24.13	3.29	3.07
159	28x2	3.40	68	1.0	3.68	3.54	79	176	12.24	0.93	22.35	4.83	21.21
160	74x1	2.24	73	3.5	3.44	4.62	104	210	3.90	0.91	22.97	-0.28	4.89
	DK-8053	6.80	64	1.0	3.03	2.97	101	232	19.80	0.96	20.58	-0.33	-1.26
	H513	7.26	65	0.5	3.34	3.31	138	267	8.26	1.05	22.66	0.30	-0.92
	PH3253	6.97	64	1.0	3.05	2.67	106	245	10.93	0.97	20.48	2.95	5.37
	DH04	6.62	65	0.0	3.31	3.39	108	229	18.06	0.99	20.92	0.30	4.13
	Duma 43	5.81	61	-0.5	3.77	3.12	94	254	30.29	0.66	19.15	2.66	4.05
Grand mean of trial		**5.85**	**70**	**0.4**	**2.9**	**2.8**	**126**	**249**	**8.21**	**0.97**	**22.90**	**1.5**	**2.6**
CV (%)		**19.35**	**2.4**	**431.7**	**13.8**	**22.8**	**11.2**	**7.8**	**73.9**	**9.57**	**4.3**	**165.1**	**212.2**
Heritability (H^2)		**0.60**	**0.91**	**0.58**	**0.67**	**0.63**	**0.22**	**0.59**	**0.65**	**0.32**	**0.72**	**0.28**	**0.61**
LSD (0.05)		**2.00**	**2.69**	**1.88**	**0.75**	**20.45**	**1.24**	**11.66**	**26.38**	**0.18**	**1.94**	**4.83**	**9.98**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; ER: Ear rot; EPP: Ears per plant; MOI: Grain moisture; RL: Root lodging; SL: Stem lodging.

Longer ASI observed for check hybrids impacted negatively on grain yield leading to below average performance as compared to the DH testcross hybrids. Consequently, check hybrids were taller than most of the DH hybrids in Kiboko and Embu (Table 7 and 8). This led to increased susceptibility by plants to stem lodging. In addition, tall plants are not desirable since photosynthates are used for upright growth instead of being channeled into sinks for kernel formation, compromising on grain yield.

Leaf blight and GLS are cosmopolitan fungal diseases, occurring world-wide (Pratt and Gordon, 2006) and cause significant losses in grain yield. These diseases sometimes occur simultaneously but recurrent epidemics are common when favored by weather conditions, planting of susceptible cultivars and continuous maize cropping (Bigirwa *et al.,* 2001; Pratt and Gordon, 2006). Non-significant differences were observed among the experimental hybrids for the foliar diseases scored in Kakamega (Table 9). High resistance to gray leaf spot (GLS) and leaf rust was observed with disease scores of 1.5 to 1.75 and moderate resistance to common leaf blight with disease scores of 1.98 to 3.5. Crosses between L_{50} x T_1, L_{45} x T_2 and L_{51} x T_2 were highly resistant to the foliar diseases and were also high yielding (8.3-10.5 t/ha). This implied that these lines carried favorable alleles for high yield potential and resistance to common tropical maize diseases thus could be selected for hybrid formation with improved resistance to maize foliar diseases.

4.1.1.2 Mean performance of DH testcross hybrids across locations

Mean values for grain yield and other agronomic traits of genotypes averaged across four locations are presented in Table 11. The performances of the DH hybrids were above or comparable to those of commercial check hybrids.

Table 11: Mean performance for grain yield and other agronomic traits of the top 10, last 5 DH hybrids and check hybrids combined across locations in Kenya under well-watered.

			GY	AD	ASI	EA	PA	EH	PH	ER	EPP	MOI	RL	SL
RANK	ENTRY	CROSS	t ha^{-1}	days	days	1-5	1-5	cm	cm	%	#	%	%	%
1	91	11x2	8.85	69	0.75	2.31	2.74	129	251	9.42	1.01	24.17	0.92	9.89
2	29	29x1	8.57	70	1.13	2.02	2.64	133	259	4.27	1.04	22.44	1.80	14.42
3	110	30x2	8.55	70	1.75	2.11	2.87	139	261	6.81	0.98	22.97	5.49	2.15
4	116	36x2	8.53	70	0.99	1.96	2.65	142	265	9.11	0.99	23.56	3.62	12.09
5	120	40x2	8.53	72	0.50	2.14	2.96	136	253	2.22	1.01	24.32	1.12	5.99
6	26	26x1	8.51	69	-1.14	2.13	2.75	141	267	5.69	1.04	21.34	1.36	10.04
7	93	13x2	8.39	68	1.75	2.00	2.89	128	244	6.45	1.03	21.46	1.12	13.41
8	135	55x2	8.38	72	-0.13	2.62	2.49	133	250	9.43	1.02	21.94	0.42	2.28
9	28	28x1	8.37	69	1.13	2.46	2.77	129	250	4.32	1.05	22.43	1.90	5.58
10	23	23x1	8.34	72	0.37	2.50	2.59	134	257	4.81	1.00	21.72	-0.15	5.56
156	80	80x1	5.28	75	1.25	2.18	3.50	134	252	5.93	1.00	21.40	2.98	8.78
157	106	26x2	5.26	67	-1.00	2.84	3.16	113	230	16.27	0.95	18.48	2.89	7.54
158	103	23x2	4.75	70	0.88	3.12	3.56	114	223	14.41	1.02	21.51	1.47	19.97
159	104	24x2	4.61	65	-2.25	3.24	4.47	102	222	13.76	1.01	19.05	7.02	36.89
160	108	28x2	4.60	68	1.62	3.21	3.12	101	206	13.23	1.00	20.59	2.58	18.57
	161	DK-8053	7.67	67	1.38	2.48	2.59	107	231	17.87	0.96	21.90	0.81	2.84
	162	H513	7.62	67	1.26	2.51	3.12	139	256	10.98	1.07	21.83	2.89	4.78
	163	PH3253	6.73	67	1.25	2.65	3.03	123	250	10.84	1.02	19.62	2.52	4.91
	164	Local check 1	7.19	68	1.74	2.45	3.57	135	256	15.75	0.96	20.93	3.03	12.41
	165	Local check 2	6.93	65	0.89	2.60	3.36	121	262	15.65	0.96	19.22	2.27	1.40
Grand mean of trial			**6.97**	**69**	**1.03**	**2.48**	**2.86**	**127**	**246**	**8.77**	**1.00**	**22.28**	**2.01**	**8.25**
Entry variance			**0.80**	**8.65**	**0.57**	**0.05**	**0.06**	**90.59**	**98.36**	**12.54**	**0.00**	**0.92**	**1.06**	**6.94**
Location variance			**1.79**	**70.65**	**1.46**	**0.20**	**0.02**	**246**	**235.9**	**21.99**	**0.01**	**10.13**	**0.20**	**162.34**
Location x Entry variance			**0.22**	**1.43**	**0.49**	**0.05**	**0.08**	**8.17**	**11.25**	**17.63**	**0.00**	**0.33**	**0.00**	**24.42**
Heritability (H^2)			**0.83**	**0.93**	**0.65**	**0.65**	**0.48**	**0.88**	**0.83**	**0.62**	**0.19**	**0.77**	**0.41**	**0.37**
LSD (0.05)			**1.10**	**2.19**	**1.51**	**0.46**	**0.69**	**9.79**	**12.22**	**7.68**	**0.09**	**1.43**	**3.43**	**9.47**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; ER: Ear rot; EPP: Ears per plant; MOI: Grain moisture; RL: Root lodging; SL: Stem lodging.

Grain yield of the DH hybrids ranged from 4.6 to 8.9 t/ha while that of check hybrids was 6.7 to 7.7 t/ha. Over 61 % of DH testcross hybrids yielded significantly higher than the best commercial check (DK-8053). This showed the superiority of the DH hybrids over the commercially available hybrids in Kenyan maize growing areas. The best DH hybrid, entry 91 (8.9 t/ha) yielded 15.4 % better than the best commercial check (DK-8053). The yield advantage recorded by the best hybrid in the present study was lower than that observed by Beyene *et al.* (2011a) while evaluating 75 DH testcrosses for performance and adaptation to different environments. They reported a 29.5 % higher grain yield for the best DH testcross hybrid over the best commercial check. The least performing hybrids for grain yield were L_{23} x T_2 (4.75 t/ha), L_{24} x T_2 (4.61 t/ha) and L_{28} x T_2 (4.6 t/ha). In addition, the top ten hybrids performed better for other agronomic traits measured (Table 11). None of the top ten entries had higher percentage of rotten ears and lower number of ears per plant than the best commercial check (DK-8053). On average, the DH hybrids flowered more or less the same time (71 days) as the check hybrids (69 days).

Mean scores recorded by the DH hybrids for ear aspect (2.41) and plant aspect (2.86) were relatively lower than those of the check hybrids for ear aspect (2.53) and plant aspect (3.13). This implied that the DH testcross hybrids had ears with desirable characteristics at harvest in terms of cob size, kernel size, color and texture, kernel row arrangement and general uniformity as well as desirable plant aspects of low and uniform ear placement, uniform plant height, complete husk cover and disease free plants compared to check hybrids. Check hybrids had higher incidence of ear rot (14.2 %) than DH hybrids (8.8 %). This indicated that most of the ears of checks were rotten at the time of harvest. This impacted negatively on yield since it reduced grain weight and led to loss of the harvestable portion.

The location variance was higher than the entry variance and location x entry variance for all the studied traits. The entry variance was greater than the location x entry variance for grain yield, days to anthesis, ASI, ear height, plant height and root lodging (Table 11) suggesting that the hybrids had wider adaptation. Therefore, hybrids could be developed targeting general production environment.

Heritability estimates for the studied traits across four locations are presented in Table 10. In agreement with findings from other studies (Olakojo and Olaoye, 2011; Beyene *et al.,* 2011a), high magnitude of broad sense heritability was observed in most of the studied traits. High estimates were observed for days to anthesis (93 %), ear height (88 %), grain yield (83 %), plant height (83 %), ASI (65 %), ear aspect (65 %) and ear rot (62 %) indicating the preponderance of additive gene action in the inheritance of these traits. Similar to the present results, Kashiani *et al.* (2008), Wannows *et al.* (2010), Rafiq *et al.* (2010) and Tengan *et al.* (2012) also estimated high heritability for most of the aforementioned characters. In contrast to the present findings, Bello *et al.* (2012) found low heritability for days to anthesis. Moderate heritability estimates were recorded for plant aspect (48 %) and root lodging (41 %). In the case of foliar diseases scored in Kakamega, high heritability estimates were observed for leaf blight (75 %), moderate estimates for leaf rust (49 %) while for gray leaf spot there was no genetic variation among genotypes (Table 9).

4.1.1.3 Analysis of variance of inbred lines *per se* and DH hybrids

The analysis of variance (ANOVA) for combining ability is presented in Table 12 and 13. Highly significant (p<0.001) differences were observed among lines, testers and line x testers for all characters except due to testers for ASI, ears per plant and stem lodging.

Table 12: Mean squares, error and coefficients of variation of parents and DH hybrids from the analysis of variance across four locations in Kenya under well-watered conditions.

		MEAN SQUARES										
SOURCE	**df**	GY **t ha^{-1}**	AD **Days**	ASI **days**	EA **1-5**	PA **1-5**	EH **cm**	PH **cm**	ER **%**	EPP **#**	RL **%**	SL **%**
Environment (E)	3	579.58***	22717.15***	474.16***	63.06***	7.73***	79339.24***	77689.42***	6971.19***	1.71***	81.49***	53516.09***
GCA $_{Lines}$	79	3.25***	55.62***	11.23***	0.77***	1.33***	1085.25***	1244.98***	185.12***	0.01***	24.19***	212.09***
GCA $_{Testers}$	1	252.97***	6155.66***	3.2	19.38***	4.75***	28167.72***	9135.68***	5905.7***	0.01	268.2***	15.45
SCA $_{Line\ x\ Tester}$	79	9.52***	8.80***	3.02***	0.33***	0.63***	335.81***	814.63***	66.67***	0.01	15.22	115.61**
GXE	237	1.09	3.77*	2.37***	0.17*	0.45*	162.57	305.2	30.05	0.01	14.05	80.55
GCA/SCA ratio		0.34	6.32	3.72	2.33	2.11	3.23	1.53	2.78	1.0	1.59	1.83
Error	639	1.09	3.15	1.44	0.14	0.38	154.34	298.59	29.89	0.01	14.10	79.61
CV%		14.99	2.49	158.5	15.45	21.42	9.53	7.03	62.38	8.45	186.14	108.23

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; ER: Ear rot; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging.

Table 13: The proportion of sum of squares (SS) attributed to environment, genotype and genotype x environment interaction as a percentage of the total sum of squares.

	% SS										
SOURCE	GY **t ha^{-1}**	AD **days**	ASI **days**	EA **1-5**	PA **1-5**	EH **cm**	PH **cm**	RL **%**	SL **%**	ER **%**	EPP **#**
Environment (E)	39.55	81.11	30.76	38.01	3.42	42.36	31.21	1.26	54.65	21.82	33.05
GCA (L)	5.84	5.23	19.19	12.28	15.46	15.26	13.17	9.85	5.70	15.26	6.66
GCA (T)	5.75	7.33	0.07	3.89	0.70	5.01	1.22	1.38	0.01	6.16	0.07
SCA (G)	17.12	0.83	5.17	5.22	7.36	4.72	8.62	6.20	3.11	5.50	4.36
G X E	5.85	1.06	12.15	8.31	15.64	6.86	9.69	17.16	6.50	7.43	12.42
Error	15.84	2.40	19.85	17.85	35.33	17.55	25.55	46.45	17.32	19.93	29.32

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; RL: Root lodging; SL: Stem lodging; ER: Ear rot; EPP: Ears per plant.

This indicated that both additive and non-additive gene effects were important in the genetic expression of most of the studied traits. Joshi *et al.* (2002) reported similar results while Sharma *et al.* (2004) reported preponderance of additive gene effects only on the assessed traits of maize. Environment had large effects on all the measured traits with the greatest being on ear and plant heights. This illustrated the distinctness of the trial sites in terms of climatic and edaphic factors, imposing differential performances by the testcross hybrids for various characters. The differential responses of lines and hybrids were consistent with the recent works of Beyene *et al.* (2011b) while inconsistent with results reported by Gakunga *et al.* (2012) who found differential responses of lines and not hybrids for grain yield and other characters used to measure stem borer resistance in maize. This implied that the the DH hybrids could be developed targeting a particular environment.

Partitioning of genotype mean squares into GCA and SCA effects revealed highly significant ($p<0.001$) mean squares due to GCA for all the studied traits, while the mean squares due to SCA were non-significant for number of ears per plant and lodging. Variance due to lines was highly significant ($p<0.001$) for all the characters studied. This indicated the variability among DH lines and possibility of identifying useful lines through selection for commercial exploitation. Variances due to testers were of a larger magnitude than those of lines and line x tester for all characters (Kanagarasu *et al.,* 2010) except ASI, ears per plant and stem lodging indicating as expected, greater diversity among the testers than the lines. The significant variation presented by genotypes pointed out the importance of SCA in governing some traits in the experimental hybrids.

The GCA mean squares of lines and testers were greater than those observed for SCA for all the traits. This showed the preponderance of additive gene action in governing these agronomic traits both in the DH lines and testers. Similarly, GCA/SCA ratio was greater than unity for most of the studied traits except for grain yield indicating superiority of additive over non-additive gene action in controlling these agronomic traits of maize. It is noted however, even though non-additive gene effects were on average small, they are still important in promotion of unique combinations (Hallauer and Miranda, 1988) in hybrid formation.

Because of the theoretical expectation of homogeneity of DH lines, the interaction of the environment with genotypes (GEI) was very important in this study if the DH lines were to be exploited for on-farm cultivation. Low effects of GEI were observed for all the studied traits compared to genotype main effects (Table 12). In contrast, a study done by Epinat-Le Signor *et al.* (2001) on interpretation of GEI for 132 early maize hybrids deviates from the current findings as they observed higher GEI effects than genotypic effects in those materials. The effect of GEI was highly significant ($p<0.001$) for ASI. This clearly showed the diversity of the genotypes and their differences in environmental responses across the four well-watered locations for this trait. Mean squares due to GEI were significant ($p<0.05$) for days to anthesis, ear and plant aspects indicating the differential performance of the DH hybrids across locations. These results concurred with study done by Wilde *et al.* (2010) evaluating doubled haploid testcrosses developed from European flint maize landraces in various environments. Thus, it was possible to improve the DH lines further for these traits through simple selection.

The sources of variation except error, explained 74.1 % of the total variation showing good experimental accuracy (Table 13). The most important source of variation was the environment main effects accounting for 39.6 % for yield, 81.1 % for days to anthesis and 30.8 % for ASI. Variability due to genotypic effects were lower than those reported by Butrón *et al*. (2004) for a set of 49 maize hybrids evaluated across five environments with different levels of pink stem borer infestation and Malvar *et al*. (2005) for a diallel among 12 populations. Genotype main effects had a yield advantage of 65.8 % over GEI signifying better performance for grain yield by the DH testcrosses across well-watered environments, and that they were less influenced by the environmental factors. Butrón *et al*. (2004) and Malvar *et al*. (2005) reported that genotypes variation for grain yield were mainly due to earliness, vigor effects and environmental factors. A small error of 1.09 for grain yield indicated a high precision and accuracy of the experiment.

4.1.1.4 Combining ability analyses across well-watered sites

The general combining ability (GCA) estimates of parents is presented in Table 14. Lines with positive GCA effects for grain yield but negative GCA effects for disease are found to be suitable parents for variety development (Simmonds, 1979). Out 80 DH lines used in this study, 54 % had positive GCA effects for grain yield. This means that there was greater source for parental selection to be considered in hybrid combinations. Inbred line L_{36} (CKDHL0331) presented the highest positive (1.55) and significant ($p<0.001$) GCA estimate for grain yield. Inbred lines L_4, L_{13}, L_{11}, L_5 and L_{71} were also found to have positive and significant ($p<0.05$) GCA effects for grain yield. This implied that these lines had a higher favorable allele frequency for grain yield and could be selected as parents in the hybridization programs or used to form a synthetic population that would be improved for grain yield.

Among the top ten high performing DH inbred lines, L_4 and L_{71} were the best general combiners for most of the studied traits. Inbred line L_4 recorded best GCA estimates for grain yield (0.78), days to anthesis (-1.6) and ASI (-1.13).

Table 14: General combining ability estimates of top 15 and last 5 DH lines for grain yield and agronomic traits evaluated in four sites in Kenya in 2012 under well-watered conditions.

RANK	LINE	NAME	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
1	36	CKDHL0331	1.55***	0.65	-0.13	-0.44***	-0.17	17.24***	22.47***	4.39***	4.46	-1.97	0.003
2	4	CKDHL0023	0.78*	-1.60**	-1.13**	0.09	0.01	6.84*	4.69	0.83	-2.01	-1.26	0.03
3	13	CKDHL0076	0.77*	-0.92	1.12**	-0.51***	0.01	-0.38	-2.47	0.003	3.00	-3.67	0.02
4	11	CKDHL0063	0.76*	1.27	-0.01	-0.10	-0.11	3.40	7.53	-0.26	2.53	0.99	0.01
5	5	CKDHL0032	0.73*	-0.17	-0.07	-0.01	0.14	1.34	0.00	-0.52	0.31	-2.23	-0.05*
6	12	CKDHL0065	0.60	-0.92	-0.01	-0.29*	-0.17	6.22	1.87	3.16***	3.35	-0.43	-0.02
7	44	CKDHL0399	0.60	-0.42	0.62	-0.07	-0.30	-6.29	-6.66	-1.69	-3.22	-1.15	0.004
8	38	CKDHL0345	0.58	0.02	0.93*	-0.07	-0.49*	-8.85**	-9.97*	-1.15	-4.01	-0.67	0.01
9	71	CKDHL0574	0.55	-2.35***	0.24	0.18	-0.17	-8.66**	-7.03	-0.18	-3.47	-1.80	0.02
10	40	CKDHL0364	0.53	2.90***	0.12	-0.23	0.08	6.74*	4.72	0.04	-3.17	-6.37**	0.002
11	72	CKDHL0585	0.45	-2.67***	0.68	-0.57***	-0.24	2.65	10.25*	0.30	-1.26	-1.13	0.02
12	64	CKDHL0501	0.44	0.71	-0.94**	-0.04	-0.05	3.93	4.97	-0.63	-1.22	3.26	-0.01
13	70	CKDHL0561	0.44	-2.10***	-0.63	0.18	-0.24	-11.09***	-10.41*	-0.96	-4.89	1.87	0.03
14	60	CKDHL0494	0.39	1.02*	-0.26	0.06	-0.42*	0.55	3.37	-0.46	-4.45	2.83	-0.02
15	68	CKDHL0526	0.39	2.58***	-0.69	0.21	-0.24	10.12**	-3.60	0.30	-1.61	1.47	-0.01
76	62	CKDHL0498	-0.51	1.33**	-1.19**	0.37**	0.08	-1.88	-8.44	-0.32	-2.34	9.36***	0.09***
77	51	CKDHL0460	-0.54	2.21***	0.12	0.06	-0.42*	4.65	2.53	-0.25	1.43	-0.22	-0.01
78	24	CKDHL0237	-1.45***	-6.17***	-1.63***	0.62***	1.20***	-20.26***	-15.78***	3.84***	15.90***	3.86	0.03
79	47	CKDHL0439	-0.9**	1.02*	-1.13**	0.27*	0.08	1. 18	4.90	-0.11	1.52	1.93	0.01
80	79	CKDHL0631	-0.83**	-3.10***	-0.32	0.12	0.76***	-9.04**	-7.53	0.14	-0.91	-3.44	-0.02
	Tester 1	CML395/CML444	-0.44***	2.19***	-0.05	-0.12*	0.06	4.69***	2.67***	0.46***	0.11	-2.15	-0.003
	Tester 2	CML312/CML442	0.44***	-2.19***	0.05	0.12*	-0.06	-4.69***	-2.67***	-0.46***	-0.11	2.15	0.003

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; RL: Root lodging; SL: Stem lodging; ER: Ear rot; EPP: Ears per plant.

Line 71 was early maturing and would produce short plants with low ear placements having recorded the best GCA estimate for days to anthesis (-2.35), ear height (-8.66) and plant height (-7.03). These lines could be suitable parents in making hybrids suitable for short growing season. Troyer and Larkins (1985) reported stronger association of plant height with flowering date, both morphologically and ontogenetically, because internodes formation stopped at floral initiation, which meant that earlier flowering maize were usually shorter. Thus, L_{71} could be best parental choice for early maturity breeding programs in maize.

Amongst the two testers used in this study, T_2 (CML312/CML442) was the better general combiner for grain yield having recorded a positive (0.44) and highly significant ($p<0.001$) GCA estimate (Table 13). In addition, it exhibited better performance for other agronomic traits than T_1 (CML395/CML444). In agreement, most of the top yielding hybrids across well-watered locations (Table11) had T_2 as one of the parents. These results are in congruence with research conducted by Beyene *et al.* (2011a) who conceded that single cross tester CML312/CML442 had proven useful in hybrid formation for sub-tropical and mid- altitude environments and had been used in many hybrids in CIMMYT and sub-Saharan national maize breeding programs.

The best yielding testcross hybrids across well-watered locations, entry 91 (L_{11} x T_2) and entry 116 (L_{36} x T_2) with grain yields of 8.85 t ha^{-1} and 8.53 t ha^{-1} respectively, (Table 11) were developed from L_{11} and L_{36} (female parents) and T_2 (male parent). These parental genotypes were also among the best general combiners for grain yield (Table 14). This inferred that these two DH inbred lines and T_2 could be successfully used for crop improvement under optimal growing conditions.

The specific combining ability (SCA) estimates of DH testcross hybrids are presented in Tables 15a and 15b. Positive SCA effects signified positive gene interaction between the two parents which led to the expression of heterosis. This could be extensively exploited in the development of hybrid varieties. Twenty-nine (29 %) of the DH lines had positive and significant SCA estimates for grain yield when crossed to T_2, 15 % when crossed to T_1 while 6 % combined well for grain yield when crossed to either T_1 or T_2. Entry 28 (L_{28} x T_1) had the highest positive (2.55) and significant ($p<0.001$) SCA effect for grain yield across well-watered environments. Entries 29, 23, 26, 25, 27, 22, 24, 69 and 71 160,120 and 110 also had relatively high, positive and significant ($p<0.001$) SCA estimates for grain yield (Table 15a). These DH hybrids can be further evaluated in advanced yield trials (AYTs) to ascertain their performance and stability across locations.

Testcross hybrids 27 (L_{27} x T_1) and 29 (L_{29} x T_1) produced very tall plants (Table 15a). This was deduced from the positive and significant ($p<0.001$) SCA estimates of 13.3; 19.2 and 12.8; 25.3 observed for ear height and plant heights, respectively. In contrast, these two DH lines when crossed to T_2 produced short plants, exhibited negative and significant ($p<0.001$) SCA estimates for those traits (Table 15b). This meant that to fully explore the potential of the drought tolerant DH inbred lines in making best hybrid combinations for any given trait, the tester choice used in the crosses was vital.

Table 15a: Specific combining ability estimates from Tester 1 of top 15 and last 5 DH testcross hybrids for grain yield and component traits averaged across four sites in Kenya under well-watered conditions in 2012.

RANK	ENTRY	CROSS	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
1	28	28x1	2.25***	-1.57**	-0.20	-0.25*	-0.25	7.87*	17.64***	-0.72	-6.66**	-2.37	0.03
2	29	29x1	2.14***	-0.94	-0.26	-0.38***	-0.25	12.75***	25.33***	-0.91	-2.24	-3.79**	0.05*
3	23	23x1	2.1***	-0.88	-0.20	-0.19	-0.56***	2.53	10.58*	-0.80	-7.32**	-2.99*	-0.003
4	26	26x1	1.91***	-1.07*	-0.01	-0.22*	-0.25	9.56**	16.36***	-0.93	3.06	-3.17*	0.05*
5	25	25x1	1.78***	-1.44**	-0.26	-0.13	-0.56***	7.84*	14.45***	-3.01**	-2.47	0.37	-0.02
6	27	27x1	1.73***	-0.94	-0.14	-0.16	-0.06	13.31***	19.22***	-0.28	-2.42	0.78	0.03
7	22	22x1	1.49***	-0.94	-0.01	-0.31**	-0.06	3.72	7.89	0.07	0.09	-2.47	0.04
8	24	24x1	1.35***	-2.32***	1.43***	-0.10	-0.50**	3.59	6.02	-1.26	-11.97***	0.67	0.02
9	69	69x1	1.27***	-0.32	-0.45	-0.06	-0.12	4.34	12.2**	0.73	-4.03	-6.07***	0.03
10	71	71x1	1.22***	-0.88	-0.45	-0.10	-0.37*	6.5*	8.08	-1.62	-0.46	-0.51	0.02
11	57	57x1	0.95***	-2.13***	0.99**	-0.13	-0.25	7.06*	9.67*	-1.12	-5.74**	3.59**	-0.02
12	70	70x1	0.94***	-0.51	-0.58	-0.16	0.19	8.32**	8.77*	-0.40	0.86	-3.13*	0.01
13	80	80x1	-0.88***	1.31**	-0.33	0.03	0.38*	0.34	-4.86	-0.15	2.61	1.42	-0.003
14	40	40x1	-0.87***	0.87	0.43	0.19	-0.12	-4.85	-8.36	0.89	1.53	2.31	-0.004
15	30	30x1	-0.86***	0.49	-0.01	0.19	0.002	-3.16	-4.58	-1.31	0.72	1.46	-0.03
76	55	55x1	-0.81**	-0.57	0.24	-0.13	0.25	-3.03	-4.67	-0.06	3.03	-0.02	-0.02
77	43	43x1	-0.83**	0.93	0.11	0.12	-0.06	-2.32	-4.27	-0.14	1.44	0.86	0.01
78	30	30x1	-0.86***	0.49	-0.01	0.19	0.002	-3.16	-4.58	-1.31	0.72	1.46	-0.03
79	40	40x1	-0.87***	0.87	0.43	0.19	-0.12	-4.85	-8.36	0.89	1.53	2.31	-0.004
80	80	80x1	-0.88***	1.31**	-0.33	0.03	0.38*	0.34	-4.86	-0.15	2.61	1.42	-0.003

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; RL: Root lodging; SL: Stem lodging; ER: Ear rot; EPP: Ears per plant.

Table 15b. Specific combining ability estimates from Tester 2 of top 15 and last 5 DH testcross hybrids for grain yield and component traits averaged across four sites in Kenya under well-watered conditions in 2012.

RANK	ENTRY	CROSS	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
1	160	80x2	0.88***	-1.31**	0.33	-0.03	-0.38*	-0.34	4.86	0.15	-2.61	-1.42	0.003
2	120	40x2	0.87***	-0.87	-0.43	-0.19	0.12	4.85	8.36	-0.89	-1.53	-2.31	0.004
3	110	30x2	0.86***	-0.49	0.01	-0.19	-0.002	3.16	4.58	1.31	-0.72	-1.46	0.03
4	123	43x2	0.83**	-0.93	-0.11	-0.12	0.06	2.32	4.27	0.14	-1.44	-0.86	-0.01
5	135	55x2	0.81**	0.57	-0.24	0.13	-0.25	3.03	4.67	0.06	-3.03	0.02	0.02
6	96	16x2	0.80**	-0.24	-0.43	0.06	-0.25	4.78	9.52*	-0.69	3.32	-1.78	0.02
7	90	10x2	0.74**	-1.31**	-0.05	-0.12	-0.19	4.19	8.64	0.14	-1.64	-0.81	0.01
8	143	63x2	0.74**	-0.43	-0.24	-0.06	-0.19	3.50	12.27**	-0.14	0.17	2.43	0.03
9	97	17x2	0.72**	-0.37	-0.11	-0.12	-0.19	3.00	4.95	0.62	-0.41	-0.63	0.03
10	146	66x2	0.71**	0.01	-0.43	-0.09	-0.06	5.53	7.52	0.42	1.05	-2.56	-0.01
11	113	33x2	0.68**	-1.18*	1.58***	-0.22*	-0.06	2.35	4.86	0.44	-2.22	-1.05	0.02
12	95	15x2	0.66**	-0.37	0.20	-0.28**	0.25	5.91	9.05*	-0.61	-1.90	-0.52	0.01
13	148	68x1	0.66**	0.44	-0.74	-0.12	0.19	5.78	5.86	-1.86*	-1.51	4.43**	0.01
14	111	31x2	0.63**	-0.37	-0.36	-0.22*	-0.13	-0.68	-1.55	0.03	3.58	-2.84*	0.01
15	156	76x2	0.60*	-0.43	-0.05	-0.06	-0.06	5.85	4.67	-0.83	-2.28	-1.42	-0.01
76	105	25x2	-1.78***	1.44**	0.26	0.13	0.56***	-7.84*	-14.45***	3.01**	2.47	-0.37	0.02
77	106	26x2	-1.91***	1.07*	0.01	0.22*	0.25	-9.56**	-16.36***	0.93	-3.06	3.17*	-0.05*
78	103	23x2	-2.10***	0.88	0.20	0.19	0.56***	-2.53	-10.58*	0.80	7.32**	2.99*	0.003
79	109	29x2	-2.14***	0.94	0.26	0.38***	0.25	-12.75***	-25.33***	0.91	2.24	3.79**	-0.05*
80	108	28x2	-2.25***	1.57**	0.20	0.25*	0.25	-7.87*	-17.64***	0.72	6.66**	2.37	-0.03

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; PA: Plant aspect; EH: Ear height; PH: Plant height; RL: Root lodging; SL: Stem lodging; ER: Ear rot; EPP: Ears per plant.

4.1.2 Managed drought environments

4.1.2.1 Mean performance of DH testcross hybrids in individual sites and across sites

Individual statistical analyses of the experimental materials are presented in Tables 16 and 17. Differential performance in grain yield was observed across drought environments. Grain yield of testcross hybrids at Kiboko ranged from 0.7 to 5.9 t/ha with a mean of 2.6 t/ha while at Homabay, yield ranged from 2.2 to 7.6 t/ha with a mean of 4.5 t/ha. This could be due to variations in intensity of drought stress experienced in these two sites. Homabay was under less severe drought stress while Kiboko was under severe drought stress. It is important to note that grain yield was significantly reduced under drought stress as compared to well-watered conditions. For example, in Kiboko, a yield reduction of 64 % was observed in genotypes when evaluated under optimum conditions (7.17 t/ha) (Table 7) and under moisture stress (2.6 t/ha) (Table 16).

All the top ten DH hybrids, in both sites out yielded the check hybrids. The best DH hybrid in Kiboko had a yield advantage of 40 % over the best commercial check PH3253 while in Homabay, the best DH hybrid had a yield advantage of 37 % over the best commercial check DK-8053. In addition, the drought tolerant variety (local check 1) that is commercially available to farmers recorded significantly low output for grain yield (2.25 t/ha) (Table 17). This showed the superiority in performance of DH hybrids compared to the available commercial hybrids. As asserted by Blum (2006) that drought-tolerant varieties from farmers' perspective are those cultivars that are higher yielding than other available commercial cultivars under limited moisture supply. The selected DH lines can therefore be further advanced in multi-location trials and national variety trials for commercial release.

Table 16: Mean performance for grain yield and other agronomic traits of the top 10 and last 5 DH hybrids and check hybrids evaluated at Kiboko, Kenya under managed drought conditions.

RANK	ENTRY	CROSS	GY t ha^{-1}	AD days	ASI days	EA 1-5	EH cm	PH cm	ER %	EPP #	MOI %	SEN 1-10	RL %	SL %
1	147	67x2	5.94	74	0.37	1.51	142	217	5.40	0.88	20.45	3.55	2.7	12.20
2	142	62x2	5.74	74	0.45	0.74	148	234	-0.56	0.97	20.14	2.50	1.3	26.20
3	24	24x1	4.87	67	0.16	1.21	132	220	2.61	0.98	17.03	4.04	0.0	44.92
4	23	23x1	4.86	73	-0.01	1.18	141	222	-0.03	1.00	20.75	4.45	0.0	27.50
5	38	38x1	4.40	75	1.28	1.08	142	214	5.93	0.98	20.73	3.89	0.0	16.60
6	13	13x1	4.40	74	2.07	1.40	152	239	11.28	0.90	21.47	3.24	1.3	22.95
7	92	12x2	4.39	70	1.63	2.06	137	223	15.35	0.91	19.11	3.86	0.0	53.32
8	4	4x1	4.33	72	0.26	1.26	149	229	2.64	1.02	18.89	4.35	0.0	82.18
9	140	60x2	4.30	72	-0.01	1.30	149	235	3.73	0.92	19.23	3.83	0.0	24.80
10	68	68x1	4.06	74	0.40	1.43	150	235	3.80	0.90	19.09	4.06	0.0	45.30
156	151	71x2	0.83	70	0.86	2.32	145	222	15.93	0.58	12.72	6.00	0.0	23.22
157	81	1x2	0.82	70	5.48	2.64	133	221	24.40	0.43	12.77	5.60	0.0	14.20
158	17	17x1	0.72	77	0.90	2.81	147	211	17.07	0.42	12.54	5.47	0.0	20.14
159	14	14x1	0.69	74	1.05	2.84	150	222	11.08	0.38	12.57	5.56	0.0	16.15
160	88	8x2	0.66	72	9.15	2.89	141	220	3.25	0.49	12.87	5.16	0.0	40.54
	161	DK-8053	2.05	69	2.91	2.18	123	204	9.42	0.48	15.41	5.52	0.0	21.42
	162	H513	1.31	71	3.97	3.25	139	220	14.40	0.40	12.63	6.78	0.0	11.66
	163	PH3253	3.55	71	2.83	1.82	144	232	21.12	0.75	17.42	4.71	0.0	20.27
	164	WH04	2.19	72	4.77	1.81	140	227	2.00	0.73	14.58	4.70	0.0	40.49
	165	Duma43	2.48	65	2.44	2.20	128	231	15.49	0.74	14.50	5.02	0.0	4.04
Grand mean of trial			**2.59**	**73**	**1.72**	**1.99**	**142**	**224**	**9.74**	**0.72**	**16.30**	**5.02**	**0.2**	**35.70**
Heritability (H^2)			**0.33**	**0.95**	**0.53**	**0.27**	**0.43**	**0.24**	**0.13**	**0.38**	**0.34**	**0.08**	**0.00**	**0.37**
CV (%)			**43.7**	**1.3**	**117.6**	**29.7**	**7.6**	**6.7**	**93.4**	**25.0**	**14.0**	**22.4**	**469.6**	**62.3**
LSD (0.05)			**2.16**	**1.76**	**3.16**	**0.96**	**20.10**	**26.50**	**20.10**	**0.33**	**4.39**	**1.83**	**1.63**	**40.80**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; EH: Ear height; PH: Plant height; ER: Ear rot; EPP: Ears per plant; MOI: Grain moisture; SEN: Leaf senescence; RL: Root lodging; SL: Stem lodging.

Table 17: Mean performance for grain yield and other agronomic traits of the top 10 and last 5 DH hybrids and check hybrids evaluated at Homabay, Kenya under managed drought conditions.

RANK	ENTRY	CROSS	GY t ha^{-1}	AD days	ASI days	EH cm	PH cm	ER %	EPP #	MOI %	RL %	SL %
1	99	19x2	7.62	59	2.09	165	245	29.72	1.00	13.09	0.05	-0.15
2	81	1x2	7.52	59	2.99	153	233	7.95	0.97	13.15	-0.22	3.47
3	71	71x1	7.22	59	2.01	155	239	28.51	0.96	13.27	0.09	2.79
4	138	58x2	7.09	59	3.33	146	213	24.59	0.94	12.62	-0.27	4.78
5	137	57x2	6.81	59	3.74	153	228	29.62	0.98	12.77	2.03	2.65
6	146	66x2	6.59	61	1.96	161	239	16.43	0.93	13.01	0.93	0.97
7	154	74x2	6.57	59	1.61	148	227	14.20	0.97	13.19	-0.57	-0.88
8	126	46x2	6.46	60	2.22	160	245	34.20	0.92	13.18	1.15	1.30
9	140	60x2	6.35	60	2.35	153	240	7.90	0.93	13.57	0.39	-0.79
10	92	12x2	6.34	60	2.01	151	238	34.30	0.97	12.65	2.21	3.50
156	152	72x2	2.65	58	2.36	147	237	20.68	0.93	13.11	0.37	2.47
157	3	3x1	2.58	62	1.16	155	228	39.41	0.82	12.91	1.76	6.91
158	15	15x1	2.57	61	3.49	165	233	29.64	0.94	13.19	1.83	2.94
159	47	47x1	2.31	60	2.10	145	208	30.90	0.82	12.67	8.58	7.53
160	6	6x1	2.23	61	2.72	151	228	14.95	0.86	12.87	3.34	3.25
	161	DK-8053	4.83	59	1.93	130	216	21.51	0.87	13.15	11.38	8.85
	162	H513	3.24	58	2.23	164	234	22.47	0.84	12.38	2.17	5.90
	163	PH3253	1.33	60	3.17	148	222	38.26	0.69	12.05	4.28	6.74
	164	DK8031	2.12	58	1.99	138	218	32.42	0.82	12.25	8.57	6.03
	165	Duma43	1.51	58	3.33	135	230	30.16	0.70	12.83	2.72	2.56
Grand mean of trial			**4.50**	**60**	**2.14**	**152**	**230**	**25.13**	**0.88**	**12.89**	**2.91**	**5.02**
Heritability (H^2)			**0.30**	**0.41**	**0.11**	**0.76**	**0.57**	**0.21**	**0.14**	**0.57**	**0.25**	**0.10**
CV (%)			**41.5**	**2.4**	**40.8**	**5.7**	**6.2**	**47.7**	**10.4**	**2.6**	**156.4**	**85.9**
LSD (0.05)			**2.78**	**2.49**	**1.79**	**13.92**	**20.53**	**21.49**	**0.17**	**0.61**	**8.93**	**9.97**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; ER: Ear rot; EPP: Ears per plant; MOI: Grain moisture; RL: Root lodging; SL: Stem lodging.

Mean performance of DH testcross hybrids for grain yield and component traits averaged across two locations is presented in Table 18. Grain yield of DH hybrids ranged from 4.92 to 5.67 t/ha with a grand mean of 3.55t/ha. The top yielding DH hybrids were similar in performance for grain yield as deduced from least square difference (LSD) of 1.92 at $p<0.05$ hence they could potentially substitute one another in any desired order. The best DH hybrid yielded higher than the best commercial check (DK-8053) by 40%. This implied that DH hybrids were superior in performance than commercially available hybrids thus could be selected for crop improvement targeting ASALs and marginal areas. Most of the top yielding genotypes across sites were among the top yielders in either of the individual sites. Prominent best performing DH hybrids under moisture stress in individual and across sites were entry 92 (L_{12} xT_2) and entry140 (L_{60} xT_2). In contrast, L_{12} and L_{60} were not among the best general and specific combiners for grain yield (Table 20 and 21b). This calls for radical evaluation of these materials to further determine their gene make-up and usefulness in crop improvement programs.

A yield reduction of 50% was observed under drought stress as compared to well-watered trials. This could be attributed to more days to silking and tasseling (66 days) and a longer ASI (2 days) noted in the genotypes as a result of decelerated growth (Table 18). In comparison to findings by Bruce *et al.* (2002), it can be concluded that water deficits in maize plant during reproductive stage reduced photosynthetic rate due to reduction in light interception as leaves senesce leading to slow ear growth, barrenness and low HI. High grain yield (5.67 t/ha) recorded by entry 142 (L_{62} x T_2) was highly correlated to small ASI (1 day), high number of ears per plant (0.9) and low scores of leaf senescence (2.3). In agreement, low yield (1.93 t/ha) for the drought susceptible check hybrid (local check 2) was due to long ASI (3 days), low number of ears per plant (0.73) and high score of leaf senescence (5.02).

Table 18: Mean performance of the top 10, last 5 DH hybrids and check hybrids combined across locations in Kenya under managed drought conditions in 2012.

RANK	ENTRY	CROSS	GY t ha^{-1}	AD days	ASI days	EA 1-5	EH cm	PH cm	ER #	EPP #	MOI %	RL %	SL %	SEN 1-10
1	142	62x2	5.67	66	1.21	0.74	149	226	13.88	0.93	16.51	1.31	16.13	2.50
2	23	23x1	5.58	67	1.19	1.18	152	228	20.06	0.89	17.17	0.97	14.54	4.45
3	92	12x2	5.50	65	1.75	2.06	144	231	24.39	0.94	15.85	0.67	28.49	3.86
4	137	57x2	5.32	65	1.86	1.31	151	228	18.19	0.9	14.78	0.96	16.31	5.05
5	147	67x2	5.30	68	1.59	1.51	149	220	9.06	0.89	16.79	2.5	10.34	3.55
6	140	60x2	5.27	66	1.17	1.30	150	237	6.39	0.93	16.39	0.32	12.51	3.83
7	126	46x2	5.08	67	1.52	1.65	153	240	22.39	0.85	15.00	0.47	18.18	4.29
8	99	19x2	5.04	64	1.83	2.14	152	234	42.12	0.69	14.11	0.07	24.91	5.15
9	138	58x2	5.03	66	2.64	1.39	148	223	15.20	0.76	15.41	-0.06	17.86	5.79
10	24	24x1	4.92	62	1.05	1.21	142	230	12.10	0.97	14.58	2.11	24.45	4.04
156	149	69x2	2.13	65	3.58	2.26	134	220	8.96	0.74	14.26	1.40	30.46	6.57
157	47	47x1	2.07	67	1.33	2.00	142	218	15.56	0.76	13.54	4.00	14.02	5.25
158	3	3x1	2.00	69	1.24	1.97	147	224	31.22	0.63	14.23	0.94	15.51	5.05
159	20	20x1	1.91	67	1.67	2.49	157	228	12.53	0.75	12.98	2.40	43.96	5.50
160	32	32x1	1.68	66	2.93	2.73	147	227	34.54	0.66	12.15	0.76	19.10	5.22
	161	DK-8053	3.43	64	2.17	2.18	126	210	13.9	0.69	14.1	5.63	16.05	5.52
	162	H513	2.16	64	2.96	3.25	152	227	18.24	0.63	12.24	0.95	8.22	6.78
	163	PH3253	2.36	65	2.97	1.82	146	227	29.2	0.71	14.81	1.93	11.60	4.71
	164	Local check 1	2.25	65	3.39	1.81	138	222	17.91	0.79	13.39	4.05	22.61	4.70
	165	Local check 2	1.93	62	2.9	2.2	132	229	22.48	0.73	13.64	1.26	5.15	5.02
Grand mean of trial			**3.55**	**66**	**1.93**	**1.99**	**147**	**227**	**17.44**	**0.8**	**14.58**	**1.55**	**20.36**	**5.02**
Entry variance			**0.20**	**2.10**	**0.21**	**0.02**	**54.91**	**51.26**	**8.07**	**0.00**	**0.00**	**0.00**	**14.21**	**0.00**
Location variance			**1.77**	**78.47**	**0.07**	**0.00**	**52.14**	**10.03**	**117.20**	**0.01**	**5.65**	**3.61**	**466.90**	**0.00**
Location x Entry variance			**0.17**	**1.75**	**0.55**	**0.02**	**2.16**	**0.00**	**3.37**	**0**	**0.67**	**1.74**	**48.55**	**0.04**
Locations rep of data.			**2**	**2**	**2**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**1**
Heritability			**0.29**	**0.64**	**0.23**	**0.14**	**0.73**	**0.59**	**0.21**	**0.1**	**0.00**	**0.00**	**0.15**	**0.00**
LSD (0.05)			**1.92**	**2.98**	**2.31**	**1.05**	**12.51**	**16.58**	**15.04**	**0.22**	**2.72**	**5.19**	**24.89**	**1.91**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; EH: Ear height; PH: Plant height; ER: Ear rot; EPP: Ears per plant; MOI: Grain moisture; RL: Root lodging; SL: Stem lodging; SEN: Leaf senescence.

These yield attributed traits reduced the mean grain yield of the susceptible check. Reduced leaf senescence translated to longer leaf area duration under drought stress. Evans and Fischer (1999) documented that retention of green leaf area for a long period increases the duration of photosynthetic activity that results in increased assimilate supply to the developing ear and increased seed set in plants. Different workers have reported similar findings in crops such as oats (Lynch and Frey, 1993), sorghum (Borrell *et al.,* 2000) and maize (Bänziger *et al.,* 2002).

Low magnitudes of broad sense heritability observed for all the studied traits indicated the preponderance of non-additive gene action in the inheritance of these traits under drought stress. These findings were in agreement with other previously documented literature by Araus *et al.* (2002) and Reynolds and Tuberosa (2008) whilst screening germplasm under drought stress. Heritability for GY at Kiboko, Homabay and across both sites was 30%. This lessened the possibility of effective selection for genetic improvement of these traits under drought stress. Therefore, to increase selection efficiency under drought, Bänziger *et al.* (2000) and Royo *et al.* (2005) proposed use of secondary traits such as ASI, number of ears per plant and leaf senescence to step up selection of drought tolerant genotypes.

4.1.2.2 Analysis of variance of DH testcross hybrids and inbred lines *per se*

Combined analysis of variance (ANOVA) for yield and yield components is presented in Table 19. Statistically, the ANOVA showed that the genotypes under study were similar in performance for all the traits investigated. Drought made the differences between genotypes disappear, limiting precise screening of drought susceptible and drought tolerant hybrids. Effects of environment were large and highly significant ($p<0.001$) on all the measured traits compared to those observed for GCA and SCA.

Table 19: Analysis of variance for grain yield and other agronomic traits of DH testcrosses combined across locations in Kenya under managed drought conditions.

		MEAN SQUARES										
SOURCE	df	GY t ha^{-1}	AD days	ASI days	EA 1-5	EH cm	PH cm	ER %	EPP #	RL %	SL %	SEN 1-10
Environment (E)	1	552.16***	137.69***	28.30**	629.05***	16425.80***	3791.78***	40265.37***	3.95***	1182.87***	150361.90***	0.01
GCA $_{\text{Lines}}$	79	3.25	5.79	3.15	0.21	184.62	349.73	106.41	0.03*	13.68	293.47	0.64
GCA $_{\text{Testers}}$	1	7.67	1.70	1.16	8.21***	2019.60***	12321.86***	15.81	0.12*	0.87	3233.21**	6.81
SCA $_{\text{Line x Tester}}$	79	1.87	5.13	2.11	0.13	148.93	220.85	158.24	0.03*	12.60	339.92	0.47
GXE	79	1.95	5.07	2.26	0.13	91.17	181.53	153.95	0.03	12.59	341.05	0.47
GCA/SCA ratio		1.74	1.13	1.49	1.62	1.24	1.58	0.67	1.00	1.09	0.86	1.36
Error	319	3.16	5.06	2.86	0.23	208.74	356.18	129.31	0.02	15.15	370.29	0.74
CV (%)		49.88	3.39	87.93	48.72	9.83	8.31	65.62	19.13	251.20	94.69	34.35

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; EH: Ear height; PH: Plant height; ER: Ear rot; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; SEN: Leaf Senescence.

This showed the differences among the trial sites leading to differential performances by the parental genotypes and testcross hybrids for the assessed traits. This implied that different hybrids should be developed targeting particular environments. Differences between experimental hybrids were greatly reduced by drought resulting into non-significant differences except for ear aspect, ear height and plant height ($p<0.001$) and number of ears per plant ($p<0.05$) in testers. This could be attributed to commonness of the drought tolerant donor parent (La Posta Sequia, C7) used to develop backcross populations for the DH inbred lines (Table 2). Both grain yield and flowering were greatly affected similar to finding by Kanagarasu *et al.* (2010).

GCA and SCA mean squares were non-significant for all studied traits in lines, testers and the interaction between lines and testers except for ear aspect, ear height and plant height in testers. This indicated similarities among parental lines and testers for GCA and among testcrosses for SCA effects for those traits. The testcross hybrids had inherited the drought tolerance genes from the parents thus were able to withstand harsh climatic conditions and perform equally better under moisture stress. Total GCA mean squares of lines and testers were substantially greater than those observed for SCA for most of the assessed traits. Similarly, GCA/SCA ratio was greater than unity for most of the studied traits except for ear rot and stem lodging indicating importance of additive over non-additive gene action in governing the assessed traits. This showed that they respond to selection. These results were similar to those observed for conventional lines and DH lines (Beyene *et al.,* 2011a; 2013). However, the importance of non-additive gene effects in promoting some unique combinations (Hallauer and Miranda, 1988) among parents for grain yield could not be ignored. Less than 10 % difference was observed for mean square values of genotypic main effects and GEI (Table 19). Additionally, GEI main effects were non-significant for all the traits assessed. This implied that environment did not influence the expression of the agronomic traits of maize testcross hybrids under drought thus screening maize germplasm for drought at one location would be adequate.

4.1.2.3 Combining ability analyses across drought environments

The general combining ability (GCA) estimates of parents is presented in Table 20. Out of eighty (80) DH lines evaluated, 50 % had positive GCA effects for grain yield. This meant that there were greater sources for parental selection to be considered in hybrid combinations for drought tolerance. Inbred lines L_9 (CKDHL0056) and L_{65} (CKDHL0505) presented significant ($p<0.01$) and highest positive GCA estimates of 1.7 and 1.54, respectively for grain yield. Inbred lines L_{64} and L_{51} were also good general combiners for grain yield with significant ($p<0.05$) GCA estimates of 1.34 and 1.21, respectively. This implied that these lines had a higher favorable allele frequency for grain yield under stress conditions and as a result could be selected as parents in breeding towards improved tolerance to drought. In addition, L_{65} and L_{64} were the worst general combiners for plant and ear heights. This meant that these hybrids were very tall. However, this did not compromise on yield since L_{65} and L_{64} were among the top performers for grain yield based on GCA. In addition, L_{64} had a high estimate for number of ears per plant (0.1) which was an indicator of drought tolerance; by being able to prolificate and yield maximally under drought stress. These observations on the superior DH inbred lines portend presence of potential use as parents in hybrid combination.

Table 20: General combining ability estimates of top 15 and last 5 DH lines for grain yield and other agronomic traits evaluated under managed drought conditions in Kenya in 2012.

RANK	LINE	NAME	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
1	9	CKDHL0056	1.70**	0.32	-0.42	-0.30	-3.18	0.77	0.04	1.45	-4.68	0.44	-6.24	-0.63*
2	65	CKDHL0505	1.54**	0.20	-0.42	-0.24	13.75***	-1.77	0.06	1.98**	19.44***	-0.55	-9.19	-0.38
3	64	CKDHL0501	1.34*	-1.05	-0.17	-0.24	8.20*	-5.81	0.10	1.17	14.88**	0.10	-3.20	-0.38
4	51	CKDHL0460	1.21*	-0.93	-0.80	-0.24	-2.28	-6.31	0.11	0.68	4.01	-0.88	7.28	-0.38
5	63	CKDHL0500	1.03	-0.80	-0.55	-0.18	5.03	5.02	0.03	0.73	7.13	0.09	-2.41	-0.13
6	10	CKDHL0058	0.86	-0.18	-0.30	-0.24	-0.86	0.43	0.06	0.74	-2.37	-1.22	-2.44	-0.63*
7	8	CKDHL0053	0.79	-0.30	-0.30	-0.24	2.80	4.16	0.12	1.34	1.44	-0.56	-0.26	-0.63*
8	21	CKDHL0172	0.77	0.32	0.20	-0.12	-0.81	0.49	0.04	0.51	-1.56	-1.22	-2.53	-0.13
9	59	CKDHL0493	0.73	-0.55	-0.55	0.07	2.18	7.14	0.03	-0.55	5.01	0.42	14.11*	0.13
10	50	CKDHL0448	0.72	0.70	0.20	0.01	-0.32	-3.14	0.06	0.41	-0.87	-1.19	4.14	-0.13
11	28	CKDHL0266	0.71	0.32	-0.05	-0.12	3.85	-3.50	0.01	0.13	1.76	-0.56	-7.43	-0.25
12	7	CKDHL0048	0.70	0.82	-0.67	-0.05	-3.82	5.40	0.03	0.87	-4.87	0.42	-2.90	-0.50
13	19	CKDHL0134	0.65	0.95	-0.42	-0.05	0.22	0.12	-0.04	0.36	-7.18	0.42	-6.09	0.38
14	5	CKDHL0032	0.55	0.82	-0.55	-0.24	-2.46	-6.20	0.07	1.50*	-8.62	0.10	0.02	-0.38
15	67	CKDHL0513	0.54	0.07	-0.55	0.01	8.88*	-1.91	-0.04	0.51	9.44	0.75	1.72	0.00
76	26	CKDHL0248	-1.01	0.70	0.20	-0.12	4.29	-0.30	-0.05	-0.31	-2.81	0.42	-3.48	0.13
77	17	CKDHL0121	-1.10	0.20	-0.05	0.13	-6.08	-0.87	-0.08	-1.59*	-3.74	-1.22	-8.88	0.88**
78	1	CKDHL0007	-1.11	0.82	0.08	0.26	-8.21*	4.31	-0.04	-1.32	-10.93*	0.42	-3.34	0.13
79	72	CKDHL0585	-1.23*	0.20	0.08	0.07	-3.06	6.41	-0.04	-0.67	-4.18	-0.56	2.30	-0.13
80	58	CKDHL0484	-1.47*	0.82	-0.17	0.13	4.85	2.51	-0.08	-0.71	10.44*	1.41	7.80	0.13
	Tester 1	CML395/CML444	0.11	0.05	0.03	-0.11	-1.78*	-0.16	0.01	0.27	-4.39***	-0.04	-2.25	-0.10
	Tester 2	CML312/CML442	-0.11	-0.05	-0.03	0.11	1.78*	0.16	-0.01	-0.27	4.39***	0.04	2.25	0.10

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; EA: Ear aspect; ER: Ear rot; RL: Root lodging; SL: Stem lodging; SEN: Leaf Senescence.

Inbred lines L_8 (CKDHL0053), L_9 (CKDHL0056) and L_{10} (CKDHL0058) were the best general combiners for most of the studied traits of maize. Additionally, lowest negative (-0.63) and significant ($p<0.05$) GCA estimates for leaf senescence were observed in these lines. This translated to lowest percentage of dead leaf area in these genotypes under drought which was indicative of drought tolerance in these lines. The possibility of transferring these traits from the above materials to those with high grain yield backgrounds should be explored. Among the testers, T_1 (CML395/CML444) was the better general combiner for yield and yield associated traits under drought stress (Table 20). This indicated that T_1 was more drought tolerant than T_2. It is therefore useful in transferring genes of drought tolerance to the progenies.

The specific combining ability (SCA) estimates of DH testcross hybrids are presented in Tables 21a and 21b. Positive SCA estimates for grain yield were observed in 57 % of the DH inbred lines when crossed to T_1, 41 % when crossed to T_2 while two 2 % of the lines combined well for grain yield when crossed to either T_1 or T_2. These observations implied that there were significant positive gene interactions between the two parents leading to the expression of heterosis; with more of it coming from T_1. Entries 49 (L_{49} x T_1), 108 (L_{28} x T_2) and 155 (L_{75} x T_2) were the best specific combiners for grain yield. They had positive and significant ($p<0.01$) SCA estimates of 1.52, 1.41 and 1.26, respectively. Entry 57 (L_{57} x T_1) was observed to be having favorable alleles for early maturity. This was exhibited by early flowering (-1.8) and short ASI (-0.53) estimates translating to high (0.17) and significant ($p<0.01$) SCA estimate for number of ears per plant. This indicated that this genotype had the ability to remobilize pre-anthesis assimilates to grain under limited water leading to rapid phenological development thus should be advanced further to determine its breeding value and stability across locations.

Table 21a: Specific combining ability estimates from Tester 1 of top 15 and last 5 DH testcross hybrids for grain yield and component traits evaluated across locations in Kenya under managed drought conditions.

RANK	ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
1	49	49x1	1.52**	-0.93	-0.15	-0.01	1.90	-2.52	0.03	0.05	5.26	-0.63	0.98	-0.02
2	57	57x1	0.92	-1.80*	-0.53	-0.07	-2.67	2.82	0.17**	0.66	1.64	1.02	6.54	-0.02
3	59	59x1	0.82	-0.18	0.10	-0.07	-1.99	2.33	0.04	0.27	-1.42	-0.62	12.89*	-0.27
4	19	19x1	0.79	-0.18	-0.03	-0.07	-2.52	0.80	0.05	0.41	2.14	-1.28	-2.81	-0.27
5	70	70x1	0.77	0.95	-0.9	-0.26*	2.24	-7.76	0.10	0.41	-2.49	0.37	9.04	-0.4
6	45	45x1	0.61	-0.68	0.97	-0.14	1.15	-0.50	-0.02	-0.29	5.45	0.04	-6.54	0.10
7	72	72x1	0.58	0.07	-0.03	-0.20	-11.1***	-12.23**	0.09	0.47	-4.61	0.37	8.07	-0.27
8	10	10x1	0.47	-0.80	-0.15	-0.14	5.23	4.86	0.06	0.52	4.95	-0.29	-0.20	-0.27
9	9	9x1	0.43	0.20	-0.28	0.05	1.00	-1.82	0.08	0.82	-0.49	0.06	-9.86	-0.27
10	7	7x1	0.41	0.20	-0.28	0.05	0.74	3.05	0.00	0.45	1.08	-0.62	-9.93	-0.15
11	56	56x1	0.39	-0.18	-0.03	-0.20	-0.29	-9.15*	0.11	0.90	-1.17	-5.88***	-0.57	-0.52*
12	20	20x1	0.38	-0.18	0.35	0.05	0.28	2.00	-0.07	-0.87	0.14	-0.29	-7.16	-0.15
13	47	47x1	0.38	-0.68	0.10	-0.01	-8.41**	8.45	-0.03	0.09	-8.05	-0.29	4.46	-0.02
14	30	30x1	0.36	0.57	-0.28	-0.2	6.09	-7.34	0.05	1.53**	6.21	0.69	6.23	-0.15
15	52	52x1	0.36	-0.30	-0.40	0.11	5.25	13.92***	-0.12	-0.22	13.33**	0.04	-0.98	-0.02
76	14	14x1	-0.80	0.07	-0.03	-0.01	5.75	-4.54	-0.05	-0.05	1.89	-0.33	-5.10	-0.15
77	29	29x1	-0.82	0.20	0.97	-0.07	-0.56	-3.78	0.01	-0.17	-3.00	-0.29	1.63	0.23
78	76	76x1	-0.88	0.45	-0.28	0.11	-1.54	0.79	-0.01	-0.69	0.58	-0.64	6.57	0.23
79	75	75x1	-1.26**	1.45	0.35	0.18	0.89	11.74**	-0.08	-0.57	3.08	0.69	2.11	0.23
80	28	28x1	-1.41**	-0.30	0.60	0.24	2.79	-0.78	-0.11	-1.07	-1.05	0.37	4.51	0.60*

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; EH: Ear height; ER: Ear rot; EPP: Ears per plant; MOI: Grain moisture; PH: Plant height; RL: Root lodging; SL: Stem lodging; SEN: Leaf senescence.

Table 21b. Specific combining ability estimates from Tester 2 of top 15 and last 5 DH testcross hybrids for grain yield and component traits evaluated across locations in Kenya under managed drought conditions.

RANK	ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
1	108	28x2	1.41**	0.30	-0.60	-0.24	-2.79	0.78	0.11	1.07	1.05	-0.37	-4.51	-0.60*
2	155	75x2	1.26**	-1.45	-0.35	-0.18	-0.89	-11.74**	0.08	0.57	-3.08	-0.69	-2.11	-0.23
3	156	76x2	0.88	-0.45	0.28	-0.11	1.54	-0.79	0.01	0.69	-0.58	0.64	-6.57	-0.23
4	109	29x2	0.82	-0.2	-0.97	0.07	0.56	3.78	0.01	0.17	3.00	0.29	-1.63	-0.23
5	94	14x2	0.8	-0.07	0.03	0.01	-5.75	4.54	0.05	0.05	-1.89	0.33	5.10	0.15
6	157	77x2	0.78	1.68*	0.15	-0.05	-2.86	-0.66	0.02	0.64	0.30	0.62	-2.47	-0.48*
7	131	51x2	0.71	1.30	0.15	0.01	1.10	0.11	0.01	0.79	-2.20	-0.70	1.07	-0.23
8	112	32x2	0.70	0.05	-1.04*	-0.05	-6.63*	0.42	-0.01	-0.09	-8.86	-0.37	-5.35	-0.10
9	128	48x2	0.66	-0.07	0.28	-0.05	5.04	0.15	0.00	-0.18	2.11	-0.04	-0.69	0.02
10	117	37x2	0.65	-0.07	0.03	-0.05	6.80*	-5.22	-0.02	0.32	3.74	-3.33**	-1.88	0.02
11	106	26x2	0.57	-0.07	-0.35	0.01	-4.23	-4.19	0.11	1.30*	4.99	0.62	3.94	-0.23
12	116	36x2	0.51	-1.07	0.65	-0.11	3.77	-0.57	0.06	0.26	9.86*	-2.01	-2.43	-0.23
13	145	65x2	0.50	-0.82	0.53	-0.11	-0.06	0.02	0.02	1.03	5.11	-0.39	6.18	0.02
14	160	80x2	0.49	1.68*	-0.47	-0.05	1.01	-0.59	0.05	0.14	-3.39	-2.26	-7.71	-0.35
15	146	66x2	0.47	-0.45	1.15*	-0.18	-7.83*	-6.17	0.08	0.54	-7.08	0.29	9.92	-0.10
76	150	70x2	-0.77	-0.95	0.90	0.26*	-2.24	7.76	-0.10	-0.41	2.49	-0.37	-9.04	0.40
77	99	19x2	-0.79	0.18	0.03	0.07	2.52	-0.8	-0.05	-0.41	-2.14	1.28	2.81	0.27
78	139	59x2	-0.82	0.18	-0.1	0.07	1.99	-2.33	-0.04	-0.27	1.42	0.62	-12.9*	0.27
79	137	57x2	-0.92	1.80*	0.53	0.07	2.67	-2.82	-0.17**	-0.66	-1.64	-1.02	-6.54	0.02
80	129	49x2	-1.52**	0.93	0.15	0.01	-1.90	2.52	-0.03	-0.05	-5.26	0.63	-0.98	0.02

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EA: Ear aspect; EH: Ear height; ER: Ear rot; EPP: Ears per plant; MOI: Grain moisture; PH: Plant height; RL: Root lodging; SL: Stem lodging; SEN: Leaf senescence.

A higher leaf senescence score of 0.6 observed in entry 28 (L_{28} x T_1) consequently led to low SCA estimate for grain yield (-1.41). It can be deduced that high percent of dead leaf area (60 %) significantly reduced the photosynthetic area resulting into insufficient transfer of assimilates to the harvestable portion. Entry 75 (L_{75} x T_1) also performed poorly for grain yield and other associated traits. These genotypes therefore, can be regarded as drought intolerant and eliminated from future selections in drought tolerance breeding programs.

4.1.2.4 Comparable analysis between well-watered and drought-stress conditions

The genetic materials used in this study exhibited a broad range of variation in grain yield and other agronomic traits under both water regimes (Table 22). Analogous observations were made by Munyiri *et al.* (2010) while working on Kenyan maize landraces to characterize them for drought tolerance.

Table 22: Effects of water stress at flowering on the phenotypic characters of DH testcrosses and check hybrids evaluated across sites in Kenya under stress and non-stress conditions.

	Well-watered (Yp)	**Stressed (Ys)**			
Variables	**Mean**	**Mean**	**Yp-Ys**	**% change**	**Check hybrids (Yp-Ys)**
Grain yield (t ha^{-1})	6.97	3.55	3.42	49.07	4.8
Days to anthesis	69.21	66.42	2.79	4.03	2.7
ASI (days)	1.03	1.93	-0.9	-87.38	-1.58
Ear height (cm)	127.4	147.09	-19.69	-15.46	-14
Plant height (cm)	245.8	227.02	18.78	7.64	28
Ear rot (%)	8.77	17.44	-8.67	-98.86	-6.13
Ears per plant (#)	1	0.8	0.2	20.00	0.28
Grain moisture (%)	22.28	14.58	7.7	34.56	7.06
Root lodging (%)	2.01	1.55	0.46	22.89	-0.46
Stem lodging (%)	8.25	20.36	-12.11	-146.79	-7.46

Withdrawal of irrigation water from the sixth week after planting to harvest induced moisture stress which significantly influenced the performance of the plants for various characters. Moisture stress reduced grain yield by 49 %, days to tasselling by 4 %, ears per plant by 20 % and kernel moisture by 35 % while ASI increased by 87 %, ear rot by 98 % and stem lodging by 147 % in addition to hastened leaf senescence. In similar working conditions, Menkir *et al.* (2006) reported that moisture deficit reduced grain yield by 58 %, plant height by 16 %, ears per plant by 30 % and ear height by 19 %, while increasing days to silking by 6 % and ASI by 144 % in comparison with well-watered condition while drought stress had little effect on days to anthesis compared to well-watered condition. These results are indicative of the negative effects of drought stress on the key economic component which is grain yield.

DH testcross hybrids had a yield advantage of 17 % over that of commercial check hybrids for grain yield under drought stress. This revealed the superiority in performance by DH hybrids under stress conditions. As a consequence, it can be concluded that these newly developed drought tolerant DH hybrids offer better opportunities for improved crop production since they have proved to be drought-tolerant and high yielding than commercially cultivated varieties. Differential performance in yield by 49 % among DH testcross hybrids under well-watered and moisture deficit conditions (Table 22) are similar to results observed by Chapman and Edmeades (1999) and Monneveux *et al.* (2005). This significantly influenced the ranking order of the DH hybrids under stress and non-stress conditions as indicated by positive (0.47) and significant ($p<0.001$) correlations of yields recorded in the two test environments (Table 24). This pointed out variations in performance among the DH lines under different moisture regimes, thus permits precise selection of genotypes that are best adapted to either both or one of the moisture regimes. DH lines 12, 13 and 38 were outstanding performers under well-watered conditions (Table 10) but yielded poorly under drought stress (Table 18). Consequently, line 51 (L_{51}) was better grain yielder under drought stress and poor yielder under optimal conditions while line 1 (L_1) yielded poorly under both moisture regimes (Tables 11 and 18). This variability in performance under different moisture regimes indicated the possibility in selection of genotypes best suited to different maize growing areas and those that are not totally adapted to tropical zones i.e. L_1.

Drought-stress decreased days to tassel anthesis by between 1 and 3 days (Table 22) in the experimental hybrids. In similar findings, Monneveux *et al.* (2005) while working on 22 putative drought tolerant sources including landraces and elite populations crossed in a diallel mating design to 13 materials possessing drought tolerance genes reported that severe stress prior to flowering led to a reduction in stomatal conductance which affected photosynthates partitioning to the male inflorescence (tassel) and was associated with a significant level of barrenness. In contrast, study done by Munyiri *et al.* (2010) reported an increase in days to anthesis for the composite checks by between 1 and 5 days while for some of the Kenyan local landraces there was no significant change in days to anthesis. It can therefore be concluded that days to anthesis was dependent on the gene makeup of a genotype as opposed to availability of water prior to flowering.

ASI increased by 1 day in DH testcross hybrids and by 2 days in check hybrids under drought stress as compared to optimal conditions (Table 22). Mugo *et al.* (1998) reiterated that ASI was one of the most important traits that could be used to indicate maize genotype's tolerance to stress. As a result, a long ASI duration caused a reduction in grain yield. This is because different plant mechanisms at the time of flowering such as delayed silking, desiccated pollen, withered or senesced silks or exhaustion of starch reserves by the ovaries as a result of delayed anthesis led to barrenness or abortion of kernels which then reduced kernel size and weight, number of ears per plant and consequently reduced grain yield per unit area. Mugo *et al.* (1998) and Frova *et al.* (1999) similarly found that when drought stress occurs just before or during the flowering period in maize, a delay in silk emergence is observed resulting in an increase in the length of the ASI. Delayed silking led to less allocation of assimilates to ear growth during the early stages of development. Entry 24 (L_{24} x T_1) and entry 140 (L_{60} x T_2) exhibited the shortest ASI. Likewise, these hybrids had high number of ears per plant (0.97) and (0.93) and were among the top for grain yield across managed drought sites, producing 4.92 and 5.27 t/ha, respectively (Table 18). This implied that these genotypes possessed alleles for drought tolerance and had high yielding ability therefore were good parental source for hybrid combinations.

Number of ears per plant is one of the most important yield components of maize. It is positively correlated to grain yield. However, water stress significantly reduces expression of this character and in some cases, severe drought stress causes complete ear abortion. For example, mean number of ears per plant reduced by 20 % under drought stress as compared to well-watered conditions (Table 11 and 18). To support the above findings, study done by Monneveux *et al.* (2005) on drought tolerance improvement in tropical maize source populations concluded that number of ears per plant varied with moisture regimes among genotypes. Mugo *et al.* (1998) noted that grain yield and numbers of ears per plant were inherently smaller in composites because of the high level of barrenness and floret and kernel abortion. This led to a significant reduction in grain yield in terms of number of kernels per ear and 100 seed weight per plant.

According to Tollenaar and Wu (1999), grain abortion occurs during the first 2 to 3 weeks after silking and is worsened by stress that reduces canopy photosynthesis and the flux of assimilates to the developing ear. Bänziger *et al.* (2000b) proposed that on the basis of consideration of heritability and correlation with yield under moisture stress, barrenness should be considered as a useful secondary trait for improving maize yields in drought prone environments. Bolaños and Edmeades (1996) attributed more than 75 % of variation in grain yield under drought to variation in number of ears and kernels per plant. Mugo *et al.* (1998) reported that as stress increases, the dependence of grain yield on ears per plant increased more than on kernels per ear. It can be concluded that better performance for grain yield and other agronomic traits in some of the genotypes under moisture stress may be as a result of the allocation of more assimilates to ear formation at the critical stages of flowering and grain filling.

4.1.2.5 Selection indices used to categorize genotypes as either drought tolerant or drought susceptible.

The calculated mean values of drought selection indices based on grain yield under stress and non-stress conditions are presented in Table 23. Drought selection indices have been widely used by scientists to identify drought susceptible and drought tolerant genotypes in maize (Jafari *et al.,* 2009; Khayatnezhad *et al.,* 2010a), wheat (Khayatnezhad *et al.,* 2010b; Akçura *et al.,* 2011; Farshadfar *et al.,* 2012), and rice (Ouk *et al.,* 2006). STI, GMP and YSI were used for screening drought tolerant genotypes under drought stress and high yielding genotypes under well-watered conditions (Mohammadi *et al.,* 2003; 2010; Akçura *et al.,* 2011).

The analysis of variance showed non-significant differences among genotypes in respect to yield and yield components under drought stress (Table 19) demonstrating narrow genetic base among the genotypes for drought tolerance. However, some DH hybrids performed better for grain yield in both water regimes (Table 24), creating possibility of getting some drought tolerant genotypes.

Table 23: Average yield of top 15 and last 5 DH testcross hybrids based on STI under optimal and drought stress conditions, and calculated drought tolerance indices.

			Yield (t ha^{-1})		Drought Tolerance Indices				
RANK	**ENTRY**	**CROSS**	**Ypi**	**Ysi**	**SSI**	**STI**	**GMP**	**TOL**	**YSI**
1	23	23x1	8.34	5.58	0.68	0.96	6.82	2.76	0.67
2	92	12x2	8.14	5.50	0.67	0.92	6.69	2.64	0.68
3	126	46x2	8.05	5.08	0.76	0.84	6.39	2.97	0.63
4	142	62x2	7.14	5.67	0.42	0.84	6.36	1.47	0.79
5	28	28x1	8.37	4.79	0.88	0.83	6.33	3.58	0.57
6	140	60x2	7.57	5.27	0.63	0.82	6.32	2.30	0.70
7	71	71x1	8.32	4.72	0.89	0.81	6.27	3.60	0.57
8	138	58x2	7.78	5.03	0.73	0.81	6.26	2.75	0.65
9	99	19x2	7.68	5.04	0.71	0.80	6.22	2.64	0.66
10	147	67x2	7.19	5.30	0.54	0.79	6.17	1.89	0.74
11	110	30x2	8.55	4.44	0.99	0.78	6.16	4.11	0.52
12	29	29x1	8.57	4.40	1.00	0.78	6.14	4.17	0.51
13	132	52x2	8.04	4.67	0.86	0.78	6.13	3.37	0.58
14	22	22x1	8.12	4.61	0.89	0.77	6.12	3.51	0.57
15	137	57x2	6.87	5.32	0.46	0.75	6.05	1.55	0.77
156	20	20x1	6.37	1.91	1.53	0.25	3.49	4.46	0.30
157	43	43x1	5.43	2.18	1.53	0.24	3.44	3.25	0.40
158	47	47x1	5.65	2.07	1.53	0.24	3.42	3.58	0.37
159	3	3x1	5.70	2.00	1.53	0.24	3.38	3.70	0.35
160	32	32x1	6.51	1.68	1.53	0.23	3.31	4.83	0.26
Mean			**6.96**	**3.58**	**1.03**	**0.52**	**4.97**	**3.38**	**0.52**

Ypi: Potential yield; Ysi: Stress yield; SSI: Stress Susceptibility Index; STI: Stress Tolerance Index; GMP: Geometric Mean Productivity; TOL: Tolerance index; YSI: Yield Stability Index.

Entry 23 (L_{23} x T_1), entry 28 (L_{28} x T_1) and entry 71 (L_{71} x T_1). In agreement, using STI to determine the genotypes' tolerance to drought, entry 23, 28 and 71 had high STI scores of 0.96, 0.83 and 0.81 respectively, and low SSI scores of 0.68, 0.88 and 0.89 respectively (Table 23). These DH materials could be said to be drought tolerant since they are high yielding under both optimal (Ypi) and drought stress (Ysi) conditions. They need to be advanced further for use in ASALs and low potential areas which experience limited rainfall.

Table 24: High and low performing DH testcross hybrids under both well-watered and drought stress environments combined across locations in Kenya.

			Grain yield (t ha^{-1})	
	ENTRY	**CROSS**	**Optimum**	**Drought stress**
High performers	23	23x1	8.34	5.58
	28	28x1	8.37	4.79
	71	71x1	8.32	4.72
Low performers	1	1x1	5.64	2.55
	3	3x1	5.7	2.00
	15	15x1	5.72	2.66
	16	16x1	5.63	2.31
	43	43x1	5.43	2.18
	47	47x1	5.65	2.07
Grand mean of trial			**6.96**	**3.58**

On the other hand, entries 1, 3, 15, 16, 43 and 47 presented low grain yield under both moisture regimes when compared to mean grain yield (Table 24) and had high SSI index (Table 23). These materials can therefore be regarded as drought susceptible and be eliminated from future selection programs. An important observation made was that the best yielding DH testcross hybrids across optimum environments i.e. entry 91 (L_{11} x T_2) and entry 29 (L_{29} x T_1) (Table 11) and across drought stress environments entries 142 (L_{62} x T_2) and 23 (L_{23} x T_1) (Table 18) were not among the top yielding DH hybrids across both water regimes. This meant that these genotypes were unstable across treatments thus require to be rigorously evaluated for yield to determine their definite performance before commercial release.

STI, GMP and YSI were significantly ($p<0.001$) and positively correlated with Ypi and Ysi (Table 25). These results were in tandem with findings by Jafari *et al.* (2009) who worked with

20 maize hybrids to determine their drought tolerance level using STI, GMP and harmonic mean indices and those of Akçura *et al.* (2011) while studying 36 bread wheat genotypes to evaluate the ability of several selection indices to identify drought tolerant genotypes under different conditions of Konya, Turkey. It was interesting to note positive correlation between SSI and Ypi (Table 25) indicating that stress susceptibility was positively correlated with non-stress yield (Ceccarelli and Grando, 1991; Akçura *et al.,* 2011).

Table 25: Correlation coefficients between different selection indices and mean yield of DH testcross hybrids under optimal and drought stress conditions.

	Ypi	**Ysi**	**SSI**	**STI**	**GMP**	**TOL**
Ysi	0.47***					
SSI	0.20**	-0.76***				
STI	0.77***	0.92***	-0.45***			
GMP	0.78***	0.92***	-0.45***	1.00***		
TOL	0.64***	-0.38***	0.87***	0.01^{ns}	0.02^{ns}	
YSI	-0.20**	0.76***	-1.00***	0.45***	0.45***	-0.87***

****, *** significant at 0.01 and 0.001 probability levels, respectively. ns: non-significant**

Ypi: Potential yield; Ysi: Stress yield; SSI: Stress Susceptibility Index; STI: Stress Tolerance Index; GMP: Geometric Mean Productivity; TOL: Tolerance index; YSI: Yield Stability Index.

The findings suggested that some characteristics that contributed to yield potential may have acted to increase susceptibility to stress and that selection for both SSI and Ypi could counteract each other. In contrast, Ehdaie and Shakiba (1996) found that there was no correlation between SSI and Ypi when screening wheat for drought tolerance. Similar to results reported by Sio-Se Mardeh *et al*. (2006); Golabadi *et al*. (2006) and Khayatnezhad *et al.* (2010a), there was positive correlation between TOL and potential yield (Ypi) and the negative correlation between TOL and yield under stress (Ysi) suggesting that selection based on TOL would result in reduced yield under well-watered conditions (Table 23). Positive and significant ($p<0.001$) correlations of Ypi and STI, GMP and TOL showed that these criteria indices were more effective in identifying high yielding cultivars under different moisture conditions as revealed in this study.

A general linear model regression for grain yield under drought stress using STI revealed a positive correlation between this criteria with a high coefficient of determination ($R^2= 0.84$) (Figure 3) and a negative correlation between SSI and grain yield (Figure 4). There was an increase in grain yield with an increase in STI. This meant that as the genotype's tolerance to drought increased, its relative performance for grain yield also significantly increased. This could be the reason why the genotypes that were drought tolerant (Table 23) yielded better under both optimal and limited water conditions (Table 24). Such genotypes could serve as sources of drought tolerance genes for the development of new drought-tolerant maize varieties.

Grain yield decreased with an increase in SSI (Figure 4). As water availability during reproductive stage of the DH testcrosses continued to be a limiting factor, growth and development of some plants were greatly affected leading to low yields observed. Such genotypes are said to be susceptible to drought. Entries 20, 43, 47, 3 and 32 had the highest SSI value of 1.53 (Table 23). This implied that these genotypes were drought susceptible. These results were supported by relatively low yields observed for these genotypes under drought stress ranging between 1.7 to 2.2 t/ha (Table 18). DH hybrids entry 23 (L_{23} x T_1) and entry 92 (L_{12} x T_2) had very high STI value of 0.96 and 0.92 respectively compared to the average of 0.52 (Table 23). These genotypes also had high yields under drought stress and performed equally well under optimum conditions (Table 24). These observations could be translated to mean that L_{23} and L_{12} could be nominated as drought tolerant genotypes to be used for hybrid formation targeting marginal regions and ASALs.

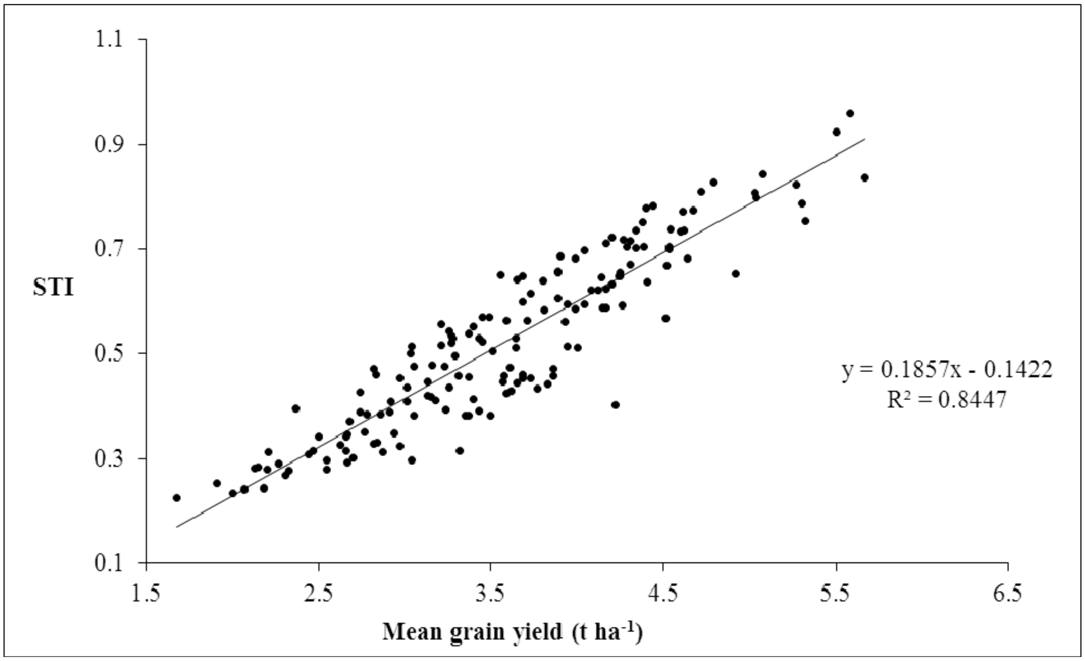


Figure 3: Plot of the variance Stress Tolerance Index (STI) against mean stress yield (Ysi) for 160 DH hybrids under managed drought environments.

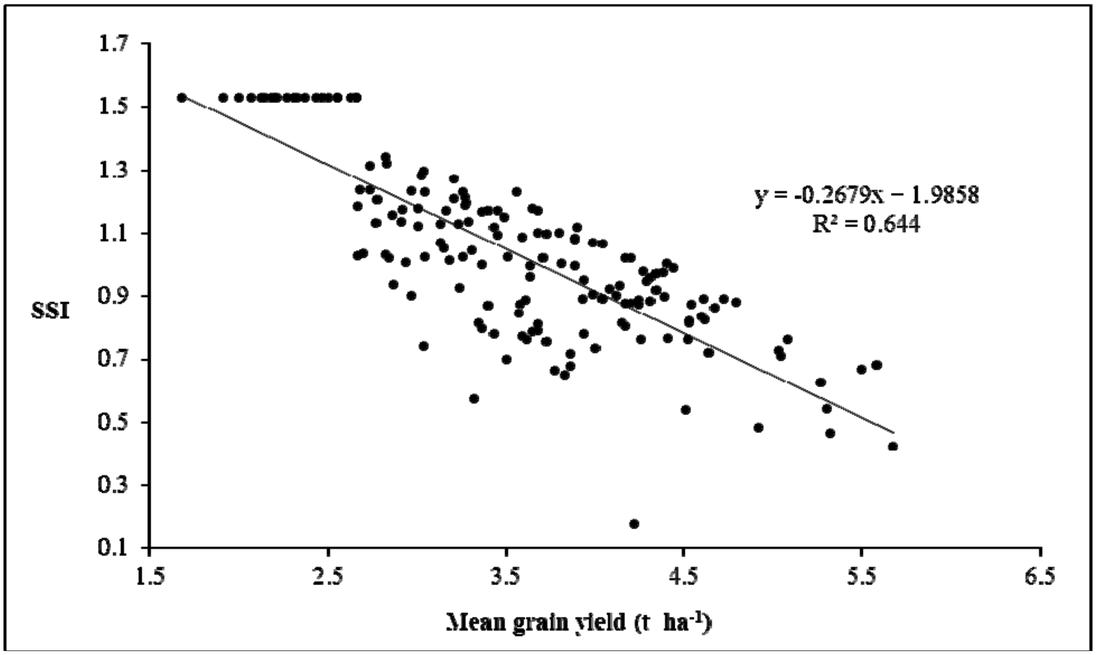


Figure 4: Plot of the variance Stress Susceptibility Index (SSI) against mean stress yield (Ysi) for 160 DH hybrids under managed drought environments.

4.1.2.6 Phenotypic correlation studies

To obtain superior genotypes, the knowledge of inter-relationship of yield and yield related traits in a particular situation is a pre-requisite. The extent of this character association between the important traits in given conditions is studied by correlation coefficients. This will aid in developing suitable selection criterion in order to decide on suitable breeding procedure for developing cultivars suitable for a wide range of environments. Correlation analysis between grain yield and other traits was computed as presented in Table 26 to identify traits associated with productivity under the two moisture regimes. The magnitude of the correlation explained the trait's association with grain yield as the reference trait. A trait that had a stronger significant correlation with grain yield provided more information in estimating grain yield per unit area.

It is interesting to note that the correlations of nine traits with yield were significant ($p<0.001$) and had the same signs under both moisture deficit and sufficient water supply. In both conditions, grain yield was positively and significantly ($p<0.001$) correlated to various characters. Positive associations were observed between grain yield and plant and ear heights (Malik *et al.,* 2005; Kashiani *et al.,* 2010), ears per plant (Miti *et al.,* 2010) and grain moisture at harvest (Menkir *et al.,* 2009) under both moisture regimes and in addition, days to anthesis and leaf senescence under drought stress. These results indicated that the measurements of these yield component traits had direct positive contribution to grain yield. For positive correlations, an increase in the respective trait also indicated an increase in yield of maize. This implied that high yield was associated with late flowering, short ASI, tall plants, lodging resistance and increased number of ears per plant under both moisture regimes and with increased retention of green leaf area under moisture deficit.

Table 26: Phenotypic correlation coefficients for grain yield and component traits of DH testcross hybrids under well-watered (lower diagonal) and drought stress conditions (upper diagonal) evaluated in Kenya in 2012.

	Grain Yield (t ha^{-1})	**Days to Anthesis**	**Anthesis Silking Interval (days)**	**Plant Height (cm)**	**Ear Height (cm)**	**Root Lodging (%)**	**Stem Lodging (%)**	**Ears per Plant (#)**	**Ear Rot (%)**	**Grain Moisture (%)**	**Ear Aspect (1-5)**	**Leaf Senescence (1-10)**
GY	1.00^{ns}	0.41***	-0.03^{ns}	0.51***	0.48***	-0.12^{ns}	-0.11^{ns}	0.53^{ns}	-0.14^{ns}	0.66***	-0.1^{ns}	0.18**
AD	-0.09***		0.09^{ns}	0.84***	0.87***	0.002^{ns}	0.09^{ns}	0.27***	0.28***	0.85***	0.49***	0.62***
ASI	-0.27***	0.04^{ns}		0.15*	0.08^{ns}	-0.15*	-0.16*	0.00	-0.08^{ns}	0.05^{ns}	0.33***	0.33***
PH	0.54***	-0.25***	-0.31***		0.97***	-0.07^{ns}	-0.37***	0.41***	-0.11^{ns}	0.89***	0.55***	0.72***
EH	0.45***	-0.28***	-0.26***	0.86***		-0.05^{ns}	-0.28***	0.34***	-0.01^{ns}	0.87***	0.52***	0.66***
RL	-0.19***	0.12***	0.02^{ns}	-0.11***	-0.08***		0.07^{ns}	-0.08^{ns}	0.06^{ns}	-0.04^{ns}	0.04^{ns}	0.01^{ns}
SL	-0.09***	-0.62***	-0.03^{ns}	0.17***	0.32***	0.07*		-0.32***	0.73***	-0.23**	-0.29***	-0.29***
EPP	0.48***	0.14***	-0.33***	0.25***	0.20***	-0.05^{ns}	-0.12***		-0.30***	0.52***	0.12^{ns}	0.22**
ER	-0.17***	0.11***	0.14***	-0.21***	-0.27***	-0.01^{ns}	-0.18***	-0.19***		-0.07^{ns}	0.001^{ns}	-0.1^{ns}
MOI	0.15***	0.76***	-0.02^{ns}	-0.09***	-0.21***	-0.01^{ns}	-0.63***	0.24***	0.09***		0.32***	0.54***
EA	-0.16***	-0.19***	-0.28***	-0.07**	-0.15***	0.002^{ns}	0.03^{ns}	0.02^{ns}	-0.03^{ns}	-0.08**		0.73***
PA	-0.21***	-0.03^{ns}	-0.11***	0.03^{ns}	0.04^{ns}	0.16***	0.11***	0.03^{ns}	-0.1***	-0.1***	0.19***	-

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

In agreement, plant height had the highest (r =0.54) significant indirect effect on yield through days to anthesis, days to silking, ears per plant and ear height with the highest effect through ear height (r = 0.45; r = 0.48). This might be attributed to the high dry matter accumulation function carried out by the high number of leaves found in tall plants. This led to increased prolificacy by the plant due to adequate photosynthates at the time of flowering and physiological maturity hence resulting into more numbers of ears per plant. Therefore, for selection of superior genotypes, reinforcement should be on the use of the above mentioned secondary traits as compared to grain yield alone.

Conversely, association between yield was weak, negative and significantly ($p<0.001$) correlated to ASI, root lodging, stem lodging, ear rots, ear and plant aspects. Comparable to results reported by Bänziger and Lafitte (1997) and Richards (2006), negative and highly significant ($p<0.001$) relationship of grain yield with ASI (weak, r = -0.27) and days to anthesis (weak, r = -0.09) under optimal conditions and with ASI (weak, r = -0.03) under moisture stress are worth noting in this study. This suggested that these traits were not closely associated and therefore may not be jointly selected. Their values reduced as GY increased thereby impacting negatively on the full potential of the DH hybrids for grain yield. The negative phenotypic correlations between grain yield and ASI, lodging, ear aspects and plant aspects suggested that yield may be reduced by a relative increase in these traits.

ASI reduced yield indirectly under drought stress through reduced number of ears per plant and increased root lodging and stem lodging with the highest effect on stem lodging (r = -0.09). Badu-Apraku *et al.* (2012) in a study of the assessment of reliability of secondary traits in selecting for improved grain yield in drought and low-nitrogen environments reported similar findings. It can be concluded that late maturing hybrids under drought stress had poor grain filling and seed setting due to limited moisture supply, less favorable photoperiod and varying temperatures induced by changing season during the reproductive stage. These results clearly indicated that for rain-fed areas, cultivated varieties ought to be early maturing and high yielding while in ASALs, the varieties developed were supposed to be drought tolerant and equally high yielding.

4.1.2.7 Heterotic grouping of DH inbred lines

Tropical maize germplasm often belong to two main heterotic groups; A and B (Vasal *et al.,* 1999). An inbred line that expresses positive SCA effects when crossed to a tester imply that the two genetic materials belong to the opposite heterotic group while the one exhibiting negative SCA effects when crossed to a tester imply that they belong to the same heterotic group (Vasal *et al.,* 1992). The 80 DH lines were grouped into heterotic group A (HGA) and heterotic group B (HGB) based on SCA estimates for grain yield. Under well-watered trials, 24 DH lines belonged to HGA, 47 to HGB and nine were intermediate between HGA and HGB therefore were grouped under HGA/B (Appendix IX). Under managed drought conditions, 24 DH lines belonged to group HGA, 39 to HGB and 17 to HGA/B (Appendix X). Outstanding DH lines belonging to the same heterotic group across both stress and non-stress conditions were 33 in total. Seven belonged to HGA, 23 to HGB and three to HGA/B (Table 27). In order to maximize genetic diversity and therefore heterosis during hybrid variety development using these inbred lines, one parent should come from HGA and the second parent from HGB. In the case of making synthetics inbred lines belonging to the same heterotic group should be used.

Table 27: Heterotic grouping of DH lines under both optimum and drought stress conditions based on specific combining ability estimates for grain yield.

	Optimum	Drought		Optimum	Drought
Line	**Heterotic Group**	**Heterotic Group**	**Line**	**Heterotic Group**	**Heterotic Group**
1	B	B	**41**	A	B
2	A	B	**42**	B	A
3	B	B	**43**	B	AB
4	A	AB	**44**	A	B
5	AB	AB	**45**	AB	B
6	B	AB	**46**	B	B
7	A	B	**47**	B	B
8	B	B	**48**	B	A
9	A	B	**49**	B	B
10	B	B	**50**	B	B
11	B	B	**51**	B	A
12	B	B	**52**	B	B
13	B	A	**53**	B	B
14	AB	A	**54**	A	AB
15	B	B	**55**	B	AB
16	B	B	**56**	AB	B
17	B	AB	**57**	A	B
18	AB	AB	**58**	B	B
19	AB	B	**59**	B	B
20	A	B	**60**	A	B
21	B	B	**61**	B	AB
22	A	B	**62**	B	A
23	A	A	**63**	B	B
24	A	AB	**64**	B	B
25	A	AB	**65**	B	A
26	A	A	**66**	B	A
27	A	B	**67**	B	A
28	A	A	**68**	B	B
29	A	A	**69**	A	B
30	B	B	**70**	A	B
31	B	B	**71**	A	A
32	B	A	**72**	B	B
33	B	AB	**73**	AB	AB
34	B	AB	**74**	B	A
35	B	AB	**75**	AB	A
36	A	A	**76**	B	A
37	A	A	**77**	B	A
38	A	B	**78**	B	AB
39	AB	A	**79**	B	AB
40	B	A	**80**	B	A

4.1.3 Random drought environments

A protracted period of deficient rainfall during the growing season is expected during random drought management conducted during short rains resulting into loss of yield. However, the rainfall intensity and duration during the short rains season was high and as a result, data collected was more or less not regarded as under random drought conditions. A casual look at the results for grain yield under optimum and random drought looked similar (Table 28) but from a critical point of view, there were differences in best performing testcross hybrids in individual sites when compared against the two water regimes. Random drought was under assorted climatic and edaphic conditions while under optimum conditions, water was the main variable for growth. Therefore, if irrigation was to be implemented in dry lands, selection should be made from best optimum as opposed to random drought conditions. In all the locations, at least one variety performed well under both water regimes except in Embu where there were two best DH hybrids across treatments. Best performers were unique across locations. In Kiboko, the best entry under both water regimes was entry 110, in Kakamega, entry 22; in Embu, entry 96 and 22; and in KTI entry 26. Entry 22 performed well in both Embu and Kakamega. These top performers can be further evaluated to determine their stability before being commercial released into farming community.

Outstanding commercial hybrids under both optimum and random drought in all locations were DK-8053 and H513 respectively, except in Kakamega where the order was reversed while in KTI, H513 performed better across both moisture regimes (Table 28). This meant that DK-8053 and H513 varieties were still good recommendations for commercial use by farmers.

Table 28: Comparison in performance of the best 10 and last 5 DH hybrids and commercial hybrids for grain yield in individual sites evaluated under optimal and random drought conditions in Kenya during 2012-2013 season.

	KIBOKO				KAKAMEGA				EMBU				KTI				MTWAPA	
	Optimum		Random drought		Optimum		Random drought		Optimum		Random drought		Optimum		Random drought		Random drought	
RANK	ENTRY	GY	ENTRY	GY	ENTRY	GY	ENTRY	GY	ENTRY	GY	ENTRY	GY	ENTRY	GY	ENTRY	GY	ENTRY	GY
1	110	9.6	152	9.2	28	11.8	22	6.7	120	8.8	116	11.5	26	8.8	126	7.1	26	5.1
2	36	9.5	110	9	22	11.6	94	6	96	8.4	136	11.2	85	8.5	117	7.0	120	5.1
3	4	9.2	81	8.8	29	11.6	143	5.3	144	8.3	70	11.1	101	8.3	92	6.9	129	5.0
4	97	9.1	115	8.6	114	11.5	140	5.3	29	7.8	22	11	91	8.3	154	6.8	29	5.0
5	93	9.0	158	8.1	71	11.4	125	5.3	129	7.7	90	10.8	95	8.2	36	6.7	91	4.9
6	68	9.0	120	8.1	116	11.4	99	5.3	22	7.7	144	10.4	27	8	140	6.7	24	4.9
7	96	9.0	153	8.1	93	11.3	144	5.2	152	7.7	156	10.3	57	7.9	133	6.7	127	4.8
8	91	8.9	83	8.0	36	11.3	87	5.2	114	7.7	115	10.2	138	7.8	26	6.6	111	4.8
9	135	8.9	25	8.0	91	11.2	102	5.1	92	7.6	96	10.1	98	7.6	122	6.6	139	4.8
10	82	8.8	125	7.8	126	11.0	90	5.1	23	7.6	25	10.1	120	7.6	125	6.6	115	4.8
156	15	5.2	51	3.8	98	6.2	53	1.6	49	3.6	20	4.6	47	3.7	58	3.8	42	2.4
157	102	5.1	8	3.7	80	6.1	75	1.6	108	3.5	68	4.4	43	3.7	107	3.8	52	2.3
158	61	4.9	33	3.5	103	5.4	6	1.6	104	3.5	63	4.4	122	3.6	14	3.8	17	2.2
159	106	4.8	92	3.5	104	5.2	13	1.6	1	3	61	4.3	108	3.4	32	3.7	5	2.1
160	108	4.7	58	3.1	3	5.0	72	1.2	79	2.7	107	4	74	2.2	66	3.5	73	2.1
Commercial	DK-8053	8.9	DK-8053	5.4	DK-8053	8.5	DK-8053	3.6	DK-8053	6.4	DK-8053	7.3	DK-8053	6.8	DK-8053	5.7	DK-8053	4.4
checks	H513	7.6	H513	7.7	H513	9	H513	1.6	H513	6.4	H513	11.7	H513	7.3	H513	6.2	H513	4.4
	PH3253	6.2	PH3253	4.6	PH3253	7.8	PH3253	1	PH3253	5.9	PH3253	9.6	PH3253	7	PH3253	6.2	PH3253	4.4
Local check 1	WH403	6.8	WH403	5.2	H624	11.2	DH04	1.8	DH04	4.1	Embu synthetic	7.2	DH04	6.6	WH403	5.3	WH403	3.7
Local check 2	Duma 43	6.6	WH507	6.4	H520	7.9	H520	2.9	Duma 43	7.2	PAN-14M-43	6.1	Duma 43	5.8	PAN-14M-43	5.7	PAN-14M-43	3.1
Mean of trial		**7.2**		**6.0**		**8.8**		**3.3**		**6.1**		**7.8**		**5.9**		**5.3**		**3.7**
Heritability		**0.7**		**0.5**		**0.8**		**0.8**		**0.6**		**0.6**		**0.6**		**0.6**		**0.0**
LSD (0.05)		**1.6**		**2.2**		**1.6**		**1.4**		**2.0**		**2.9**		**2.0**		**1.4**		**1.1**

GY: Grain Yield; Local check 1 = Drought tolerant hybrid; Local check 2 = Drought susceptible hybrid.

However, some local hybrids performed better than the commercial hybrids. In Kakamega, H624 out yielded the best commercial hybrid (DK-8053) by 20 % while in Embu, Duma 43 out yielded the best commercial hybrid (DK-8053) by 11 %. This suggested that further evaluations need to be conducted on the local checks recommended for each location since they portrayed high yield potential that can be commercially exploited. In Kakamega, mean grain yield was significantly reduced (3.6t/ha) under random drought (Table 28) because of the Maize Lethal Necrotic (MLN) disease that severely affected plant growth during reproductive stage, interfering with proper development of ears and also leading to kernel abortion and barrenness and ultimately death of the plant.

Combined analysis across locations under the three treatments revealed that the top 10 DH hybrids performed better than the commercial checks for grain yield (Table 29). The best DH hybrid entry 91 (8.85t/ha) out yielded the best check DK-8053 (7.67 t/ha) by 13 % under well-watered conditions, entry 142 (5.67 t/ha) out yielded the best check DK-8053 (3.43 t/ha) by 62 % under managed drought conditions and entry 22 (6.72 t/ha) out yielded the best check H513 (6.32t/ha) by 6 % under random drought conditions. This demonstrated the superiority of the respective DH lines and their usefulness in hybrid formation for use in drought prone areas of Kenya and ESA. The best performers across locations under well-watered, managed drought and random drought conditions were test hybrids 91, 23, 26, 116 and 120 (Table 29). These five DH testcrosses maintained superior performance for grain yield under varying moisture levels thus might be useful for seed companies interested in seed multiplication for multi-location production.

Table 29: Mean performance of the best 10 and last 5 DH tesctross hybrids and checks hybrids for grain yield across locations evaluated under different conditions in Kenya during 2012-2013 season.

COMBINED ANALYSIS ACROSS TRIAL SITES							
Optimum			**Managed drought**		**Random drought**		
RANK	**ENTRY**	**Grain yield (t ha^{-1})**	**ENTRY**	**Grain yield (t ha^{-1})**	**ENTRY**	**Grain yield (t ha^{-1})**
1	91	8.85	142	5.67	22	6.72
2	29	8.57	23	5.58	81	6.61
3	110	8.55	92	5.50	144	6.53
4	116	8.53	137	5.32	84	6.44
5	120	8.53	147	5.30	26	6.43
6	26	8.51	140	5.27	116	6.43
7	93	8.39	126	5.08	136	6.39
8	135	8.38	99	5.04	91	6.39
9	28	8.37	138	5.03	115	6.38
10	23	8.34	24	4.92	120	6.38
156	80	5.28	149	2.13	61	3.65
157	106	5.26	47	2.07	53	3.65
158	103	4.75	3	2.00	107	3.63
159	104	4.61	20	1.91	68	3.60
160	108	4.60	32	1.68	58	3.53
	DK-8053	7.67		3.43		5.32
	H513	7.62		2.16		6.32
	PH3253	6.73		2.36		5.09
	Local check 1	7.19		2.25		4.52
	Local check 2	6.93		1.93		4.81
Grand mean of trial		**6.97**		**3.55**		**5.21**
Entry variance		**0.80**		**0.20**		**0.57**
Location variance		**1.79**		**1.77**		**3.30**
Location x Entry variance		**0.22**		**0.17**		**0.21**
Heritability		**0.83**		**0.29**		**0.81**
LSD (0.05)		**1.12**		**1.92**		**1.01**

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL DISCUSSION

Doubled haploid technology significantly shortens the breeding cycle to obtain pure lines yet still leads to development of homozygous and homogeneous inbred lines. On the other hand, haploid plants are small and less vigorous than their corresponding diploid plants thus seems to be unstable across environments. However, the results observed in this study overrule the latter assertions. Combined analyses across locations under different water regimes revealed that the DH hybrids were similar to or better than the commercial checks for all the agronomic traits investigated. Under all the water regimes, all the top ten DH hybrids had a yield advantage of 16 %, 62 % and 6 % respectively over the best check hybrids DK-8053 (7.7 t/ha), DK-8053 (3.43 t/ha) and H513 (6.32 t/ha), respectively. This implied that the performances of DH hybrids relative to those of the best commercial hybrids were superior suggesting that the donor parents used in developing the DH lines are excellent sources of germplasm to improve drought tolerance and combining ability of locally adapted germplasm for maize growing areas in Kenya and within the sub-Saharan Africa.

Generally, drought had significant effects on the assessed traits. Mean grain yield under drought stress across locations was significantly reduced by almost 50 % compared to the well-watered environments. Drought increased ASI by 87 % compared to measurement under optimum conditions. The short ASI under non-stress conditions was indicative of the expected complete synchronization during flowering which allows for fertilization and good cob fill. Westgate *et al.* (1997) found that drought stress at flowering did not affect days to flowering instead, it slowed silk elongation resulting in large ASI for drought susceptible genotypes. Similar to findings by Beyene *et al.* (2013), most of the testcross hybrids had shorter ASI suggesting that the DH lines had favorable genes from the drought tolerant parents (Table 2).

Evaluation of the DH hybrids across treatments exhibited differential performance by the hybrids for various characters. Prominent top performing DH hybrids for grain yield in two or three locations across various moisture regimes were entry 91 ($L_{11}xT_2$), entry 116 ($L_{36}xT_2$), entry 120 ($L_{40}xT_2$), entry 26 ($L_{26}xT_1$) and entry 23 ($L_{23}xT_1$). Consequently, entries 23, 28 and 71 had high grain yield in both moisture regimes. In agreement, these DH hybrids had high STI and low SSI scores. These hybrids should be further evaluated in generational trials to determine their stability and trueness-to-type to their parental genotypes. Their parental components were also indicative of presence of good genetic materials that should be used to form desirable hybrid combinations for drought tolerance and improved yield. These very good DH lines that have been identified should be further evaluated for commercial exploitation. Out of the top ten hybrids under well-watered conditions, only one entry 23 ($L_{23}xT_1$) was among the top ten under drought stress conditions. This finding showed that there was no guarantee that a genotype selected for optimum rain-fed trial would produce high under drought stress conditions. It is important, therefore, to differentiate between genotypes that produce high yields under drought stress because of inherent yield potential and those that produce high yields under drought stress because of their inherent drought tolerance.

In evaluating an inbred line for the production of hybrid maize, two factors are always considered important: the characteristics of the inbred line *per se* and its combination with another inbred line or tester to form a hybrid. Combining ability results under well-watered and random drought conditions showed existence of significant differences of genotype mean squares for yield and yield associated traits showing variability among lines, testers and F_1 hybrids. Non-significant observation of GCA and SCA under drought stress for the assessed traits displayed similarity in performance of F_1s and parental genotypes for those traits. This was because drought the experimental materials showed no differences when evaluated under drought; selection for suitable parents to be used in hybrid combinations should therefore be done under optimal conditions but with consideration of the performance of the same lines under drought stress conditions plus their reaction to the maize foliar diseases. Inbred lines L_{36}, L_4, L_{13}, L_{11}, L_5 and L_{71} and T_2 had positive and significant ($0.05<p<0.001$) GCA effects for grain yield and other agronomic traits under optimal conditions while inbred lines L_9, L_{65}, L_{64} and L_{51} had positive and significant ($p<0.01$; $p<0.05$) GCA estimates for grain yield under drought stress. This implied that these lines and T_2 had favorable alleles for most of the maize agronomic traits thus should be evaluated further on their suitability for use in commercial hybrid production of maize.

Test hybrids 28, 29, 23, 26, 25, 27, 22, 24, 69, 71, 160, 120 and 110 had positive and significant ($p<0.001$) SCA estimates for grain yield under optimal conditions while entries 49, 108 and 155 were the best specific combiners for grain yield under drought stress. An important inference that was drawn from these results is that cross combinations involving L_{36}, L_{11}, L_{23}, L_{28} and L_{71} as a common parent recorded desirable GCA and SCA effects and high mean performance for most of the traits studied. These inbred lines therefore had desirable attributes and could be used as donor lines in a maize improvement program to develop high yielding and drought tolerant germplasm. Additionally, T_1 was found to be the better general and specific combiner for most of the studied traits under drought stress conditions (Table 20 and 21a) while T_2 was better under well-watered conditions (Table 14 and 15b). These two testers were therefore considered appropriate to separate DH lines used in this study into HGA and HGB just as they have been used to separate conventional inbred lines. It is therefore recommended that when selecting for parental combination for any given trait, emphasis should be put on the type of tester used as this will determine the performance of the testcross hybrids in targeted environments. The experimental hybrids used in this study showed high resistance to gray leaf spot and leaf rust with disease scores of 1.5 to 1.75 and moderate resistance to leaf blight with disease scores of 1.98 to 3.46. This implied that these hybrids carried favorable alleles for resistance to the cosmopolitan foliar diseases of maize, an added advantage to their high yielding capacity and drought tolerant genes.

High magnitude of broad-sense heritability and larger genetic variance for grain yield in optimum and random drought conditions indicated the preponderance of additive gene action in the inheritance of these maize agronomic traits. This inferred the possibility of effective selection for genetic improvement of these traits. However, under drought stress where heritability of all investigated characters was reduced, secondary traits such as ASI, number of ears per plant, ear aspect (visual assessment of quality) and leaf senescence which were positively correlated to grain yield (Table 25) should be used to increase selection efficiency for improved yield under drought stress as corroborated in literature reported by Lafitte and Bänziger (1997); Bänziger and Cooper (2001); Magorokosho *et al.* (2003); Badu-Apraku *et al.* (2011).

Characterization of crop heterotic group and genetic diversity aids in efficiently exploiting the allelic variation for genetic improvement of economically desirable traits. The 80 DH lines used in this study exhibited differences in positions for HGA, HGB and HGA/B under different moisture regimes. The SC testers successfully grouped the DH lines into their respective groups Seven to HGA, 23 to HGB and three to HGA/B (Table 27). However, more insight into why some of these DH lines belonged to either of the heterotic groups when exposed to varying moisture conditions and were not stable across environments is required.

5.2 CONCLUSIONS

The DH testcross hybrids in this study exhibited excellent performance for grain yield and other measured agronomic traits. Seven DH test-cross hybrids performed best for grain yield and yield associated traits under optimum, managed drought or random drought conditions. These hybrids derived from DH inbred lines have proved to be superior in different ecologies thus they can be further evaluated targeting a particular environment. The corresponding parental genotypes can be used in developing hybrid combinations for commercial production. However, Out of the top ten hybrids under well-watered conditions, only one test hybrid, entry 23 ($L_{23}xT_1$) was among the top ten under drought stress condition. This finding showed that there was no guarantee that a genotype selected for optimum rain-fed trial would produce high under drought stress conditions. It is important therefore, to differentiate between genotypes that produce high yields under drought stress because of inherent yield potential and those that produce high yields under drought stress because of their inherent drought tolerance.

Ten DH inbred were found to have impressive GCA effects for grain yield and other assessed agronomic traits. Thirteen DH hybrids had impressive SCA for grain yield. Important inferences made from the current study were i) T_2 was a better parental genotype under non-stress environments while T_1 exhibited better performance under stress conditions ii) the best specific combinations for grain yield and yield related traits had T_1 as a common parent as opposed to T_2. This pointed out the necessity of a rigorous testing of the DH lines in a diallel mating design so as to evaluate the performance of the lines *per se* and their resultant hybrids to identify stable ones for commercial exploitation. Additive gene action was found to be useful in governing most if not all of the assessed characters. Breeding methods that take advantage of additive gene actions in recurrent selection strategies would be efficient in the development of new varieties from these DH germplasm evaluated more so if the selection for grain yield is considered.

High heritability estimates observed for the studied traits under well-watered conditions enables precise selection and transfer of desirable traits to the progenies. This would eventually widen the genetic base of these DH lines used in the current study. Drought stress adversely affected heritability of most assessed traits. This negative impact could be reduced through indirect selection of yield associated secondary traits. Phenotypic correlations between grain yield and days to 50 % pollen shed, ear and plant heights, kernel moisture and leaf senescence under drought stress were positive and significant ($p<0.001$). These secondary traits were identified as the most reliable traits to step-up selection for yield under drought stress in the DH testcross hybrids instead of using heritability estimates which were significantly reduced under drought stress.

This research confirmed that DH lines developed from tropical adapted BC populations had favorable genes for improving yield under stress and non-stress conditions. DH lines represent homozygous and true-breeding lines, which can be repeatedly phenotyped. The DH technology also increases speed and efficiency to produce new products in the market. The results showed that these newly developed DH hybrid maize were significantly better in performance for grain yield than the best commercial checks developed through pedigree breeding and comparable in other major agronomic traits of maize under both stress and non-stress conditions. Thus, they could be commercially exploited to curb the emerging food insecurity issues.

5.3 RECOMMENDATIONS

1. Doubled haploid testcross hybrids identified to have stable and high yield potential across various moisture regimes should be evaluated further in a broad range of locations to capture genes associated with adaptation to a target environment for commercial exploitation.

2. The ten DH lines with good GCA values for grain yield should be further evaluated in a diallel design to determine their *per se* performance and usefulness in making hybrids while the best 13 DH testcross hybrids should be further evaluated in advanced yield trials to further characterize them in terms of performance and stability across locations.

3. The DH lines changed positions in regard to heterotic grouping under stress and non-stress conditions. It is therefore recommended that further scrutiny be done to determine the cause of this instability and its usefulness in breeding.

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APPENDICES

Appendix I: Pedigree of genetic materials used in this study.

LINE	NAME	PEDIGREE
1	CKDHL0007	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-8-B-B-B
2	CKDHL0020	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-28-B-B-B
3	CKDHL0021	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-29-B-B-B
4	CKDHL0023	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-31-B-B-B
5	CKDHL0032	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-40-B-B
6	CKDHL0043	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-58-B-B-B
7	CKDHL0048	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-63-B-B-B
8	CKDHL0053	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-69-B-B-B
9	CKDHL0056	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-73-B-B-B
10	CKDHL0058	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-75-B-B
11	CKDHL0063	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-81-B-B-B
12	CKDHL0065	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-83-B-B-B
13	CKDHL0076	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML395/CML395) DH-99-B-B
14	CKDHL0086	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-11-B-B
15	CKDHL0104	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-38-B-B-B
16	CKDHL0110	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-45-B-B-B
17	CKDHL0114	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-49-B-B-B
18	CKDHL0121	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-57-B-B
19	CKDHL0130	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-66-B-B-B
20	CKDHL0134	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-70-B-B-B
21	CKDHL0140	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-77-B-B-B
22	CKDHL0150	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-88-B-B-B
23	CKDHL0161	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-99-B-B-B
24	CKDHL0166	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-105-B-B-B
25	CKDHL0167	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-107-B-B
26	CKDHL0170	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-111-B-B-B
27	CKDHL0172	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML444/CML444) DH-113-B-B-B
28	CKDHL0182	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML488/CML488) DH-7-B-B
29	CKDHL0183	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML488/CML488) DH-10-B-B
30	CKDHL0198	(La Posta Seq C7-F96-1-2-1-1-B-B-B/CML488/CML488) DH-26-B-B
31	CKDHL0219	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-8-B-B-B
32	CKDHL0225	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-14-B-B-B
33	CKDHL0235	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-27-B-B
34	CKDHL0237	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-30-B-B
35	CKDHL0241	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-34-B-B-B
36	CKDHL0248	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-43-B-B-B
37	CKDHL0254	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-51-B-B
38	CKDHL0266	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-74-B-B
39	CKDHL0267	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML312SR = MAS[MSR/312]-117-2-2-1-2-B*4-B-B-B-B/CML312SR) DH-77-B-B-B
40	CKDHL0283	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-4-B-B-B
41	CKDHL0284	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-5-B-B-B
42	CKDHL0298	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-24-B-B
43	CKDHL0299	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-25-B-B-B
44	CKDHL0313	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-43-B-B-B
45	CKDHL0324	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-54-B-B
46	CKDHL0331	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-61-B-B-B
47	CKDHL0340	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-73-B-B-B
48	CKDHL0345	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-78-B-B-B
49	CKDHL0356	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-89-B-B
50	CKDHL0364	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-97-B-B-B
51	CKDHL0369	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-102-B-B-B
52	CKDHL0380	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-114-B-B-B

53	CKDHL0386	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-123-B-B-B
54	CKDHL0399	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-136-B-B-B
55	CKDHL0416	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML395/CML395) DH-160-B-B-B
56	CKDHL0430	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-2-B-B-B
57	CKDHL0437	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-12-B-B-B
58	CKDHL0438	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-13-B-B-B
59	CKDHL0439	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-14-B-B-B
60	CKDHL0441	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-17-B-B-B
61	CKDHL0443	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-20-B-B-B
62	CKDHL0444	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-21-B-B
63	CKDHL0448	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-25-B-B-B
64	CKDHL0460	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-38-B-B-B
65	CKDHL0470	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-49-B-B-B
66	CKDHL0471	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-51-B-B-B
67	CKDHL0474	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-55-B-B
68	CKDHL0475	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-56-B-B-B
69	CKDHL0476	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-57-B-B
70	CKDHL0482	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-67-B
71	CKDHL0484	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-69-B-B-B
72	CKDHL0486	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-71-B-B-B
73	CKDHL0487	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-72-B-B
74	CKDHL0493	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-79-B-B-B
75	CKDHL0494	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-80-B-B-B
76	CKDHL0497	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-83-B-B-B
77	CKDHL0498	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-84-B-B
78	CKDHL0499	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-85-B-B
79	CKDHL0500	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-86-B-B
80	CKDHL0501	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-87-B-B-B
81	CKDHL0502	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-88-B-B
82	CKDHL0503	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-89-B-B
83	CKDHL0505	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-91-B-B-B
84	CKDHL0509	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-95-B-B-B
85	CKDHL0513	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-102-B-B-B
86	CKDHL0520	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-110-B-B
87	CKDHL0526	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML444/CML444) DH-116-B-B
88	CKDHL0535	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML488/CML488) DH-4-B-B
89	CKDHL0556	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML488/CML488) DH-28-B-B
90	CKDHL0561	(La Posta Seq C7-F71-1-2-1-2-B-B-B/CML488/CML488) DH-37-B-B
91	CKDHL0574	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395) DH-8-B-B
92	CKDHL0585	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395) DH-19-B-B-B
93	CKDHL0588	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395) DH-22-B-B-B
94	CKDHL0591	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395) DH-25-B-B-B
95	CKDHL0608	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395) DH-43-B-B-B
96	CKDHL0610	(CML395/[M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BB-B-xP84c1 F27-4-3-3-B-1-B] F29-1-2-2 x [KILIMA ST94A]-30/MSV-03-101-08-B-B-1xP84c1 F27-4-1-4-B-3-B] F2-1-2-1-1-1-B x CML486]-1-1/CML395) DH-46-B-B-B
97	CKDHL0624	(CML395/La Posta Seq C7-F102-1-3-1-2-B-B-B/CML395) DH-1-B-B
98	CKDHL0625	(CML395/La Posta Seq C7-F102-1-3-1-2-B-B-B/CML395) DH-2-B-B-B
99	CKDHL0631	(CML395/La Posta Seq C7-F102-1-3-1-2-B-B-B/CML395) DH-9-B-B-B
100	CKDHL0634	(CML395/La Posta Seq C7-F102-1-3-1-2-B-B-B/CML395) DH-13-B-B-B
TESTERS		
Tester 1 CML395/CML444		**CML395:** 90323(B)-1-B-1-B*4 **CML444:** P43C9-1-1-1-1-1-BBBB
Tester 2 CML312/CML442		**CML312:** S89500F2-2-2-1-1-B*5 **CML442:** [M37W/ZM607#bF37sr-2-3sr-6-2-X]-8-2-X-1-BBB

Appendix II: General combining ability estimates of DH lines and single cross testers for grain yield and traits evaluated across four sites in Kenya under well-watered conditions

LINE	NAME	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
1	CKDHL0007	-0.5	2.21***	1.37***	-0.19	0.01	0.99	-7.44	-0.39	0.52	-3.01	-0.03
2	CKDHL0020	0.13	0.21	0.81*	-0.01	0.33	-4.2	-9.6*	-0.97	8.88**	-2.33	-0.01
3	CKDHL0021	-0.5	-0.04	0.99**	-0.01	0.33	1.74	2.62	-1.35	-4.49	-4.1	-0.05*
4	CKDHL0023	0.78*	-1.6**	-1.13**	0.09	0.01	6.84*	4.69	0.83	-2.01	-1.26	0.03
5	CKDHL0032	0.73*	-0.17	-0.07	-0.01	0.14	1.34	0	-0.52	0.31	-2.23	-0.05*
6	CKDHL0043	0.04	0.71	1.93***	-0.6***	-0.49*	-1.04	-1.19	-0.76	-5.11	-1.33	0.01
7	CKDHL0048	-0.35	-2.54***	-0.01	0.15	-0.05	-12.41***	-7.69	-1.53	-0.36	-3.36	-0.02
8	CKDHL0053	0.19	0.02	0.31	0.06	0.08	0.82	3	-0.14	3.17	-3.05	0.004
9	CKDHL0056	0.29	-0.67	-0.88*	-0.1	-0.05	-10.23***	-11.91**	-0.8	-1.88	0.42	0.02
10	CKDHL0058	-0.29	-1.04*	1.24***	-0.1	0.14	-8.73**	-7.63	-1.35	7.24*	-1.22	-0.01
11	CKDHL0063	0.76*	1.27	-0.01	-0.1	-0.11	3.4	7.53	-0.26	2.53	0.99	0.01
12	CKDHL0065	0.6	-0.92	-0.01	-0.29*	-0.17	6.22	1.87	3.16***	3.35	-0.43	-0.02
13	CKDHL0076	0.77*	-0.92	1.12**	-0.51***	0.01	-0.38	-2.47	0.003	3	-3.67	0.02
14	CKDHL0086	-0.11	-0.67	-1.19**	0.31*	-0.05	-0.04	-1.31	-0.12	-0.21	-0.98	0.03
15	CKDHL0110	0.16	1.02*	-0.63	0.06	0.08	17.43***	19.65***	0.71	2.57	-3.61	-0.01
16	CKDHL0114	0.08	0.65	-0.26	-0.23	-0.05	12.37***	5.56	-0.23	0.75	-3.82	-0.02
17	CKDHL0121	-0.31	1.77***	-0.94**	0.15	-0.11	8.15*	2.87	-0.11	3.16	2.14	0.04
18	CKDHL0130	-0.4	-1.48**	-1.44***	0.02	0.26	7.3*	10.47*	0.55	-1.11	-0.6	-0.02
19	CKDHL0134	0.2	-0.04	-1.26***	0.12	0.01	6.68*	6.65	-0.45	-1.79	4.11	-0.02
20	CKDHL0140	-0.48	1.21*	-0.76*	-0.1	0.08	7.68*	5.59	0.05	5.7*	-2.51	0.03
21	CKDHL0172	-0.14	1.15*	-0.88*	0.12	0.01	9.99**	13.65**	0.73	1.93	-3.2	0.01
22	CKDHL0225	0.22	-2.17***	0.68	-0.35**	-0.24	-11.57***	-18.1***	-1.16	0.51	2.23	-0.03
23	CKDHL0235	-0.4	-0.73	-0.13	0.4**	0.26	-4.2	-3.53	-1.02	3.4	1.2	0.01
24	CKDHL0237	-1.45***	-6.17***	-1.63***	0.62***	1.2***	-20.26***	-15.78***	3.84***	15.9***	3.86	0.03
25	CKDHL0241	-0.31	-5.67***	0.06	0.27*	0.89***	-5.45	10.9**	1.52	-1.34	11.61***	-0.01
26	CKDHL0248	-0.04	-3.29***	-1.82***	0.06	0.08	-3.85	2.31	0.14	0.42	2.07	0.003
27	CKDHL0254	0.2	2.71***	-0.44	0.12	-0.36	14.15***	12.61**	-1.19	4.19	-2.37	0.06**
28	CKDHL0266	-0.25	-3.04***	0.62	0.4**	0.08	-14.73***	-16.6***	0.24	3.47	0.37	0.02
29	CKDHL0267	-0.01	-2.67***	0.68	0.15	-0.05	-13.35***	-13.1**	-0.18	8.23**	2.11	-0.01
30	CKDHL0283	0.11	1.77***	0.93*	-0.23	0.08	10.8**	10.87*	2.52**	-5.43	-3.15	-0.05*
31	CKDHL0284	0.01	-0.1	1.43***	-0.13	-0.3	-5.29	-5.31	-0.87	0.25	-1.41	-0.04
32	CKDHL0298	0.17	-1.17*	1.18**	-0.07	-0.24	-1.82	-2.72	-1.51	-3.34	-1.5	0.001
33	CKDHL0299	-0.1	-0.04	0.37	-0.01	-0.11	-6.13	-5.03	-1.34	-4.94	-3.81	0.003
34	CKDHL0313	0.36	0.4	1.81***	-0.35**	-0.17	-3.04	-6.53	2.34**	1.03	-1.69	-0.01
35	CKDHL0324	0.01	0.33	-0.13	-0.07	-0.17	-7.9**	-8.13	-1.18	-1.9	-2.53	0.01
36	CKDHL0331	1.55***	0.65	-0.13	-0.44***	-0.17	17.24***	22.47***	4.39***	4.46	-1.97	0.003
37	CKDHL0340	-0.12	-0.35	0.43	-0.1	-0.11	-10.16**	-10.63*	-0.84	3.35	2.39	-0.02
38	CKDHL0345	0.58	0.02	0.93*	-0.07	-0.49*	-8.85**	-9.97*	-1.15	-4.01	-0.67	0.01
39	CKDHL0356	0.09	-0.23	0.74*	-0.16	0.08	15.09***	18.84***	1.04	-3.32	0.44	-0.02

LINE	NAME	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
40	CKDHL0364	0.53	2.9***	0.12	-0.23	0.08	6.74*	4.72	0.04	-3.17	-6.37**	0.002
41	CKDHL0369	0.08	-0.29	0.31	-0.13	-0.3	-11.6***	-15.35***	-0.99	2.47	0.07	0.004
42	CKDHL0380	0.21	1.02*	1.37***	-0.16	-0.17	1.09	3.94	0.14	1.46	-4.51*	0.01
43	CKDHL0386	-0.31	1.83***	1.06**	-0.16	0.01	-0.48	1.87	0.95	-3.02	-3.49	-0.04
44	CKDHL0399	0.6	-0.42	0.62	-0.07	-0.3	-6.29	-6.66	-1.69	-3.22	-1.15	0.004
45	CKDHL0416	0.03	-0.23	0.68	-0.04	-0.36	-17.73***	-21.75***	-2.02*	-6.01*	3.06	-0.04
46	CKDHL0430	0.15	1.83***	-0.19	0.09	-0.36	4.05	2.69	0.06	-2.55	1.13	-0.01
47	CKDHL0439	-0.9**	1.02*	-1.13**	0.27*	0.08	1.18	4.9	-0.11	1.52	1.93	0.01
48	CKDHL0441	-0.37	2.02***	0.24	0.24	-0.05	-2.32	-5.1	0.45	-2.37	-2.27	-0.02
49	CKDHL0443	-0.04	0.83	-0.26	-0.07	-0.3	-0.2	3.25	0.2	2.8	4.64*	0.06*
50	CKDHL0448	-0.44	1.77***	0.31	0.12	-0.3	-9.48***	-0.41	1.57	-0.89	6.14**	-0.07**
51	CKDHL0460	-0.54	2.21***	0.12	0.06	-0.42*	4.65	2.53	-0.25	1.43	-0.22	-0.01
52	CKDHL0470	0.16	2.46***	-0.69	0.02	-0.05	1.62	7.37	-0.66	-2.71	-2.68	-0.02
53	CKDHL0471	0.01	3.15***	-0.94**	0.18	-0.17	9.93**	5.2	0.37	3.68	-3.41	0.05*
54	CKDHL0474	0.26	-0.23	-0.88*	-0.01	-0.05	-2.88	6.34	-0.99	-1.78	4.2*	0
55	CKDHL0475	0.18	1.58**	-0.69	-0.04	-0.05	5.3	2.59	-0.96	-2.78	-1.36	0.004
56	CKDHL0476	0.36	1.02*	-0.63	0.02	0.14	9.77**	13.25**	2.81**	0.62	-1.75	-0.02
57	CKDHL0482	0.37	-2.23***	-0.44	0.02	0.33	3.84	6.12	1.35	-0.93	-2.03	0.06*
58	CKDHL0484	-0.44	2.46***	-0.19	-0.16	0.33	4.62	7.87	0.48	-2.32	1.2	0.03
59	CKDHL0493	-0.42	1.52**	-0.51	0.27*	0.14	1.93	-1.85	-0.82	-5.22	8.15***	0.01
60	CKDHL0494	0.39	1.02*	-0.26	0.06	-0.42*	0.55	3.37	-0.46	-4.45	2.83	-0.02
61	CKDHL0497	-0.5	1.08*	0.24	0.09	-0.05	-7.95*	-5.47	-0.75	-0.78	3.11	0.01
62	CKDHL0498	-0.51	1.33**	-1.19**	0.37**	0.08	-1.88	-8.44	-0.32	-2.34	9.36***	0.09***
63	CKDHL0500	-0.46	2.71***	-0.57	0.15	0.26	15.21***	1	-0.76	-0.18	0.51	0.01
64	CKDHL0501	0.44	0.71	-0.94**	-0.04	-0.05	3.93	4.97	-0.63	-1.22	3.26	-0.01
65	CKDHL0505	-0.28	0.9	-0.82*	-0.1	-0.3	1.4	-1.19	-0.99	0.85	1.51	0
66	CKDHL0509	-0.31	1.27*	-0.63	0.31*	0.01	5.17	-0.75	-0.29	1.47	-1.97	0.02
67	CKDHL0513	-0.3	2.02***	-0.69	0.24	0.2	9.02**	6.65	-1.34	0.48	8.43***	-0.02
68	CKDHL0526	0.39	2.58***	-0.69	0.21	-0.24	10.12**	-3.6	0.3	-1.61	1.47	-0.01
69	CKDHL0556	0.22	-1.54**	-0.63	0.34**	-0.17	-9.45**	0.15	0.51	-0.15	6.65**	0.08***
70	CKDHL0561	0.44	-2.1***	-0.63	0.18	-0.24	-11.09***	-10.41*	-0.96	-4.89	1.87	0.03
71	CKDHL0574	0.55	-2.35***	0.24	0.18	-0.17	-8.66**	-7.03	-0.18	-3.47	-1.8	0.02
72	CKDHL0585	0.45	-2.67***	0.68	-0.57***	-0.24	2.65	10.25*	0.3	-1.26	-1.13	0.02
73	CKDHL0588	0.2	-0.92	1.12**	-0.19	0.45*	6.27	-0.75	-0.22	-1.7	-3.36	-0.02
74	CKDHL0591	-0.49	-2.23***	0.74*	0.06	0.33	-2.53	-12.72**	-0.01	-0.24	1.23	0.01
75	CKDHL0608	-0.12	-2.35***	0.74*	-0.1	0.26	6.18	8.84*	1	2.65	1.21	-0.01
76	CKDHL0610	-0.25	0.33	0.49	-0.16	-0.11	-1.38	0.47	1.99*	-0.07	-1.66	-0.01
77	CKDHL0624	-0.17	-0.54	0.18	-0.1	0.33	-1.63	1.62	0.25	-3.47	-1.05	-0.01
78	CKDHL0625	-0.26	-0.98	-0.07	0.06	0.2	-4.66	-6.97	-0.81	1.15	0.29	-0.03
79	CKDHL0631	-0.83**	-3.1***	-0.32	0.12	0.76***	-9.04**	-7.53	0.14	-0.91	-3.44	-0.02
80	CKDHL0634	-0.35	0.21	0.87*	-0.13	0.2	-0.57	8.53	0.63	-3.97	-2.72	0.002
Tester 1	**CML395/CML444**	**-0.44*** **	**2.19*** **	**-0.05**	**-0.12***	**0.06**	**4.69*** **	**2.67*** **	**0.46*** **	**0.11**	**-2.15**	**-0.003**
Tester 2	**CML312/CML442**	**0.44*** **	**-2.19*** **	**0.05**	**0.12***	**-0.06**	**-4.69*** **	**-2.67*** **	**-0.46*** **	**-0.11**	**2.15**	**0.003**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; EA: Ear aspect; PA: Plant aspect; ER: Ear rot; RL: Root lodging; SL: Stem lodging.

Appendix III: Specific combining ability estimates of DH maize testcrosses for grain yield and component traits evaluated across four sites in Kenya under well-watered conditions.

ENTRY	CROSS	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
1	1x1	-0.54*	1.81***	-0.58	0.22*	-0.06	-3.16	-7.7	0.47	-0.78	0.22	0.001
2	2x1	0.28	-0.44	-0.64	-0.03	0.002	4.34	1.7	-0.84	1.84	2.22	0.06**
3	3x1	-0.32	0.18	0.05	0.03	0.13	4.47	4.55	-0.76	2.67	1.78	0.04
4	4x1	0.78**	-1.26**	0.18	-0.25*	-0.31	2.43	2.55	-0.47	-3.27	0.04	-0.04
5	5x1	-0.02	0.93	-0.51	-0.03	0.19	-0.5	-5.95	0.07	2.17	-1.88	0.02
6	6x1	-0.11	0.06	-0.26	0.25*	-0.06	2.37	0.8	0.45	-0.9	-0.34	0.04
7	7x1	0.16	0.43	0.18	0.06	-0.25	1.62	0.86	-0.63	-1.18	0.44	0.003
8	8x1	-0.56*	0.49	0.11	0.22*	0.13	-1.99	-4.08	-0.61	2.41	0.64	-0.01
9	9x1	0.21	-0.19	-0.45	-0.002	-0.12	4.18	0.64	-1.33	2.74	1.71	0.002
10	10x1	-0.74**	1.31**	0.05	0.12	0.19	-4.19	-8.64	-0.14	1.64	0.81	-0.01
11	11x1	-0.56*	0.87	0.05	0.12	-0.06	0.62	-0.42	0.62	2.11	2.03	0.001
12	12x1	-0.23	1.06*	-0.58	0	0.13	-2.12	-4.58	0.83	0.13	-1.76	0.03
13	13x1	-0.3	0.68	0.18	0.09	-0.06	-0.1	-3.3	0.24	-0.76	1.38	-0.02
14	14x1	-0.07	-0.07	0.36	0.03	0.13	0.06	-0.45	0.39	1.44	0.77	0.01
15	15x1	-0.66**	0.37	-0.2	0.28**	-0.25	-5.91	-9.05*	0.61	1.9	0.52	-0.01
16	16x1	-0.8**	0.24	0.43	-0.06	0.25	-4.78	-9.52*	0.69	-3.32	1.78	-0.02
17	17x1	-0.72**	0.37	0.11	0.12	0.19	-3	-4.95	-0.62	0.41	0.63	-0.03
18	18x1	-0.02	-0.38	-0.01	-0.06	0.06	-0.97	-1.36	1.42	-1.06	0.96	-0.001
19	19x1	0.06	-0.19	0.18	0.15	-0.06	3.4	4.89	0.1	1.06	0.68	-0.01
20	20x1	0.21	-0.69	0.05	-0.19	-0.12	2.22	6.89	-1.19	0.98	0.25	-0.002
21	21x1	-0.21	0.24	0.05	-0.1	0.19	4.72	5.33	0.25	3.73	-0.56	-0.01
22	22x1	1.49***	-0.94	-0.01	-0.31**	-0.06	3.72	7.89	0.07	0.09	-2.47	0.04
23	23x1	2.1***	-0.88	-0.2	-0.19	-0.56***	2.53	10.58*	-0.8	-7.32**	-2.99*	-0.003
24	24x1	1.35***	-2.32***	1.43***	-0.1	-0.5**	3.59	6.02	-1.26	-11.97***	0.67	0.02
25	25x1	1.78***	-1.44**	-0.26	-0.13	-0.56***	7.84*	14.45***	-3.01**	-2.47	0.37	-0.02
26	26x1	1.91***	-1.07*	-0.01	-0.22*	-0.25	9.56**	16.36***	-0.93	3.06	-3.17*	0.05*
27	27x1	1.73***	-0.94	-0.14	-0.16	-0.06	13.31***	19.22***	-0.28	-2.42	0.78	0.03
28	28x1	2.25***	-1.57**	-0.2	-0.25*	-0.25	7.87*	17.64***	-0.72	-6.66**	-2.37	0.03
29	29x1	2.14***	-0.94	-0.26	-0.38***	-0.25	12.75***	25.33***	-0.91	-2.24	-3.79**	0.05*
30	30x1	-0.86***	0.49	-0.01	0.19	0.002	-3.16	-4.58	-1.31	0.72	1.46	-0.03
31	31x1	-0.63**	0.37	0.36	0.22*	0.13	0.68	1.55	-0.03	-3.58	2.84*	-0.01
32	32x1	-0.32	-0.07	-0.14	0.09	0.19	1.15	0.52	-0.62	3.48	1.66	0.003
33	33x1	-0.68**	1.18*	-1.58***	0.22*	0.06	-2.35	-4.86	-0.44	2.22	1.05	-0.02
34	34x1	-0.49	-0.26	-0.01	-0.002	0.38*	-1.82	-3.17	2.89**	1.53	0.83	0.02
35	35x1	-0.16	0.18	-0.45	0.09	0.002	5.17	2.55	0.38	4.1	-0.13	-0.02
36	36x1	0.12	0.24	-0.33	0.15	0.002	-0.85	-2.48	2.64**	0.08	-0.19	0.02
37	37x1	0.11	-0.01	-0.39	0	-0.06	0.68	0.17	0.06	2.61	-1.61	-0.02
38	38x1	0.35	0.37	-0.64	-0.16	0.06	2.62	-1.17	0.07	0.11	0.54	0.01
39	39x1	-0.001	-0.01	-0.33	0	-0.12	-1.32	-0.67	2.27*	2.25	2.47	0.06*
40	40x1	-0.87***	0.87	0.43	0.19	-0.12	-4.85	-8.36	0.89	1.53	2.31	-0.004
41	41x1	0.24	-0.32	-0.14	-0.1	0.002	3.12	4.14	-0.46	3.58	0.4	-0.001
42	42x1	-0.52*	0.49	0.18	0.19	0.13	-6.63*	-10.33*	1.37	-3.12	2.97*	-0.01
43	43x1	-0.83**	0.93	0.11	0.12	-0.06	-2.32	-4.27	-0.14	1.44	0.86	0.01
44	44x1	0.19	-0.32	0.05	-0.16	0.002	-4.07	-2.3	-0.79	-1.08	-2.01	-0.01
45	45x1	-0.02	0.49	-0.39	-0.31**	-0.06	-1.94	-2.83	-0.46	-0.94	-1.04	-0.01
46	46x1	-0.54*	0.43	0.11	-0.002	0.06	1.15	-1.39	0.95	0.87	-1.02	0.02
47	47x1	-0.15	-0.76	0.3	0.19	-0.12	-5.6	-4.73	1.12	-0.64	3.21*	0.01
48	48x1	-0.52*	0.62	0.05	0.03	-0.12	-2.78	-3.55	-0.18	1.68	-0.17	-0.01
49	49x1	-0.34	0.81	0.05	-0.16	-0.12	-7.41*	-2.7	1.09	-0.52	-4.15**	0.01
50	50x1	-0.48	0.74	1.11**	-0.03	0.002	-3.5	-8.55*	2.09*	2.22	-2.61	-0.05*
51	51x1	-0.42	0.56	0.55	-0.03	0.25	-7.5*	-6.92	-0.05	-0.67	1.14	-0.04
52	52x1	-0.41	0.06	0.36	0.12	0.25	-3.47	-2.95	-0.12	-0.65	-0.03	-0.03

ENTRY	CROSS	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
53	53x1	-0.57*	-0.26	0.49	0.09	0.002	-2.41	-0.97	0.22	0.95	1.97	-0.02
54	54x1	0.41	0.24	-0.95*	-0.22*	-0.12	1.03	4.58	-0.45	0.95	-3.92**	-0.03
55	55x1	-0.81**	-0.57	0.24	-0.13	0.25	-3.03	-4.67	-0.06	3.03	-0.02	-0.02
56	56x1	0.01	-0.26	0.05	0.06	-0.19	-9.57**	-8.2	-1.1	1.01	1.57	0.01
57	57x1	0.95***	-2.13***	0.99**	-0.13	-0.25	7.06*	9.67*	-1.12	-5.74**	3.59**	-0.02
58	58x1	-0.53*	-0.32	-0.14	-0.002	0.25	-0.47	1.67	-0.04	-0.12	2.77*	-0.01
59	59x1	-0.24	-0.26	0.18	-0.06	-0.06	-4.97	-5.05	-0.61	-1.47	2.65	0.01
60	60x1	0.1	-0.26	0.3	0.03	-0.12	-0.72	0.73	0.1	-1.93	-1.26	0.03
61	61x1	-0.21	0.31	-0.08	-0.06	0.13	-2.85	-3.55	0.14	-1.43	-2.77*	0.02
62	62x1	-0.24	0.31	-0.01	-0.1	0.13	-2.85	-1.14	0.23	1.02	-1.15	-0.04
63	63x1	-0.74**	0.43	0.24	0.06	0.19	-3.5	-12.27**	0.14	-0.17	-2.43	-0.03
64	64x1	-0.23	-0.32	0.36	-0.002	0.002	0.59	3.7	-1.14	-2.56	-0.26	-0.02
65	65x1	-0.23	0.49	-0.39	-0.002	0.13	-3.38	-5.02	-1.14	-0.1	-2.76*	-0.01
66	66x1	-0.71**	-0.01	0.43	0.09	0.06	-5.53	-7.52	-0.42	-1.05	2.56	0.01
67	67x1	-0.19	-0.26	0.36	-0.03	0.13	-1.63	-3.23	-0.45	-2.26	-1.61	-0.01
68	68x1	-0.66**	-0.44	0.74	0.12	-0.19	-5.78	-5.86	1.86*	1.51	-4.43**	-0.01
69	69x1	1.27***	-0.32	-0.45	-0.06	-0.12	4.34	12.2**	0.73	-4.03	-6.07***	0.03
70	70x1	0.94***	-0.51	-0.58	-0.16	0.19	8.32**	8.77*	-0.4	0.86	-3.13*	0.01
71	71x1	1.22***	-0.88	-0.45	-0.1	-0.37*	6.5*	8.08	-1.62	-0.46	-0.51	0.02
72	72x1	-0.52*	-0.19	0.11	0.09	-0.06	-1.63	-3.02	-0.31	1.28	1.34	-0.02
73	73x1	-0.09	-0.07	0.3	0.09	0.38*	-5.63	-7.95	0.61	0.47	3.67**	0.03
74	74x1	-0.26	0.12	0.43	0.22*	0.13	1.5	-1.61	-0.82	-0.19	0.09	-0.003
75	75x1	0.01	-0.13	-0.2	-0.002	-0.06	3.53	2.45	0.81	3.71	-0.14	-0.02
76	76x1	-0.6*	0.43	0.05	0.06	0.06	-5.85	-4.67	0.83	2.28	1.42	0.01
77	77x1	-0.25	0.93	0.11	-0.06	0.13	1.34	0.48	0.79	0.53	-0.19	-0.01
78	78x1	-0.15	0.12	0.11	0.03	0.25	3.56	3.02	-0.24	1.61	-1.3	-0.004
79	79x1	-0.21	-0.38	-0.26	0.09	0.31	1.81	5.39	0.69	-1.56	0.77	0.01
80	80x1	-0.88***	1.31**	-0.33	0.03	0.38*	0.34	-4.86	-0.15	2.61	1.42	-0.003
81	1x2	0.54*	-1.81***	0.58	-0.22*	0.06	3.16	7.7	-0.47	0.78	-0.22	-0.001
82	2x2	-0.28	0.44	0.64	0.03	-0.002	-4.34	-1.7	0.84	-1.84	-2.22	-0.06**
83	3x2	0.32	-0.18	-0.05	-0.03	-0.13	-4.47	-4.55	0.76	-2.67	-1.78	-0.04
84	4x2	-0.78**	1.26**	-0.18	0.25*	0.31	-2.43	-2.55	0.47	3.27	-0.04	0.04
85	5x2	0.02	-0.93	0.51	0.03	-0.19	0.5	5.95	-0.07	-2.17	1.88	-0.02
86	6x2	0.11	-0.06	0.26	-0.25*	0.06	-2.37	-0.8	-0.45	0.9	0.34	-0.04
87	7x2	-0.16	-0.43	-0.18	-0.06	0.25	-1.62	-0.86	0.63	1.18	-0.44	-0.003
88	8x2	0.56*	-0.49	-0.11	-0.22*	-0.13	1.99	4.08	0.61	-2.41	-0.64	0.01
89	9x2	-0.21	0.19	0.45	0.002	0.12	-4.18	-0.64	1.33	-2.74	-1.71	-0.002
90	10x2	0.74**	-1.31**	-0.05	-0.12	-0.19	4.19	8.64	0.14	-1.64	-0.81	0.01
91	11x2	0.56*	-0.87	-0.05	-0.12	0.06	-0.62	0.42	-0.62	-2.11	-2.03	-0.001
92	12x2	0.23	-1.06*	0.58	0	-0.13	2.12	4.58	-0.83	-0.13	1.76	-0.03
93	13x2	0.3	-0.68	-0.18	-0.09	0.06	0.1	3.3	-0.24	0.76	-1.38	0.02
94	14x2	0.07	0.07	-0.36	-0.03	-0.13	-0.06	0.45	-0.39	-1.44	-0.77	-0.01
95	15x2	0.66**	-0.37	0.2	-0.28**	0.25	5.91	9.05*	-0.61	-1.9	-0.52	0.01
96	16x2	0.8**	-0.24	-0.43	0.06	-0.25	4.78	9.52*	-0.69	3.32	-1.78	0.02
97	17x2	0.72**	-0.37	-0.11	-0.12	-0.19	3	4.95	0.62	-0.41	-0.63	0.03
98	18x2	0.02	0.38	0.01	0.06	-0.06	0.97	1.36	-1.42	1.06	-0.96	0.001
99	19x2	-0.06	0.19	-0.18	-0.15	0.06	-3.4	-4.89	-0.1	-1.06	-0.68	0.01
100	20x2	-0.21	0.69	-0.05	0.19	0.12	-2.22	-6.89	1.19	-0.98	-0.25	0.002
101	21x2	0.21	-0.24	-0.05	0.1	-0.19	-4.72	-5.33	-0.25	-3.73	0.56	0.01
102	22x2	-1.49***	0.94	0.01	0.31**	0.06	-3.72	-7.89	-0.07	-0.09	2.47	-0.04
103	23x2	-2.1***	0.88	0.2	0.19	0.56***	-2.53	-10.58*	0.8	7.32**	2.99*	0.003
104	24x2	-1.35***	2.32***	-1.43***	0.1	0.5**	-3.59	-6.02	1.26	11.97***	-0.67	-0.02
105	25x2	-1.78***	1.44**	0.26	0.13	0.56***	-7.84*	-14.45***	3.01**	2.47	-0.37	0.02
106	26x2	-1.91***	1.07*	0.01	0.22*	0.25	-9.56**	-16.36***	0.93	-3.06	3.17*	-0.05*
107	27x2	-1.73***	0.94	0.14	0.16	0.06	-13.31***	-19.22***	0.28	2.42	-0.78	-0.03
108	28x2	-2.25***	1.57**	0.2	0.25*	0.25	-7.87*	-17.64***	0.72	6.66**	2.37	-0.03
109	29x2	-2.14***	0.94	0.26	0.38***	0.25	-12.75***	-25.33***	0.91	2.24	3.79**	-0.05*
110	30x2	0.86***	-0.49	0.01	-0.19	-0.002	3.16	4.58	1.31	-0.72	-1.46	0.03

ENTRY	CROSS	GY	AD	ASI	EA	PA	EH	PH	RL	SL	ER	EPP
111	31x2	0.63**	-0.37	-0.36	-0.22*	-0.13	-0.68	-1.55	0.03	3.58	-2.84*	0.01
112	32x2	0.32	0.07	0.14	-0.09	-0.19	-1.15	-0.52	0.62	-3.48	-1.66	-0.003
113	33x2	0.68**	-1.18*	1.58***	-0.22*	-0.06	2.35	4.86	0.44	-2.22	-1.05	0.02
114	34x2	0.49	0.26	0.01	0.002	-0.38*	1.82	3.17	-2.89**	-1.53	-0.83	-0.02
115	35x2	0.16	-0.18	0.45	-0.09	-0.002	-5.17	-2.55	-0.38	-4.1	0.13	0.02
116	36x2	-0.12	-0.24	0.33	-0.15	-0.002	0.85	2.48	-2.64**	-0.08	0.19	-0.02
117	37x2	-0.11	0.01	0.39	0	0.06	-0.68	-0.17	-0.06	-2.61	1.61	0.02
118	38x2	-0.35	-0.37	0.64	0.16	-0.06	-2.62	1.17	-0.07	-0.11	-0.54	-0.01
119	39x2	0.001	0.01	0.33	0	0.12	1.32	0.67	-2.27*	-2.25	-2.47	-0.06*
120	40x2	0.87***	-0.87	-0.43	-0.19	0.12	4.85	8.36	-0.89	-1.53	-2.31	0.004
121	41x2	-0.24	0.32	0.14	0.1	-0.002	-3.12	-4.14	0.46	-3.58	-0.4	0.001
122	42x2	0.52*	-0.49	-0.18	-0.19	-0.13	6.63*	10.33*	-1.37	3.12	-2.97*	0.01
123	43x1	0.83**	-0.93	-0.11	-0.12	0.06	2.32	4.27	0.14	-1.44	-0.86	-0.01
124	44x2	-0.19	0.32	-0.05	0.16	-0.002	4.07	2.3	0.79	1.08	2.01	0.01
125	45x2	0.02	-0.49	0.39	0.31**	0.06	1.94	2.83	0.46	0.94	1.04	0.01
126	46x2	0.54*	-0.43	-0.11	0.002	-0.06	-1.15	1.39	-0.95	-0.87	1.02	-0.02
127	47x2	0.15	0.76	-0.3	-0.19	0.12	5.6	4.73	-1.12	0.64	-3.21*	-0.01
128	48x2	0.52*	-0.62	-0.05	-0.03	0.12	2.78	3.55	0.18	-1.68	0.17	0.01
129	49x2	0.34	-0.81	-0.05	0.16	0.12	7.41*	2.7	-1.09	0.52	4.15**	-0.01
130	50x2	0.48	-0.74	-1.11**	0.03	-0.002	3.5	8.55*	-2.09*	-2.22	2.61	0.05*
131	51x2	0.42	-0.56	-0.55	0.03	-0.25	7.5*	6.92	0.05	0.67	-1.14	0.04
132	52x2	0.41	-0.06	-0.36	-0.12	-0.25	3.47	2.95	0.12	0.65	0.03	0.03
133	53x2	0.57*	0.26	-0.49	-0.09	-0.002	2.41	0.97	-0.22	-0.95	-1.97	0.02
134	54x2	-0.41	-0.24	0.95*	0.22*	0.12	-1.03	-4.58	0.45	-0.95	3.92**	0.03
135	55x2	0.81**	0.57	-0.24	0.13	-0.25	3.03	4.67	0.06	-3.03	0.02	0.02
136	56x2	-0.01	0.26	-0.05	-0.06	0.19	9.57**	8.2	1.1	-1.01	-1.57	-0.01
137	57x2	-0.95***	2.13***	-0.99**	0.13	0.25	-7.06*	-9.67*	1.12	5.74**	-3.59**	0.02
138	58x2	0.53*	0.32	0.14	0.002	-0.25	0.47	-1.67	0.04	0.12	-2.77*	0.01
139	59x2	0.24	0.26	-0.18	0.06	0.06	4.97	5.05	0.61	1.47	-2.65	-0.01
140	60x2	-0.1	0.26	-0.3	-0.03	0.12	0.72	-0.73	-0.1	1.93	1.26	-0.03
141	61x2	0.21	-0.31	0.08	0.06	-0.13	2.85	3.55	-0.14	1.43	2.77*	-0.02
142	62x2	0.24	-0.31	0.01	0.1	-0.13	2.85	1.14	-0.23	-1.02	1.15	0.04
143	63x2	0.74**	-0.43	-0.24	-0.06	-0.19	3.5	12.27**	-0.14	0.17	2.43	0.03
144	64x2	0.23	0.32	-0.36	0.002	-0.002	-0.59	-3.7	1.14	2.56	0.26	0.02
145	65x2	0.23	-0.49	0.39	0.002	-0.13	3.38	5.02	1.14	0.1	2.76*	0.01
146	66x2	0.71**	0.01	-0.43	-0.09	-0.06	5.53	7.52	0.42	1.05	-2.56	-0.01
147	67x2	0.19	0.26	-0.36	0.03	-0.13	1.63	3.23	0.45	2.26	1.61	0.01
148	68x1	0.66**	0.44	-0.74	-0.12	0.19	5.78	5.86	-1.86*	-1.51	4.43**	0.01
149	69x2	-1.27***	0.32	0.45	0.06	0.12	-4.34	-12.2**	-0.73	4.03	6.07***	-0.03
150	70x2	-0.94***	0.51	0.58	0.16	-0.19	-8.32**	-8.77*	0.4	-0.86	3.13*	-0.01
151	71x2	-1.22***	0.88	0.45	0.1	0.37*	-6.5*	-8.08	1.62	0.46	0.51	-0.02
152	72x2	0.52*	0.19	-0.11	-0.09	0.06	1.63	3.02	0.31	-1.28	-1.34	0.02
153	73x2	0.09	0.07	-0.3	-0.09	-0.38*	5.63	7.95	-0.61	-0.47	-3.67**	-0.03
154	74x2	0.26	-0.12	-0.43	-0.22*	-0.13	-1.5	1.61	0.82	0.19	-0.09	0.003
155	75x2	-0.01	0.13	0.2	0.002	0.06	-3.53	-2.45	-0.81	-3.71	0.14	0.02
156	76x2	0.6*	-0.43	-0.05	-0.06	-0.06	5.85	4.67	-0.83	-2.28	-1.42	-0.01
157	77x2	0.25	-0.93	-0.11	0.06	-0.13	-1.34	-0.48	-0.79	-0.53	0.19	0.01
158	78x2	0.15	-0.12	-0.11	-0.03	-0.25	-3.56	-3.02	0.24	-1.61	1.3	0.004
159	79x2	0.21	0.38	0.26	-0.09	-0.31	-1.81	-5.39	-0.69	1.56	-0.77	-0.01
160	80x2	0.88***	-1.31**	0.33	-0.03	-0.38*	-0.34	4.86	0.15	-2.61	-1.42	0.003

***, **, *** Significant at 0.05, 0.01 and 0.001 level of probability, respectively**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; EA: Ear aspect; PA: Plant aspect; ER: Ear rot; RL: Root lodging; SL: Stem lodging.

Appendix IV: Mean grain yield and other agronomic traits of DH maize testcrosses evaluated across four sites under well-watered conditions

ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PA	PH	RL	SL
1	1x1	5.64	76.88	1.50	2.33	134.61	4.00	0.97	22.60	2.84	236.46	2.29	9.01
2	2x1	6.71	73.91	0.88	2.21	131.19	5.83	1.05	22.72	3.22	234.80	1.16	18.25
3	3x1	5.70	73.77	1.75	2.26	139.58	4.30	0.99	23.03	3.36	254.55	0.41	7.07
4	4x1	8.15	70.86	-0.24	2.23	144.96	5.31	0.99	21.76	2.64	255.26	3.01	2.95
5	5x1	7.15	74.39	0.12	2.22	135.70	2.81	0.96	22.87	3.25	244.58	1.51	9.38
6	6x1	6.39	74.47	2.37	1.97	134.88	5.19	1.04	23.86	2.35	245.72	2.61	3.84
7	7x1	6.44	71.07	0.88	2.47	126.89	3.88	0.97	20.87	2.60	246.61	0.22	6.11
8	8x1	6.16	74.28	1.14	2.51	130.00	3.91	0.98	21.26	3.10	244.36	1.72	12.15
9	9x1	6.82	72.97	-0.61	2.18	126.15	8.59	1.02	23.37	2.74	235.23	0.83	8.34
10	10x1	5.60	73.48	2.00	2.27	125.98	6.68	0.98	22.77	3.30	236.75	0.17	15.53
11	11x1	6.62	75.95	0.74	2.30	137.55	9.29	1.01	22.61	2.78	253.75	2.86	11.70
12	12x1	6.86	73.90	0.12	1.99	140.66	4.81	1.01	23.31	2.89	246.93	6.63	11.14
13	13x1	7.12	72.89	2.00	1.87	138.38	5.22	1.00	23.32	2.91	247.69	2.29	11.17
14	14x1	6.17	73.47	-0.12	2.66	130.41	5.58	1.04	21.79	2.96	240.84	2.81	7.92
15	15x1	5.72	75.46	-0.12	2.61	141.93	2.94	0.97	21.52	2.71	254.16	4.04	13.15
16	16x1	5.63	74.76	0.88	1.99	141.41	4.37	0.96	22.97	3.14	242.02	3.07	6.57
17	17x1	5.42	75.24	-0.13	2.54	145.78	9.94	1.01	22.08	3.02	256.42	1.44	11.55
18	18x1	6.06	71.72	-0.74	2.28	141.51	6.51	0.97	21.10	3.32	256.64	4.43	8.08
19	19x1	6.54	73.56	-0.37	2.55	144.31	11.50	0.96	22.26	2.95	258.15	2.66	8.41
20	20x1	6.37	73.78	0.00	2.00	144.94	4.78	1.03	21.29	2.87	260.97	1.42	14.09
21	21x1	6.10	75.32	-0.13	2.34	143.94	2.54	1.00	22.30	3.09	258.08	3.94	14.82
22	22x1	8.12	70.69	1.38	1.68	128.59	6.57	1.00	24.23	2.63	237.15	1.49	10.17
23	23x1	8.34	71.64	0.37	2.50	134.40	4.81	1.00	21.72	2.59	256.49	-0.15	5.56
24	24x1	6.43	64.78	0.50	2.80	120.37	11.61	1.05	20.56	3.68	243.86	4.86	13.09
25	25x1	7.88	66.92	0.50	2.42	132.01	18.01	0.97	21.34	3.24	265.38	1.32	4.27
26	26x1	8.51	69.12	-1.14	2.13	141.37	5.69	1.04	21.34	2.75	267.34	1.36	10.04
27	27x1	8.31	75.41	0.13	2.27	158.07	4.27	1.08	25.26	2.56	274.90	1.32	11.19
28	28x1	8.37	68.96	1.13	2.46	128.76	4.32	1.05	22.43	2.77	249.67	1.90	5.58
29	29x1	8.57	70.35	1.13	2.02	133.08	4.27	1.04	22.44	2.64	259.11	1.80	14.42
30	30x1	6.20	75.30	1.63	2.16	146.94	5.59	0.92	22.03	2.96	264.74	3.48	3.43
31	31x1	5.76	74.22	2.49	2.39	127.72	7.66	0.94	22.23	2.75	242.31	2.22	6.47
32	32x1	6.51	72.54	1.75	2.34	135.89	6.61	1.00	21.18	2.81	246.08	0.45	8.68
33	33x1	5.97	74.30	-0.51	2.51	127.74	3.87	0.98	23.48	2.87	241.22	0.73	5.11
34	34x1	6.29	74.31	2.50	1.94	128.48	5.86	1.00	24.65	3.14	235.44	8.03	10.13
35	35x1	6.47	74.12	0.14	2.34	128.34	4.14	0.98	21.66	2.76	239.07	1.97	9.98
36	36x1	8.09	74.78	0.26	2.00	145.89	4.09	1.02	23.30	2.72	259.87	9.93	13.63
37	37x1	6.50	73.49	0.75	2.15	126.23	7.29	0.96	23.01	2.74	238.17	1.86	15.27
38	38x1	7.32	74.01	0.99	2.10	127.30	6.45	1.02	24.24	2.52	236.70	1.78	3.56
39	39x1	6.51	73.59	1.12	2.14	146.43	9.44	1.03	22.65	2.91	262.98	5.80	5.46
40	40x1	6.12	77.26	1.25	2.25	137.08	3.26	1.00	24.41	2.87	245.32	3.27	7.09
41	41x1	6.71	73.16	0.88	2.04	122.45	6.73	1.00	22.66	2.61	230.97	1.30	15.20
42	42x1	6.26	75.30	2.25	2.33	131.21	5.01	1.00	23.47	2.87	246.60	4.15	6.47
43	43x1	5.43	76.56	1.86	2.26	131.76	3.89	0.97	22.73	2.88	244.86	3.18	6.57
44	44x1	7.25	72.95	1.37	2.13	126.62	4.21	0.98	23.66	2.67	240.71	0.27	3.25
45	45x1	6.60	73.65	1.00	1.96	118.86	8.85	0.95	23.93	2.55	228.13	-0.21	2.34
46	46x1	6.24	75.80	0.63	2.37	141.73	6.38	1.01	23.39	2.64	251.97	3.48	7.52
47	47x1	5.65	73.77	-0.13	2.73	134.42	11.96	1.02	22.23	2.81	252.83	3.39	7.63
48	48x1	5.75	76.08	1.00	2.53	133.25	5.22	0.97	23.95	2.78	246.31	2.42	8.41
49	49x1	6.02	75.16	0.50	2.09	132.24	7.00	1.06	22.62	2.53	253.53	3.63	11.90
50	50x1	5.74	75.95	2.13	2.33	126.71	9.97	0.88	22.84	2.61	246.41	5.62	9.38
51	51x1	5.52	76.54	1.36	2.30	133.60	8.01	0.95	22.73	2.78	244.66	2.38	9.32
52	52x1	6.33	76.64	0.37	2.44	130.39	3.40	0.95	23.28	3.10	249.01	1.98	4.37
53	53x1	5.92	76.56	0.26	2.58	141.76	5.28	1.02	23.27	2.76	250.09	2.45	11.93

ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PA	PH	RL	SL
54	54x1	7.36	73.30	-1.13	2.12	131.70	6.45	0.97	22.23	2.72	257.65	0.90	5.85
55	55x1	5.89	74.75	0.25	2.09	136.51	4.87	0.97	22.67	3.10	243.03	1.25	8.51
56	56x1	7.02	74.22	0.12	2.33	139.95	7.07	0.98	23.24	2.87	256.61	3.13	10.43
57	57x1	7.95	69.38	1.24	2.24	145.39	7.82	1.04	22.60	3.00	261.23	2.26	4.06
58	58x1	5.32	76.03	0.38	2.14	134.44	10.29	1.03	22.25	3.49	250.50	3.54	5.63
59	59x1	6.06	74.96	0.37	2.42	134.23	17.67	1.02	22.33	3.00	244.67	1.08	0.61
60	60x1	6.83	74.59	0.75	2.42	132.70	8.21	1.00	23.22	2.39	247.21	2.81	2.61
61	61x1	5.63	75.27	0.88	2.40	120.75	6.78	1.02	21.42	2.98	231.06	2.21	5.58
62	62x1	5.65	75.59	-0.51	2.65	127.22	14.76	1.04	23.40	3.17	233.15	2.40	6.27
63	63x1	5.54	76.60	0.37	2.52	151.28	5.08	0.96	22.43	3.33	243.76	1.75	6.79
64	64x1	6.86	74.29	0.12	2.19	138.24	9.17	0.96	22.95	2.85	253.93	0.59	5.26
65	65x1	5.88	75.06	-0.50	2.26	132.36	5.25	0.98	21.73	2.77	239.09	0.60	11.74
66	66x1	5.74	74.47	0.51	2.66	136.12	8.05	1.02	21.26	3.02	244.74	2.17	6.43
67	67x1	6.15	75.58	0.37	2.48	142.91	12.96	0.97	21.76	3.26	250.53	0.49	7.14
68	68x1	6.21	75.55	0.75	2.58	141.67	3.65	0.98	24.47	2.50	242.77	4.50	8.54
69	69x1	8.05	71.43	-0.37	2.53	131.22	7.43	1.10	22.59	2.65	261.39	3.73	5.75
70	70x1	7.73	71.64	-0.51	2.34	128.45	4.83	1.03	22.25	2.88	243.76	1.48	3.87
71	71x1	8.32	70.48	0.52	2.36	130.02	3.85	1.04	22.54	2.37	247.14	0.59	2.30
72	72x1	6.80	70.47	1.50	1.86	139.64	7.51	0.99	21.79	2.62	259.51	2.41	4.70
73	73x1	6.48	72.80	2.12	2.19	136.70	7.08	1.01	21.52	3.76	239.88	3.38	7.90
74	74x1	5.91	71.01	1.87	2.49	139.48	7.99	1.01	23.24	3.35	242.10	0.82	8.06
75	75x1	6.21	71.62	1.25	2.21	141.08	7.55	0.97	21.39	3.13	252.65	4.69	14.15
76	76x1	5.74	74.32	1.26	2.16	132.53	6.99	0.99	22.31	2.86	246.87	4.88	10.52
77	77x1	6.07	73.91	1.01	2.13	135.92	5.72	0.97	22.03	3.40	252.41	3.54	6.14
78	78x1	6.35	72.45	0.74	2.33	137.99	5.86	0.97	21.69	3.30	250.28	0.61	9.25
79	79x1	5.49	69.88	0.12	2.47	129.67	4.17	0.98	20.94	4.03	249.96	3.64	6.87
80	80x1	5.28	75.12	1.25	2.18	133.63	5.93	1.00	21.40	3.50	251.98	2.98	8.78
81	1x2	7.46	69.87	2.75	2.15	127.65	7.38	0.97	22.98	2.84	239.11	0.70	10.86
82	2x2	7.57	69.36	2.25	2.48	121.07	6.67	0.94	23.13	3.06	237.17	0.65	13.82
83	3x2	7.40	68.77	1.75	2.44	128.64	5.70	0.91	22.08	3.00	248.71	0.02	0.95
84	4x2	7.43	68.70	-0.50	2.86	132.59	9.70	1.07	22.27	3.16	249.23	2.61	10.18
85	5x2	8.16	68.18	1.26	2.59	122.50	10.36	0.93	22.08	2.79	243.30	1.31	6.26
86	6x2	7.71	69.52	3.01	1.70	126.08	10.48	0.97	23.75	2.36	248.96	0.51	4.35
87	7x2	7.01	66.46	0.63	2.70	111.73	7.50	0.98	20.97	3.01	234.05	0.75	8.33
88	8x2	8.20	68.70	1.00	2.37	131.29	7.05	1.01	22.19	2.76	253.94	1.50	6.73
89	9x2	7.83	68.10	0.37	2.35	118.95	9.71	1.02	21.97	2.83	242.06	0.96	2.79
90	10x2	7.86	66.82	2.01	2.28	119.92	9.33	1.00	21.88	2.77	241.90	0.63	12.41
91	11x2	8.85	69.39	0.75	2.31	128.65	9.42	1.01	24.17	2.74	250.63	0.92	9.89
92	12x2	8.14	67.45	1.37	2.20	135.34	12.03	0.96	22.56	2.48	250.45	4.00	10.51
93	13x2	8.39	67.96	1.75	2.00	128.15	6.45	1.03	21.46	2.89	244.25	1.12	13.41
94	14x2	7.32	68.23	-0.75	2.86	128.30	9.77	1.02	21.08	2.64	245.09	0.96	8.07
95	15x2	8.14	70.50	0.37	2.29	145.45	6.50	1.00	20.45	3.12	264.81	1.58	6.38
96	16x2	8.22	70.29	0.12	2.37	140.69	4.70	1.00	22.22	2.49	254.36	1.02	9.22
97	17x2	7.90	70.29	-0.25	2.53	139.06	12.72	1.08	21.07	2.49	255.03	1.49	11.85
98	18x2	6.97	68.29	-0.62	2.66	130.67	9.41	0.98	20.19	3.01	250.50	1.10	7.88
99	19x2	7.68	69.47	-0.65	2.44	132.48	14.25	0.99	21.10	2.87	249.34	0.81	2.52
100	20x2	6.87	70.77	0.00	2.66	134.49	8.41	1.03	20.40	3.00	247.74	2.86	11.12
101	21x2	7.54	70.02	-0.12	2.72	132.88	8.98	1.02	21.01	2.59	254.03	1.64	6.23
102	22x2	5.89	68.27	1.49	2.62	106.49	15.84	0.93	21.83	2.61	210.36	0.90	10.62
103	23x2	4.75	69.84	0.88	3.12	113.87	14.41	1.02	21.51	3.56	222.56	1.47	19.97
104	24x2	4.61	65.27	-2.25	3.24	101.81	13.76	1.01	19.05	4.47	221.59	7.02	36.89
105	25x2	5.31	64.87	1.11	2.93	114.29	22.37	1.02	20.13	4.16	240.95	5.90	12.21
106	26x2	5.26	67.07	-1.00	2.84	113.00	16.27	0.95	18.48	3.16	229.61	2.89	7.54
107	27x2	5.56	73.01	0.50	2.81	123.29	6.80	1.04	23.20	2.54	231.38	0.76	14.74
108	28x2	4.60	67.91	1.62	3.21	101.31	13.23	1.00	20.59	3.12	206.38	2.58	18.57

ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PA	PH	RL	SL
109	29x2	5.29	67.14	1.75	3.13	101.36	17.50	0.94	20.36	3.05	209.88	2.60	15.43
110	30x2	8.55	70.28	1.75	2.11	139.39	6.81	0.98	22.97	2.87	260.66	5.49	2.15
111	31x2	8.09	68.68	1.87	2.13	122.33	6.65	0.97	23.06	2.42	240.69	0.03	11.85
112	32x2	8.00	68.00	2.13	2.33	120.45	7.59	1.00	21.45	2.36	238.94	0.50	1.58
113	33x2	7.82	68.29	2.76	2.26	117.97	5.42	1.03	24.15	2.66	236.27	0.55	2.63
114	34x2	8.25	69.82	2.63	2.12	123.53	7.60	0.97	23.58	2.28	239.39	1.01	9.19
115	35x2	7.49	69.10	1.13	2.38	116.87	8.92	1.02	22.40	2.65	236.34	-0.34	1.99
116	36x2	8.53	70.26	0.99	1.96	141.72	9.11	0.99	23.56	2.65	265.07	3.62	12.09
117	37x2	7.04	69.00	1.62	2.47	114.10	15.19	1.01	22.52	2.74	232.10	0.72	8.80
118	38x2	7.78	69.03	2.38	2.61	116.98	9.43	1.00	23.63	2.23	239.26	-0.18	3.15
119	39x2	7.55	69.03	1.87	2.38	140.93	8.94	0.93	22.57	2.98	261.00	0.78	4.36
120	40x2	8.53	71.69	0.50	2.14	135.97	2.22	1.01	24.32	2.96	252.68	1.12	5.99
121	41x2	7.40	69.12	1.25	2.46	111.00	10.98	1.01	22.25	2.46	223.52	1.45	8.56
122	42x2	8.28	69.71	2.01	2.16	131.09	3.19	1.02	23.33	2.48	256.75	0.07	12.52
123	43x1	7.90	70.23	1.76	2.25	128.19	6.14	0.96	22.89	2.87	250.72	2.25	3.83
124	44x2	7.93	69.03	1.36	2.65	122.97	12.00	1.01	21.86	2.49	239.69	1.10	7.32
125	45x2	7.56	68.35	1.89	2.85	110.46	15.09	0.98	22.70	2.41	224.62	0.28	3.95
126	46x2	8.05	70.68	0.50	2.61	129.49	12.90	0.98	22.30	2.39	249.39	0.44	4.83
127	47x2	6.75	70.83	-0.62	2.64	131.00	9.56	1.00	21.62	3.00	250.62	0.02	10.01
128	48x2	7.49	70.86	1.00	2.75	122.74	8.40	0.99	22.72	2.93	235.92	2.16	3.99
129	49x2	7.54	69.45	0.51	2.61	131.10	19.15	1.05	21.33	2.67	245.85	0.98	11.28
130	50x2	7.35	70.64	0.00	2.73	118.33	19.14	0.98	21.89	2.52	248.63	1.09	3.63
131	51x2	7.38	70.62	0.38	2.63	135.36	9.21	1.03	21.76	2.14	249.21	1.39	9.07
132	52x2	8.04	71.38	-0.24	2.47	131.08	8.11	1.02	22.48	2.51	253.60	1.41	5.18
133	53x2	7.99	72.86	-0.62	2.65	139.53	5.78	1.07	23.00	2.62	250.93	2.03	10.38
134	54x2	7.13	68.64	0.88	2.73	122.52	19.21	1.03	21.99	2.92	247.30	0.97	3.41
135	55x2	8.38	71.60	-0.13	2.62	132.55	9.43	1.02	21.94	2.49	250.16	0.42	2.28
136	56x2	7.76	70.07	0.14	2.52	144.52	7.46	0.98	21.49	3.11	264.82	5.43	10.34
137	57x2	6.87	68.99	-0.63	2.66	126.30	5.78	1.08	20.66	3.42	243.43	4.10	12.95
138	58x2	7.78	71.62	0.74	2.33	135.13	9.31	1.04	22.62	2.86	254.53	2.06	4.36
139	59x2	7.17	70.82	0.12	2.89	133.75	16.78	1.01	21.83	3.01	247.63	0.59	5.30
140	60x2	7.57	70.68	0.25	2.58	126.37	14.81	0.95	21.87	2.59	243.92	0.96	7.74
141	61x2	7.12	69.97	1.13	2.67	120.75	16.61	0.99	22.26	2.61	242.46	1.05	7.39
142	62x2	7.14	70.00	-0.37	3.00	128.13	21.87	1.13	21.74	2.76	235.78	1.09	6.14
143	63x2	7.77	71.47	-0.01	2.64	143.73	14.01	1.03	22.13	2.91	256.27	0.81	5.62
144	64x2	8.19	70.11	-0.51	2.49	129.47	14.80	1.02	22.52	2.71	246.01	1.10	7.99
145	65x2	7.53	69.80	0.36	2.38	132.39	14.89	1.02	22.64	2.35	249.43	1.33	9.49
146	66x2	7.71	70.51	-0.25	2.73	135.48	6.58	1.01	20.63	2.74	252.16	1.84	9.15
147	67x2	7.19	71.74	-0.25	2.84	134.38	20.85	0.99	21.89	2.88	248.80	0.69	10.88
148	68x1	8.33	72.06	-0.63	2.63	140.34	16.12	0.99	23.64	2.76	244.94	0.65	6.88
149	69x2	6.39	68.13	0.63	2.94	110.14	23.17	1.06	21.22	2.77	230.34	1.22	7.45
150	70x2	6.92	67.64	0.75	2.83	105.90	15.96	1.02	21.70	2.34	225.88	0.49	3.94
151	71x2	6.71	67.57	1.51	2.81	111.31	10.12	1.00	22.44	3.00	226.94	2.86	5.42
152	72x2	8.07	67.11	1.37	1.91	125.73	7.88	1.05	21.66	2.68	250.76	2.51	6.89
153	73x2	7.59	68.19	1.62	2.26	133.79	4.45	0.96	22.03	2.86	245.94	1.15	7.41
154	74x2	7.31	66.66	1.13	2.36	122.88	11.51	1.01	22.60	2.98	235.25	2.65	5.57
155	75x2	7.38	66.64	1.75	2.44	127.99	12.79	1.01	22.15	3.09	247.44	1.91	6.09
156	76x2	7.89	68.52	1.25	2.31	132.08	8.16	0.99	23.24	2.61	251.09	1.60	8.64
157	77x2	7.32	67.85	0.87	2.57	122.58	9.95	1.01	21.34	3.02	240.53	1.28	7.02
158	78x2	7.32	67.80	0.63	2.58	120.93	12.08	0.96	21.74	2.74	241.01	1.08	8.13
159	79x2	6.93	66.05	0.75	2.44	117.95	7.45	0.98	20.93	3.25	237.18	0.69	10.69
160	80x2	8.01	68.44	1.98	2.41	124.22	5.91	1.01	21.78	2.61	255.67	2.59	2.22
161	DK-8053	7.67	67.07	1.38	2.48	106.99	17.87	0.96	21.90	2.59	230.78	0.81	2.84
162	H513	7.62	67.03	1.26	2.51	138.87	10.98	1.07	21.83	3.12	256.42	2.89	4.78
163	PH3253	6.73	67.35	1.25	2.65	122.76	10.84	1.02	19.62	3.03	250.01	2.52	4.91
164	Local check 1	7.19	68.06	1.74	2.45	135.32	15.75	0.96	20.93	3.57	256.05	3.03	12.41
165	Local check 2	6.93	65.51	0.89	2.60	121.16	15.65	0.96	19.22	3.36	261.53	2.27	1.40

Appendix V: General combining ability estimates of DH inbred lines for grain yield and other traits evaluated across two sites in Kenya under managed drought conditions.

LINE	NAME	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
1	CKDHL0007	-1.11	0.82	0.08	0.26	-8.21*	4.31	-0.04	-1.32	-10.93	0.42	-3.34	0.13
2	CKDHL0020	-0.3	-0.43	0.2	-0.05	-4.57	2.76	0.02	-0.17	-11.31	0.44	-5.81	-0.13
3	CKDHL0021	0.52	0.57	-0.55	-0.05	0.14	1.75	0.04	0.5	-7.43	0.12	-11.18	0
4	CKDHL0023	0.31	-0.55	-0.92	-0.05	-7.68	-3.64	0.09	0.78	-8.99	-0.23	7.59	0
5	CKDHL0032	0.55	0.82	-0.55	-0.24	-2.46	-6.2	0.07	1.5*	-8.62	0.1	0.02	-0.38
6	CKDHL0043	-0.36	-1.18	-0.67	-0.12	-11.8*	0.78	0.06	0.37	-7.68	-1.22	-2.46	0
7	CKDHL0048	0.7	0.82	-0.67	-0.05	-3.82	5.4	0.03	0.87	-4.87	0.42	-2.9	-0.5
8	CKDHL0053	0.79	-0.3	-0.3	-0.24	2.8	4.16	0.12	1.34	1.44	-0.56	-0.26	-0.63*
9	CKDHL0056	1.7**	0.32	-0.42	-0.3	-3.18	0.77	0.04	1.45	-4.68	0.44	-6.24	-0.63*
10	CKDHL0058	0.86	-0.18	-0.3	-0.24	-0.86	0.43	0.06	0.74	-2.37	-1.22	-2.44	-0.63*
11	CKDHL0063	0.49	-1.05	0.33	-0.37*	-2.51	0.73	0.09	1.01	-3.31	-0.23	1.72	-0.38
12	CKDHL0065	-0.77	1.95*	0.08	0.07	-1.67	-1.85	0.02	-0.19	-2.68	-0.89	-9	0
13	CKDHL0076	-0.98	-1.05	0.2	0.13	-9.85*	1.46	-0.01	-0.28	-9.06	0.21	15.17*	0.13
14	CKDHL0086	0.23	-0.8	-0.17	0.13	-4.21	3.03	0.01	-0.05	-9.43	0.79	6.1	0.5
15	CKDHL0110	-0.82	-0.8	0.58	-0.05	-6.12	0.55	-0.05	-0.45	-1.31	-0.89	6.98	0.13
16	CKDHL0114	-0.39	0.07	-0.3	0.38*	4.3	3.07	-0.09	-1.68*	4.63	-1.55	0.01	0.5
17	CKDHL0121	-1.1	0.2	-0.05	0.13	-6.08	-0.87	-0.08	-1.59*	-3.74	-1.22	-8.88	0.88**
18	CKDHL0130	-0.69	-0.18	1.33*	0.2	2.28	7.36*	-0.05	-0.61	-1.99	-0.57	-4.68	0.63*
19	CKDHL0134	0.65	0.95	-0.42	-0.05	0.22	0.12	-0.04	0.36	-7.18	0.42	-6.09	0.38
20	CKDHL0140	0.15	0.95	-0.3	0.07	-0.83	2.37	0.02	0.4	-0.81	-1.22	-9.52	0
21	CKDHL0172	0.77	0.32	0.2	-0.12	-0.81	0.49	0.04	0.51	-1.56	-1.22	-2.53	-0.13
22	CKDHL0225	-0.02	-0.8	0.7	-0.18	5.34	-0.03	-0.001	0.03	13.76*	-1.22	4.9	0.13
23	CKDHL0235	0.21	0.82	-0.3	-0.05	8.17*	-0.76	0.01	0.54	1.32	0.42	-2.79	-0.13
24	CKDHL0237	0.45	0.57	-0.05	-0.05	0.17	-5.67	0.06	0.76	0.13	-1.22	7.62	0.13
25	CKDHL0241	-0.18	1.7*	-0.55	0.01	1.55	-0.61	0.05	-0.3	-5.68	0.42	8.1	0.25
26	CKDHL0248	-1.01	0.7	0.2	-0.12	4.29	-0.3	-0.05	-0.31	-2.81	0.42	-3.48	0.13
27	CKDHL0254	0.14	0.32	-0.05	0.01	5.09	0.53	0.1	0.37	1.63	-1.2	9.26	0
28	CKDHL0266	0.71	0.32	-0.05	-0.12	3.85	-3.5	0.01	0.13	1.76	-0.56	-7.43	-0.25
29	CKDHL0267	0.3	-1.18	1.08	0.2	-0.3	-0.28	-0.02	-0.06	1.68	-1.22	3.28	0.13
30	CKDHL0283	0.04	0.45	0.08	0.2	-0.52	1.06	0.01	-0.03	-2.98	-0.23	-8.21	0
31	CKDHL0284	-0.33	-1.18	1.7**	0.32	-5.7	-1.47	-0.1	-0.76	-4.12	1.74	-6.32	0.25
32	CKDHL0298	-0.7	-0.18	0.65	0.2	-2.38	-5.91	-0.17*	-1.42	-1.16	-0.56	-4.59	0.5
33	CKDHL0299	-0.38	1.2	0.2	0.13	7.58	-5.08	-0.09	-0.16	8.01	-0.23	4.07	0.38
34	CKDHL0313	0.05	-0.68	-0.07	-0.05	1.75	-5.28	-0.04	-0.23	2.69	-0.89	5.21	0.25
35	CKDHL0324	0.1	0.7	0.08	-0.12	-8.27*	-0.82	-0.001	0.36	13.19*	1.14	-3.19	0
36	CKDHL0331	-0.59	0.7	0.45	0.01	-5.58	-3.13	-0.08	-0.18	-7.43	1.08	-8.45	0.38
37	CKDHL0340	-0.05	-0.05	0.33	0.07	-3.88	-2.45	-0.05	0.07	-9.81	3.06*	-0.95	0.13
38	CKDHL0345	-0.96	0.82	0.2	0.2	-1.37	-4.2	-0.14*	-0.85	-3.49	-1.55	1.65	0.25
39	CKDHL0356	-0.54	1.45	0.08	0.01	-0.25	-3.12	-0.07	-0.71	-3.37	0.09	2.99	0.13
40	CKDHL0364	-0.48	1.07	0.83	0.01	4.04	-2.74	-0.1	-0.76	-1.12	0.09	0.73	0.13

LINE	NAME	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
41	CKDHL0369	-0.39	0.45	-0.42	0.01	5.47	1.53	-0.01	-0.58	3.38	-0.56	5.75	0.38
42	CKDHL0380	-0.13	0.57	1.08	0.13	0.5	2.86	-0.1	-1.5*	0.13	-0.89	8.15	0.25
43	CKDHL0386	-0.23	1.45	-0.05	0.2	4.57	3.65	-0.01	-0.75	1.63	-1.22	5.68	0.25
44	CKDHL0399	-0.15	-0.8	2.45**	0.13	-2.58	1.98	-0.07	-1.09	1.13	-1.22	-0.58	0.25
45	CKDHL0416	0.05	-0.55	2.33**	0.01	0.77	0.17	-0.03	-0.42	1.01	-0.89	0.1	0
46	CKDHL0430	0.31	0.82	-0.05	0.01	2.77	0.32	0.05	-0.24	5.44	0.75	-3.98	-0.25
47	CKDHL0439	-0.25	0.45	-0.3	-0.12	-1.75	1.99	0.08	1.07	-3.49	0.09	3.28	-0.13
48	CKDHL0441	-0.24	1.7*	0.08	0.07	1.73	-6.67	-0.04	-0.34	0.94	-1.55	-4.78	-0.13
49	CKDHL0443	0.5	-0.05	-0.3	-0.12	4.64	-0.01	-0.001	-0.02	4.07	-0.23	-3.13	-0.38
50	CKDHL0448	0.72	0.7	0.2	0.01	-0.32	-3.14	0.06	0.41	-0.87	-1.19	4.14	-0.13
51	CKDHL0460	1.21*	-0.93	-0.8	-0.24	-2.28	-6.31	0.11	0.68	4.01	-0.88	7.28	-0.38
52	CKDHL0470	0.51	-0.68	-0.8	-0.24	-0.48	10.51*	0.01	0.65	-0.74	-1.55	3.98	-0.38
53	CKDHL0471	0.45	-0.93	-0.3	-0.3	-3.12	-0.72	0.11	0.69	2.19	0.09	8.62	-0.13
54	CKDHL0474	0.09	-1.55	-0.42	-0.3	-1.28	0.39	0.1	0.38	5.44	2.78*	5.52	-0.25
55	CKDHL0475	0.12	-0.8	-0.17	-0.12	-3.01	1.53	0.03	0.08	5.26	1.81	1.22	-0.13
56	CKDHL0476	-0.34	-0.05	0.08	0.07	3.73	8.89*	-0.08	0.08	6.88	5.03**	-1.5	-0.13
57	CKDHL0482	-0.38	0.57	0.08	0.07	1.67	1.02	-0.1	-0.91	9.57	0.09	-9.12	0.13
58	CKDHL0484	-1.47*	0.82	-0.17	0.13	4.85	2.51	-0.08	-0.71	10.44*	1.41	7.8	0.13
59	CKDHL0493	0.73	-0.55	-0.55	0.07	2.18	7.14	0.03	-0.55	5.01	0.42	14.11*	0.13
60	CKDHL0494	-0.22	0.2	0.33	0.26	-1.27	1.46	0.01	-0.58	3.32	-0.85	-4.71	0.13
61	CKDHL0497	0.16	-0.93	0.08	0.01	-3.55	-0.49	0.03	-0.32	1.69	-0.23	-9.4	0
62	CKDHL0498	-0.32	-1.8*	-0.55	-0.05	-4.15	2.3	-0.04	-0.67	3.52	0.09	4.77	-0.25
63	CKDHL0500	1.03	-0.8	-0.55	-0.18	5.03	5.02	0.03	0.73	7.13	0.09	-2.41	-0.13
64	CKDHL0501	1.34*	-1.05	-0.17	-0.24	8.2*	-5.81	0.1	1.17	14.88*	0.1	-3.2	-0.38
65	CKDHL0505	1.54**	0.2	-0.42	-0.24	13.75*	-1.77	0.06	1.98**	19.44*	-0.55	-9.19	-0.38
66	CKDHL0509	0.33	-1.43	0.45	0.07	5.79	-3.55	-0.03	0.31	11.51*	-1.22	1.91	0
67	CKDHL0513	0.54	0.07	-0.55	0.01	8.88*	-1.91	-0.04	0.51	9.44	0.75	1.72	0
68	CKDHL0526	0.16	-0.55	0.08	0.07	-0.77	-3.54	-0.001	0.49	5.32	-1.55	0.6	0
69	CKDHL0556	0.24	0.32	-0.67	-0.05	7.63	-0.24	-0.01	0.18	9.26	-0.89	-1.7	0
70	CKDHL0561	-0.36	-0.68	-0.3	0.01	8.63*	1.23	0.05	-0.17	12.07*	0.75	5.69	0
71	CKDHL0574	-0.53	-0.55	-0.3	-0.05	3.19	2.64	0.02	-0.03	2.01	1.1	1.83	0
72	CKDHL0585	-1.23*	0.2	0.08	0.07	-3.06	6.41	-0.04	-0.67	-4.18	-0.56	2.3	-0.13
73	CKDHL0588	-0.67	0.7	-0.42	0.32*	1.55	2.6	-0.09	-0.22	-3.87	-0.56	-8.35	0.13
74	CKDHL0591	0.26	-1.05	0.33	-0.05	-2.93	-5.63	0.04	0.22	-3.81	0.09	-5.03	-0.25
75	CKDHL0608	-0.1	0.57	-0.3	-0.05	1.53	0.14	0.01	-0.23	1.38	0.42	-5.67	-0.13
76	CKDHL0610	0.06	0.32	-0.42	0.01	-6.42	-8.12*	0.05	0.88	15.62*	0.44	-8.04	-0.38
77	CKDHL0624	-0.13	-1.3	-0.3	-0.05	-6.37	-3.87	0.07	0.45	-3.99	1.08	11.48*	-0.13
78	CKDHL0625	-0.09	-0.05	-0.3	0.13	-6.25	1.49	0.06	-0.32	-2.68	-0.56	0.9	-0.25
79	CKDHL0631	-0.15	-1.05	-0.3	0.13	1.64	0.75	0.06	0.18	-0.12	5.23**	6.74	0.13
80	CKDHL0634	-0.91	0.2	-0.42	0.32*	2.33	-0.03	-0.06	-0.86	-2.06	2.65	2.58	0.25

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; EA: Ear aspect; PA: Plant aspect; ER: Ear rot; RL: Root lodging; SL: Stem lodging

Appendix VI: Specific combining ability estimates of DH maize testcrosses for grain yield and other agronomic traits evaluated across two sites in Kenya under managed drought conditions in 2012.

ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
1	1x1	0.26	0.2	0.22	-0.14	-5.55	-4.71	0.01	-0.24	-7.36	-1.94	2.12	-0.02
2	2x1	0.25	0.95	-0.65	-0.2	-8.99**	-3.82	0.001	0.32	-10.86*	0.71	2.94	-0.02
3	3x1	0.15	0.45	-0.15	-0.2	-6.55*	-3.31	0.03	0.59	0.14	-0.98	1.66	-0.15
4	4x1	-0.04	0.82	-0.28	0.05	-1.5	-2.43	-0.03	0.41	-0.3	-0.62	-7.46	-0.15
5	5x1	0.03	0.45	-0.15	-0.01	-2.8	1.81	0.04	0.21	-6.42	1.68	-2.3	-0.02
6	6x1	-0.02	-1.8*	0.72	0.11	-9.21**	-4.43	-0.08	-0.74	-4.49	0.37	-6.17	0.35
7	7x1	0.41	0.2	-0.28	0.05	0.74	3.05	0	0.45	1.08	-0.62	-9.93	-0.15
8	8x1	0.15	-0.18	0.1	-0.01	2.61	-6.9	-0.01	0.46	6.89	-0.95	-10.74	-0.02
9	9x1	0.43	0.2	-0.28	0.05	1	-1.82	0.08	0.82	-0.49	0.06	-9.86	-0.27
10	10x1	0.47	-0.8	-0.15	-0.14	5.23	4.86	0.06	0.52	4.95	-0.29	-0.2	-0.27
11	11x1	0.18	-0.18	-0.53	0.11	7.05*	1.88	-0.04	-0.14	6.64	0.04	1.26	-0.02
12	12x1	0.15	0.07	-0.78	0.05	1.84	-2.81	0	-0.32	3.89	0.04	4.56	0.1
13	13x1	-0.39	0.32	0.35	0.24	-4.09	-0.99	-0.11	-1.76**	-3.36	-1.06	-11.02	0.23
14	14x1	-0.8	0.07	-0.03	-0.01	5.75	-4.54	-0.05	-0.05	1.89	-0.33	-5.1	-0.15
15	15x1	0.12	-0.68	0.72	-0.07	-0.84	0.03	-0.02	-0.25	4.26	-0.62	-14.47*	-0.02
16	16x1	0.22	-1.05	-0.65	0.11	-0.64	4.61	0.03	0.07	2.58	0.04	-8.76	0.1
17	17x1	0.02	1.57*	-0.9	-0.01	0.45	-3.2	-0.01	-0.13	-2.3	-0.29	-2.49	-0.27
18	18x1	0	0.7	0.47	-0.07	-1.71	-6.88	0.04	0.73	-1.3	0.36	-0.74	-0.27
19	19x1	0.79	-0.18	-0.03	-0.07	-2.52	0.8	0.05	0.41	2.14	-1.28	-2.81	-0.27
20	20x1	0.38	-0.18	0.35	0.05	0.28	2	-0.07	-0.87	0.14	-0.29	-7.16	-0.15
21	21x1	0.33	-0.05	0.1	0.11	1	8.42	-0.06	-0.52	1.01	-0.29	-2.06	-0.02
22	22x1	0.18	-0.18	0.6	0.18	-6.8*	1.14	-0.07	0.46	-5.17	-0.29	-12.66*	-0.02
23	23x1	-0.25	0.95	-0.65	0.3*	3.45	3.59	-0.09	-0.58	-0.61	-1.28	-8.05	0.23
24	24x1	-0.09	1.2	-0.15	0.05	7.98*	-0.95	-0.04	-0.26	0.58	0.37	-2.6	-0.02
25	25x1	-0.03	1.32	0.1	0.11	-0.01	-1.65	-0.09	-0.93	-6.99	-1.28	-10.91	0.1
26	26x1	-0.57	0.07	0.35	-0.01	4.23	4.19	-0.11	-1.3*	-4.99	-0.62	-3.94	0.23
27	27x1	0.17	-0.8	0.6	-0.01	-5.42	-2.51	0.001	0.12	-9.42*	-0.31	2.72	0.35
28	28x1	-1.41**	-0.3	0.6	0.24	2.79	-0.78	-0.11	-1.07	-1.05	0.37	4.51	0.6*
29	29x1	-0.82	0.2	0.97	-0.07	-0.56	-3.78	0.01	-0.17	-3	-0.29	1.63	0.23
30	30x1	0.36	0.57	-0.28	-0.2	6.09	-7.34	0.05	1.53**	6.21	0.69	6.23	-0.15
31	31x1	0.19	0.2	0.35	-0.07	-0.19	0.78	0.07	0.81	-4.3	0.04	2.24	0.1
32	32x1	-0.7	-0.05	1.4**	0.05	6.63*	-0.42	0.01	0.09	8.86	0.37	5.35	0.1
33	33x1	0	1.32	0.6	0.11	6.16	-7.73	-0.04	0.13	10.83*	0.69	-2.78	0.23
34	34x1	0.01	0.7	0.61	0.05	7.86*	0.63	0.04	-0.05	8.26	0.69	2.98	0.1
35	35x1	-0.05	0.07	-0.28	-0.01	1.79	4.57	0.02	-0.63	-2.87	2.06	10.7	0.1
36	36x1	-0.51	1.07	-0.65	0.11	-3.77	0.57	-0.06	-0.26	-9.86*	2.01	2.43	0.23
37	37x1	-0.65	0.07	-0.03	0.05	-6.8*	5.22	0.02	-0.32	-3.74	3.33**	1.88	-0.02
38	38x1	0.13	-1.3	-0.4	0.05	-0.69	-0.9	0.02	0.67	-1.42	0.04	0.53	0.1
39	39x1	-0.37	0.57	-0.03	-0.01	-2.61	1.77	-0.05	0.17	-5.55	-0.29	-3.2	0.23
40	40x1	-0.39	-0.3	0.22	-0.01	0.9	-1.35	0.03	0.3	-5.05	1.03	4.11	-0.02
41	41x1	0.13	-1.18	0.72	-0.26*	2.25	-5.09	0.04	0.57	5.83	-0.95	-0.02	-0.02
42	42x1	-0.14	-0.3	0.47	-0.14	-2.19	-2.29	0.05	0.01	-1.67	-0.62	10.08	0.1
43	43x1	-0.05	-0.68	0.35	-0.2	1.68	3.73	0.12*	0.83	-3.67	0.37	-0.46	0.1
44	44x1	0.25	-0.68	1.1*	-0.01	-2.37	-8.14	0.05	0.15	-6.42	0.37	2.02	-0.15
45	45x1	0.61	-0.68	0.97	-0.14	1.15	-0.5	-0.02	-0.29	5.45	0.04	-6.54	0.1
46	46x1	0.32	-0.05	-0.65	-0.01	1.98	1.62	0	-0.04	0.39	0.37	-1.25	-0.15
47	47x1	0.38	-0.68	0.1	-0.01	-8.41**	8.45	-0.03	0.09	-8.05	-0.29	4.46	-0.02
48	48x1	-0.66	0.07	-0.28	0.05	-5.04	-0.15	0	0.18	-2.11	0.04	0.69	-0.02
49	49x1	1.52**	-0.93	-0.15	-0.01	1.9	-2.52	0.03	0.05	5.26	-0.63	0.98	-0.02
50	50x1	0.12	-0.18	0.1	0.11	1.11	-0.31	0.06	-0.2	-0.8	0.39	10.26	-0.02
51	51x1	-0.71	-1.3	-0.15	-0.01	-1.1	-0.11	-0.01	-0.79	2.2	0.7	-1.07	0.23
52	52x1	0.36	-0.3	-0.4	0.11	5.25	13.9***	-0.12	-0.22	13.33**	0.04	-0.98	-0.02
53	53x1	0.13	0.2	-0.65	0.05	2.41	3.94	0.01	-0.3	3.76	0.37	5.53	0.23
54	54x1	0.08	0.32	-0.53	-0.07	3.9	2.37	0.01	-0.3	1.51	0.42	-8.35	0.35

ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
55	55x1	-0.09	-1.18	0.72	-0.01	-3.07	3.52	0	-0.95	-4.67	-2.01	13.23*	-0.02
56	56x1	0.39	-0.18	-0.03	-0.2	-0.29	-9.15*	0.11	0.9	-1.17	-5.9***	-0.57	-0.52*
57	57x1	0.92	-1.8*	-0.53	-0.07	-2.67	2.82	0.17**	0.66	1.64	1.02	6.54	-0.02
58	58x1	0.29	-1.05	0.22	-0.14	3.46	1.75	0.16*	0.98	2.89	-2.27	6.58	-0.27
59	59x1	0.82	-0.18	0.1	-0.07	-1.99	2.33	0.04	0.27	-1.42	-0.62	12.89*	-0.27
60	60x1	0.31	1.07	0.47	-0.01	4.06	1.93	0.01	0.83	-1.99	0	-4.81	-0.52*
61	61x1	0.03	0.7	0.22	-0.01	-8.24*	-0.18	0.06	0.89	-5.99	0.04	6.6	-0.4
62	62x1	-0.27	0.32	-0.65	-0.07	-1.91	-2.01	0.03	0.24	-1.91	1.68	2.15	-0.65**
63	63x1	0.24	0.07	-0.15	-0.07	-1.16	-2.75	0.01	0.13	-4.05	1.02	-1.59	-0.27
64	64x1	0.16	0.07	-0.03	-0.01	1.29	3.77	-0.01	0.22	3.83	-0.95	-6.18	-0.02
65	65x1	-0.5	0.82	-0.53	0.11	0.06	-0.02	-0.02	-1.03	-5.11	0.39	-6.18	-0.02
66	66x1	-0.47	0.45	-1.15*	0.18	7.83*	6.17	-0.08	-0.54	7.08	-0.29	-9.92	0.1
67	67x1	-0.38	-0.55	-0.15	0.11	6.31	1.88	-0.07	-0.51	12.64**	-1.61	-4.66	0.35
68	68x1	0.25	0.32	-0.28	-0.07	4.79	-2.37	-0.03	-0.26	5.26	0.04	-8.48	0.1
69	69x1	0.29	0.2	-0.28	-0.07	1.61	0.99	0.04	0.83	8.95	-0.62	8.37	-0.15
70	70x1	0.77	0.95	-0.9	-0.26*	2.24	-7.76	0.1	0.41	-2.49	0.37	9.04	-0.4
71	71x1	-0.2	0.07	-0.15	-0.07	1.3	0.08	0.01	0.29	3.95	1.37	8.9	-0.15
72	72x1	0.58	0.07	-0.03	-0.2	-11***	-12.2**	0.09	0.47	-4.61	0.37	8.07	-0.27
73	73x1	0.07	-0.93	-0.03	-0.32**	-6.81*	3.67	0.06	0.7	-0.17	-0.95	-0.36	-0.27
74	74x1	-0.32	-0.18	0.47	-0.07	-3	0.66	-0.06	0	-7.24	0.37	-5.08	-0.4
75	75x1	-1.26**	1.45	0.35	0.18	0.89	11.74**	-0.08	-0.57	3.08	0.69	2.11	0.23
76	76x1	-0.88	0.45	-0.28	0.11	-1.54	0.79	-0.01	-0.69	0.58	-0.64	6.57	0.23
77	77x1	-0.78	-1.68*	-0.15	0.05	2.86	0.66	-0.02	-0.64	-0.3	-0.62	2.47	0.48*
78	78x1	-0.06	2.07**	-0.15	0.36**	-2.59	-3.01	-0.05	-0.29	-4.11	1.02	8	0.35
79	79x1	-0.03	0.32	-0.15	0.24	3.53	4.5	-0.03	-0.57	7.58	4.19***	10.89	0.48*
80	80x1	-0.49	-1.68*	0.47	0.05	-1.01	0.59	-0.05	-0.14	3.39	2.26	7.71	0.35
81	1x2	-0.26	-0.2	-0.22	0.14	5.55	4.71	-0.01	0.24	7.36	1.94	-2.12	0.02
82	2x2	-0.25	-0.95	0.65	0.2	8.99**	3.82	0.001	-0.32	10.86*	-0.71	-2.94	0.02
83	3x2	-0.15	-0.45	0.15	0.2	6.55*	3.31	-0.03	-0.59	-0.14	0.98	-1.66	0.15
84	4x2	0.04	-0.82	0.28	-0.05	1.5	2.43	0.03	-0.41	0.3	0.62	7.46	0.15
85	5x2	-0.03	-0.45	0.15	0.01	2.8	-1.81	-0.04	-0.21	6.42	-1.68	2.3	0.02
86	6x2	0.02	1.8*	-0.72	-0.11	9.21**	4.43	0.08	0.74	4.49	-0.37	6.17	-0.35
87	7x2	-0.41	-0.2	0.28	-0.05	-0.74	-3.05	0	-0.45	-1.08	0.62	9.93	0.15
88	8x2	-0.15	0.18	-0.1	0.01	-2.61	6.9	0.01	-0.46	-6.89	0.95	10.74	0.02
89	9x2	-0.43	-0.2	0.28	-0.05	-1	1.82	-0.08	-0.82	0.49	-0.06	9.86	0.27
90	10x2	-0.47	0.8	0.15	0.14	-5.23	-4.86	-0.06	-0.52	-4.95	0.29	0.2	0.27
91	11x2	-0.18	0.18	0.53	-0.11	-7.05*	-1.88	0.04	0.14	-6.64	-0.04	-1.26	0.02
92	12x2	-0.15	-0.07	0.78	-0.05	-1.84	2.81	0	0.32	-3.89	-0.04	-4.56	-0.1
93	13x2	0.39	-0.32	-0.35	-0.24	4.09	0.99	0.11	1.76**	3.36	1.06	11.02	-0.23
94	14x2	0.8	-0.07	0.03	0.01	-5.75	4.54	0.05	0.05	-1.89	0.33	5.1	0.15
95	15x2	-0.12	0.68	-0.72	0.07	0.84	-0.03	0.02	0.25	-4.26	0.62	14.47*	0.02
96	16x2	-0.22	1.05	0.65	-0.11	0.64	-4.61	-0.03	-0.07	-2.58	-0.04	8.76	-0.1
97	17x2	-0.02	-1.57*	0.9	0.01	-0.45	3.2	0.01	0.13	2.3	0.29	2.49	0.27
98	18x2	0	-0.7	-0.47	0.07	1.71	6.88	-0.04	-0.73	1.3	-0.36	0.74	0.27
99	19x2	-0.79	0.18	0.03	0.07	2.52	-0.8	-0.05	-0.41	-2.14	1.28	2.81	0.27
100	20x2	-0.38	0.18	-0.35	-0.05	-0.28	-2	0.07	0.87	-0.14	0.29	7.16	0.15
101	21x2	-0.33	0.05	-0.1	-0.11	-1	-8.42	0.06	0.52	-1.01	0.29	2.06	0.02
102	22x2	-0.18	0.18	-0.6	-0.18	6.8*	-1.14	0.07	-0.46	5.17	0.29	12.66*	0.02
103	23x2	0.25	-0.95	0.65	-0.3*	-3.45	-3.59	0.09	0.58	0.61	1.28	8.05	-0.23
104	24x2	0.09	-1.2	0.15	-0.05	-7.98*	0.95	0.04	0.26	-0.58	-0.37	2.6	0.02

ENTRY	CROSS	GY	AD	ASI	EA	EH	ER	EPP	MOI	PH	RL	SL	SEN
105	25x2	0.03	-1.32	-0.1	-0.11	0.01	1.65	0.09	0.93	6.99	1.28	10.91	-0.1
106	26x2	0.57	-0.07	-0.35	0.01	-4.23	-4.19	0.11	1.3*	4.99	0.62	3.94	-0.23
107	27x2	-0.17	0.8	-0.6	0.01	5.42	2.51	0.001	-0.12	9.42*	0.31	-2.72	-0.35
108	28x2	1.41**	0.3	-0.6	-0.24	-2.79	0.78	0.11	1.07	1.05	-0.37	-4.51	-0.6*
109	29x2	0.82	-0.2	-0.97	0.07	0.56	3.78	0.01	0.17	3	0.29	-1.63	-0.23
110	30x2	-0.36	-0.57	0.28	0.2	-6.09	7.34	-0.05	-1.53**	-6.21	-0.69	-6.23	0.15
111	31x2	-0.19	-0.2	-0.35	0.07	0.19	-0.78	-0.07	-0.81	4.3	-0.04	-2.24	-0.1
112	32x2	0.7	0.05	-1.04*	-0.05	-6.63*	0.42	-0.01	-0.09	-8.86	-0.37	-5.35	-0.1
113	33x2	0	-1.32	-0.6	-0.11	-6.16	7.73	0.04	-0.13	-10.83*	-0.69	2.78	-0.23
114	34x2	-0.01	-0.7	-0.83	-0.05	-7.86*	-0.63	-0.04	0.05	-8.26	-0.69	-2.98	-0.1
115	35x2	0.05	-0.07	0.28	0.01	-1.79	-4.57	-0.02	0.63	2.87	-2.06	-10.7	-0.1
116	36x2	0.51	-1.07	0.65	-0.11	3.77	-0.57	0.06	0.26	9.86*	-2.01	-2.43	-0.23
117	37x2	0.65	-0.07	0.03	-0.05	6.8*	-5.22	-0.02	0.32	3.74	-3.33**	-1.88	0.02
118	38x2	-0.13	1.3	0.4	-0.05	0.69	0.9	-0.02	-0.67	1.42	-0.04	-0.53	-0.1
119	39x2	0.37	-0.57	0.03	0.01	2.61	-1.77	0.05	-0.17	5.55	0.29	3.2	-0.23
120	40x2	0.39	0.3	-0.22	0.01	-0.9	1.35	-0.03	-0.3	5.05	-1.03	-4.11	0.02
121	41x2	-0.13	1.18	-0.72	0.26*	-2.25	5.09	-0.04	-0.57	-5.83	0.95	0.02	0.02
122	42x2	0.14	0.3	-0.47	0.14	2.19	2.29	-0.05	-0.01	1.67	0.62	-10.08	-0.1
123	43x2	0.05	0.68	-0.35	0.2	-1.68	-3.73	-0.12*	-0.83	3.67	-0.37	0.46	-0.1
124	44x2	-0.25	0.68	-1.1*	0.01	2.37	8.14	-0.05	-0.15	6.42	-0.37	-2.02	0.15
125	45x2	-0.61	0.68	-0.97	0.14	-1.15	0.5	0.02	0.29	-5.45	-0.04	6.54	-0.1
126	46x2	-0.32	0.05	0.65	0.01	-1.98	-1.62	0	0.04	-0.39	-0.37	1.25	0.15
127	47x2	-0.38	0.68	-0.1	0.01	8.41**	-8.45	0.03	-0.09	8.05	0.29	-4.46	0.02
128	48x2	0.66	-0.07	0.28	-0.05	5.04	0.15	0	-0.18	2.11	-0.04	-0.69	0.02
129	49x2	-1.52**	0.93	0.15	0.01	-1.9	2.52	-0.03	-0.05	-5.26	0.63	-0.98	0.02
130	50x2	-0.12	0.18	-0.1	-0.11	-1.11	0.31	-0.06	0.2	0.8	-0.39	-10.26	0.02
131	51x2	0.71	1.3	0.15	0.01	1.1	0.11	0.01	0.79	-2.2	-0.7	1.07	-0.23
132	52x2	-0.36	0.3	0.4	-0.11	-5.25	-13.92*	0.12	0.22	-13.33*	-0.04	0.98	0.02
133	53x2	-0.13	-0.2	0.65	-0.05	-2.41	-3.94	-0.01	0.3	-3.76	-0.37	-5.53	-0.23
134	54x2	-0.08	-0.32	0.53	0.07	-3.9	-2.37	-0.01	0.3	-1.51	-0.42	8.35	-0.35
135	55x2	0.09	1.18	-0.72	0.01	3.07	-3.52	0	0.95	4.67	2.01	-13.23*	0.02
136	56x2	-0.39	0.18	0.03	0.2	0.29	9.15*	-0.11	-0.9	1.17	5.88***	0.57	0.52*
137	57x2	-0.92	1.8*	0.53	0.07	2.67	-2.82	-0.17**	-0.66	-1.64	-1.02	-6.54	0.02
138	58x2	-0.29	1.05	-0.22	0.14	-3.46	-1.75	-0.16*	-0.98	-2.89	2.27	-6.58	0.27
139	59x2	-0.82	0.18	-0.1	0.07	1.99	-2.33	-0.04	-0.27	1.42	0.62	-12.89*	0.27
140	60x2	-0.31	-1.07	-0.47	0.01	-4.06	-1.93	-0.01	-0.83	1.99	0	4.81	0.52*
141	61x2	-0.03	-0.7	-0.22	0.01	8.24*	0.18	-0.06	-0.89	5.99	-0.04	-6.6	0.4
142	62x2	0.27	-0.32	0.65	0.07	1.91	2.01	-0.03	-0.24	1.91	-1.68	-2.15	0.65**
143	63x2	-0.24	-0.07	0.15	0.07	1.16	2.75	-0.01	-0.13	4.05	-1.02	1.59	0.27
144	64x2	-0.16	-0.07	0.03	0.01	-1.29	-3.77	0.01	-0.22	-3.83	0.95	6.18	0.02
145	65x2	0.5	-0.82	0.53	-0.11	-0.06	0.02	0.02	1.03	5.11	-0.39	6.18	0.02
146	66x2	0.47	-0.45	1.15*	-0.18	-7.83*	-6.17	0.08	0.54	-7.08	0.29	9.92	-0.1
147	67x2	0.38	0.55	0.15	-0.11	-6.31	-1.88	0.07	0.51	-12.6**	1.61	4.66	-0.35
148	68x1	-0.25	-0.32	0.28	0.07	-4.79	2.37	0.03	0.26	-5.26	-0.04	8.48	-0.1
149	69x2	-0.29	-0.2	0.28	0.07	-1.61	-0.99	-0.04	-0.83	-8.95	0.62	-8.37	0.15
150	70x2	-0.77	-0.95	0.9	0.26*	-2.24	7.76	-0.1	-0.41	2.49	-0.37	-9.04	0.4
151	71x2	0.2	-0.07	0.15	0.07	-1.3	-0.08	-0.01	-0.29	-3.95	-1.37	-8.9	0.15
152	72x2	-0.58	-0.07	0.03	0.2	11.1***	12.23**	-0.09	-0.47	4.61	-0.37	-8.07	0.27
153	73x2	-0.07	0.93	0.03	0.32**	6.81*	-3.67	-0.06	-0.7	0.17	0.95	0.36	0.27
154	74x2	0.32	0.18	-0.47	0.07	3	-0.66	0.06	0	7.24	-0.37	5.08	0.4
155	75x2	1.26**	-1.45	-0.35	-0.18	-0.89	-11.74*	0.08	0.57	-3.08	-0.69	-2.11	-0.23
156	76x2	0.88	-0.45	0.28	-0.11	1.54	-0.79	0.01	0.69	-0.58	0.64	-6.57	-0.23
157	77x2	0.78	1.68*	0.15	-0.05	-2.86	-0.66	0.02	0.64	0.3	0.62	-2.47	-0.48*
158	78x2	0.06	-2.07**	0.15	-0.36**	2.59	3.01	0.05	0.29	4.11	-1.02	-8	-0.35
159	79x2	0.03	-0.32	0.15	-0.24	-3.53	-4.5	0.03	0.57	-7.58	-4.19**	-10.89	-0.48*
160	80x2	0.49	1.68*	-0.47	-0.05	1.01	-0.59	0.05	0.14	-3.39	-2.26	-7.71	-0.35

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; EA: Ear aspect; PA: Plant aspect; ER: Ear rot; RL: Root lodging; SL: Stem lodging.

Appendix VII: Combined analysis of means for grain yield and other agronomic traits of DH maize testcrosses evaluated across two sites under managed drought conditions.

ENTRY	CROSS	GY	AD	ASI	EA	EH	PH	ER	EPP	MOI	RL	SL	SEN
1	1x1	2.55	68.23	2.89	2.48	147.69	218.22	18.73	0.83	14.46	1.34	6.89	5.33
2	2x1	3.31	68.31	1.89	2.46	148.32	228.38	31.46	0.85	14.24	0.12	31.85	4.76
3	3x1	2.00	68.82	1.24	1.97	147.22	224.16	31.22	0.63	14.23	0.94	15.51	5.05
4	4x1	3.80	66.31	0.61	1.26	153.17	231.65	11.13	1.02	16.03	1.14	43.78	4.35
5	5x1	3.23	68.78	1.69	2.15	149.32	223.32	16.05	0.74	14.55	1.16	28.57	5.16
6	6x1	2.15	67.63	2.24	2.04	149.91	232.07	18.57	0.77	13.50	3.22	29.64	4.69
7	7x1	3.15	65.47	1.23	1.77	145.97	229.85	19.90	0.91	14.72	3.64	20.07	4.62
8	8x1	2.20	67.53	2.25	2.88	142.71	220.17	24.89	0.61	13.28	2.92	12.74	5.29
9	9x1	3.64	66.61	1.34	1.52	141.65	230.02	11.98	0.85	15.22	2.61	14.19	4.65
10	10x1	3.83	67.63	1.83	2.33	142.53	221.76	29.58	0.74	14.97	0.26	9.53	4.44
11	11x1	2.50	69.22	0.88	2.34	148.05	229.53	32.11	0.84	14.88	1.22	28.11	4.81
12	12x1	2.74	67.11	2.95	2.44	148.36	227.32	24.14	0.74	13.65	2.34	21.22	5.04
13	13x1	4.04	66.77	1.88	1.40	158.74	244.80	19.45	0.90	16.97	3.44	13.16	3.24
14	14x1	2.47	67.01	1.65	2.84	151.71	223.39	14.99	0.67	13.06	3.74	10.09	5.56
15	15x1	2.66	68.91	2.61	2.42	152.39	220.96	18.35	0.80	14.62	1.65	11.42	4.32
16	16x1	2.31	67.58	2.31	2.55	157.08	233.28	22.85	0.66	13.16	2.72	9.17	4.99
17	17x1	2.70	68.94	1.39	2.81	155.45	221.71	17.76	0.65	12.99	0.24	13.19	5.47
18	18x1	3.68	66.25	1.52	1.89	151.33	228.95	13.88	0.83	14.33	0.57	12.88	4.57
19	19x1	3.37	66.40	1.19	2.48	155.60	232.29	12.61	0.86	13.85	0.47	13.11	5.84
20	20x1	1.91	66.67	1.67	2.49	156.99	228.21	12.53	0.75	12.98	2.40	43.96	5.50
21	21x1	4.51	67.65	0.85	1.29	149.10	228.04	20.57	0.91	16.28	0.99	25.57	4.26
22	22x1	4.61	65.84	1.80	2.10	158.63	235.76	15.28	0.82	16.21	6.76	21.90	4.30
23	23x1	5.58	66.73	1.19	1.18	151.67	228.27	20.06	0.89	17.17	0.97	14.54	4.45
24	24x1	4.92	62.40	1.05	1.21	141.85	230.28	12.10	0.97	14.58	2.11	24.45	4.04
25	25x1	4.54	64.32	1.27	1.74	153.23	238.91	9.31	0.84	14.68	8.39	12.27	5.15
26	26x1	3.65	64.04	0.13	2.47	146.19	232.44	21.56	0.90	14.09	12.2	23.77	5.76
27	27x1	4.38	69.04	1.19	1.93	160.96	237.36	19.33	0.94	16.80	2.34	31.76	4.85
28	28x1	4.79	64.97	1.60	1.89	152.38	235.24	10.42	0.90	14.53	0.74	34.48	5.51
29	29x1	4.40	66.38	1.49	1.58	154.08	231.02	21.12	0.85	15.60	0.30	30.94	4.59
30	30x1	2.27	70.10	2.85	2.42	167.80	252.05	23.12	0.68	13.32	2.13	7.74	5.51
31	31x1	2.33	68.94	1.40	2.39	141.46	226.06	23.65	0.65	13.21	0.34	16.51	5.44
32	32x1	1.68	66.10	2.93	2.73	146.97	227.22	34.54	0.66	12.15	0.76	19.10	5.22
33	33x1	3.68	67.27	2.26	1.98	141.46	220.27	13.88	0.80	14.28	3.03	7.16	5.04
34	34x1	2.67	68.35	1.79	1.74	140.93	201.50	18.54	0.76	14.52	1.99	21.36	4.98
35	35x1	3.26	68.05	0.45	2.11	142.71	225.75	21.26	0.84	14.89	2.25	15.68	5.22
36	36x1	2.82	68.86	1.10	2.08	165.26	243.62	25.28	0.79	14.81	0.21	29.66	4.50
37	37x1	3.13	67.99	1.11	2.36	142.88	211.10	26.41	0.68	13.28	4.02	19.15	6.21
38	38x1	4.12	68.27	1.84	1.08	149.09	218.02	13.91	0.98	17.08	1.73	10.63	3.89
39	39x1	2.86	67.43	2.61	2.22	159.84	236.77	16.84	0.63	13.03	0.42	9.60	5.21
40	40x1	2.44	71.27	1.56	2.56	153.84	231.80	18.26	0.67	14.58	2.95	17.52	4.60
41	41x1	2.68	69.01	0.72	2.05	142.06	219.35	24.70	0.72	14.00	3.73	7.60	4.79
42	42x1	3.18	68.11	1.49	2.55	154.00	227.29	23.41	0.76	14.61	0.63	26.85	5.23
43	43x1	2.18	70.06	3.21	2.13	158.67	239.60	22.25	0.60	12.92	4.69	17.82	5.09
44	44x1	4.17	67.36	2.13	1.79	145.29	231.53	13.58	0.84	15.15	1.03	16.32	4.60
45	45x1	3.01	66.81	2.10	2.46	137.93	216.04	18.17	0.82	15.18	0.38	10.23	5.26
46	46x1	2.66	68.79	1.20	2.37	153.12	230.10	18.32	0.71	14.56	0.86	22.56	4.85
47	47x1	2.07	67.38	1.33	2.00	142.16	218.29	15.56	0.76	13.54	4.00	14.02	5.25
48	48x1	3.86	69.62	2.27	2.09	154.87	229.22	7.07	0.80	14.49	1.74	21.50	4.49
49	49x1	2.63	68.10	1.74	2.51	143.48	220.76	14.73	0.67	13.78	2.49	11.34	5.94
50	50x1	2.94	68.68	1.46	1.76	148.75	228.34	16.62	0.79	14.38	1.87	8.77	4.78
51	51x1	3.43	68.95	2.55	2.10	150.32	224.45	12.84	0.76	14.27	2.46	7.19	4.78
52	52x1	3.94	69.04	1.16	1.80	152.12	234.00	21.63	0.91	16.33	0.75	9.37	4.58
53	53x1	3.86	68.81	1.42	1.66	160.55	231.78	10.26	0.84	15.93	1.67	5.61	4.78
54	54x1	3.45	66.18	1.79	2.24	148.47	230.33	9.22	0.73	13.61	0.57	-1.29	5.40
55	55x1	3.24	67.81	1.39	2.24	155.96	231.24	24.79	0.81	14.12	2.14	5.90	4.61

ENTRY	CROSS	GY	AD	ASI	EA	EH	PH	ER	EPP	MOI	RL	SL	SEN
56	56x1	3.01	68.23	0.95	1.98	162.22	230.39	10.56	0.69	15.37	2.44	20.04	6.19
57	57x1	4.29	66.81	1.83	1.82	158.64	245.12	15.40	0.86	15.22	3.15	24.00	4.99
58	58x1	2.67	68.95	1.21	2.16	147.72	222.10	9.24	0.78	14.35	1.37	8.72	4.81
59	59x1	3.57	69.93	0.98	1.98	156.62	230.66	12.72	0.84	15.03	1.99	9.46	4.91
60	60x1	4.17	67.41	1.27	2.02	150.26	234.59	7.84	0.93	15.66	-0.07	16.16	4.01
61	61x1	2.84	67.51	1.69	1.87	141.30	215.38	15.66	0.84	15.41	1.56	24.08	4.36
62	62x1	2.82	68.30	1.19	1.86	140.20	206.10	13.17	0.84	15.16	0.01	16.70	4.57
63	63x1	3.35	70.52	-0.33	2.27	165.99	234.56	18.72	0.83	14.46	1.13	7.53	5.13
64	64x1	2.21	69.50	1.66	2.01	147.97	215.52	12.04	0.60	13.35	2.60	14.74	5.85
65	65x1	3.40	67.68	1.09	1.86	148.87	220.04	10.08	0.90	16.38	2.47	18.44	5.02
66	66x1	3.59	67.35	1.44	1.97	152.92	228.95	14.84	0.87	15.26	2.62	10.17	4.31
67	67x1	2.77	68.83	1.57	3.02	154.37	221.06	12.48	0.66	12.78	3.08	20.85	5.44
68	68x1	3.58	68.59	1.70	1.63	146.89	214.75	16.57	0.77	15.76	2.29	6.08	3.87
69	69x1	4.31	65.98	1.24	1.78	151.97	247.26	15.26	0.80	14.92	1.26	29.48	5.22
70	70x1	4.60	66.20	0.75	1.69	151.44	230.89	22.79	0.93	14.85	2.66	6.36	3.97
71	71x1	4.72	65.37	2.42	2.05	146.40	226.61	17.91	0.88	14.07	0.08	18.59	5.63
72	72x1	2.92	66.83	2.38	1.82	155.49	241.34	21.62	0.83	14.48	-0.38	15.07	4.78
73	73x1	2.91	68.91	2.20	2.24	160.12	230.26	37.34	0.66	13.24	1.46	22.39	5.97
74	74x1	3.65	66.41	1.71	1.79	149.53	225.55	17.76	0.86	14.76	0.29	29.92	4.28
75	75x1	4.00	66.31	2.10	1.60	149.93	235.08	17.65	0.83	15.59	0.33	34.70	3.60
76	76x1	3.62	68.51	1.33	2.21	148.93	228.66	13.63	0.78	14.80	2.05	14.98	4.60
77	77x1	3.05	67.26	1.36	2.70	153.62	234.36	22.81	0.78	14.04	2.18	17.58	5.62
78	78x1	3.61	68.01	1.49	1.91	144.31	222.16	7.96	0.88	14.41	0.17	17.83	5.45
79	79x1	3.37	65.48	1.18	1.63	160.33	236.84	18.99	0.82	14.45	1.05	4.65	4.41
80	80x1	2.97	68.63	0.16	2.29	152.80	242.19	18.92	0.82	14.69	1.24	16.73	4.51
81	1x2	4.25	64.80	4.39	2.64	143.25	227.62	15.13	0.69	12.94	-0.34	8.56	5.60
82	2x2	4.14	66.10	1.67	1.98	140.38	219.74	17.56	0.87	14.51	0.01	40.69	5.12
83	3x2	4.24	64.95	2.90	2.23	149.39	238.26	27.48	0.75	14.06	0.56	10.66	6.04
84	4x2	3.81	64.97	1.16	1.76	141.73	224.60	15.82	0.85	14.72	0.90	26.89	4.30
85	5x2	3.89	64.59	2.48	2.07	139.80	224.65	14.94	0.78	13.80	-0.1	35.66	6.28
86	6x2	3.27	65.27	3.63	1.93	137.81	218.73	16.61	0.85	14.79	0.18	23.34	5.06
87	7x2	4.41	63.89	1.61	2.33	136.74	230.06	14.00	0.89	13.75	-0.4	28.70	4.52
88	8x2	3.04	65.53	6.78	2.89	146.45	226.48	6.95	0.69	12.61	0.58	23.03	5.16
89	9x2	4.34	64.26	1.51	1.57	135.33	218.69	4.68	0.87	14.26	0.57	36.83	5.42
90	10x2	3.40	64.39	3.27	2.19	136.16	210.87	23.98	0.70	13.98	0.67	27.06	5.78
91	11x2	3.56	65.39	2.82	2.47	139.16	230.54	24.09	0.75	14.74	1.93	29.13	5.28
92	12x2	5.50	64.65	1.75	2.06	144.33	231.07	24.39	0.94	15.85	0.67	28.49	3.86
93	13x2	3.21	64.10	1.63	2.58	145.60	232.30	17.75	0.83	15.12	1.05	41.33	5.26
94	14x2	3.29	65.18	1.63	2.12	140.69	214.07	9.00	0.79	14.30	0.50	21.76	5.00
95	15x2	4.27	67.08	3.04	2.32	155.00	234.52	6.87	0.80	14.12	1.75	25.44	4.99
96	16x2	4.34	65.24	2.04	1.09	153.45	232.52	14.27	0.76	15.82	1.40	9.73	3.86
97	17x2	3.49	66.54	0.17	2.56	150.61	227.88	23.46	0.81	13.52	0.53	35.80	5.68
98	18x2	3.51	64.05	0.98	1.56	143.67	229.87	18.11	0.88	13.47	0.15	34.91	4.58
99	19x2	5.04	64.32	1.83	2.14	152.26	234.21	42.12	0.69	14.11	0.07	24.91	5.15
100	20x2	4.15	65.59	1.45	1.93	145.09	229.66	13.60	0.84	15.06	-0.5	29.19	4.88
101	21x2	4.31	67.17	2.24	1.83	148.51	228.29	8.99	0.88	16.77	0.98	17.17	5.20
102	22x2	3.73	65.41	3.27	1.52	131.33	202.88	13.86	0.85	16.30	4.35	34.19	4.11
103	23x2	3.04	65.59	2.32	1.97	135.64	219.76	23.73	0.84	13.63	0.57	26.23	5.23
104	24x2	4.22	61.93	1.69	1.32	135.00	220.84	16.24	0.79	13.55	2.18	48.74	5.87
105	25x2	2.55	62.79	1.92	1.67	138.88	222.87	19.72	0.65	14.80	5.42	20.11	5.52
106	26x2	2.87	64.47	0.32	1.98	127.55	203.11	14.44	0.78	13.82	5.34	24.91	5.33
107	27x2	3.77	67.29	1.61	2.04	142.61	212.80	21.69	0.81	15.66	2.13	16.12	4.98
108	28x2	3.32	65.16	2.25	2.20	115.39	192.14	20.10	0.91	14.93	2.15	36.92	4.60
109	29x2	3.50	65.07	1.51	2.17	130.73	208.48	16.77	0.81	14.21	0.88	39.68	4.75
110	30x2	4.44	66.10	2.54	1.95	162.15	246.84	9.25	0.85	14.90	0.32	29.56	5.32
111	31x2	3.26	64.63	2.68	2.10	134.37	225.53	12.02	0.76	13.61	0.93	27.55	5.64
112	32x2	3.45	65.00	1.74	1.73	139.23	224.94	17.42	0.84	14.31	0.28	17.26	4.90
113	33x2	3.28	63.41	3.92	2.00	147.38	227.41	22.18	0.71	13.27	0.12	3.97	5.70

ENTRY	CROSS	GY	AD	ASI	EA	EH	PH	ER	EPP	MOI	RL	SL	SEN
114	34x2	4.17	64.92	3.13	1.81	143.87	218.78	9.95	0.86	15.41	1.91	29.18	5.07
115	35x2	3.43	65.44	2.35	2.09	143.55	229.09	16.31	0.88	14.41	2.72	25.56	5.67
116	36x2	3.68	66.37	1.86	2.07	153.95	245.87	17.65	0.79	14.93	0.26	40.98	5.33
117	37x2	3.64	64.84	3.53	1.96	134.56	216.84	11.74	0.83	13.49	1.64	34.46	5.96
118	38x2	3.21	64.79	2.60	1.54	141.04	225.22	17.27	0.81	13.99	4.84	23.67	4.71
119	39x2	2.74	64.74	2.78	1.88	145.85	223.95	27.37	0.83	14.25	0.42	21.62	5.65
120	40x2	3.90	65.69	3.37	1.71	145.85	226.69	22.21	0.81	16.08	0.32	23.14	5.01
121	41x2	2.97	65.66	3.65	2.34	131.27	208.37	22.90	0.75	13.32	2.27	20.42	6.29
122	42x2	3.99	66.16	1.83	1.13	147.35	234.43	18.87	0.72	15.20	0.61	37.80	5.30
123	43x2	2.83	65.76	3.57	2.38	134.19	213.46	23.31	0.78	12.62	0.25	18.03	5.84
124	44x2	3.27	65.68	6.69	2.31	133.96	220.61	9.35	0.65	12.91	-0.17	6.45	6.23
125	45x2	3.05	64.84	3.03	2.05	123.13	205.86	17.46	0.73	15.23	0.12	4.29	5.20
126	46x2	5.08	66.46	1.52	1.65	152.58	239.96	22.39	0.85	15.00	0.47	18.18	4.29
127	47x2	4.26	65.54	1.25	1.59	149.02	235.36	17.10	0.91	15.69	-0.64	31.00	3.99
128	48x2	4.53	66.46	1.51	1.26	143.44	227.63	7.25	0.86	16.02	0.10	20.00	4.85
129	49x2	3.89	65.51	2.19	2.09	148.07	235.55	20.10	0.81	14.57	0.48	22.84	5.57
130	50x2	3.71	65.86	1.84	1.27	143.14	224.39	20.06	0.86	16.36	-0.05	18.68	3.88
131	51x2	4.25	66.03	2.07	1.35	154.31	239.72	16.53	0.88	15.39	0.39	16.74	3.66
132	52x2	4.67	67.28	1.97	1.75	149.87	228.60	17.85	0.86	16.22	0.44	11.63	4.42
133	53x2	3.73	68.36	1.28	2.16	148.63	225.43	17.67	0.67	14.26	12.54	30.09	6.23
134	54x2	4.64	64.87	1.14	1.53	141.19	231.59	15.44	0.90	14.70	0.49	27.54	6.46
135	55x2	4.04	67.27	2.13	2.07	158.20	231.72	28.58	0.77	14.56	1.71	6.49	4.99
136	56x2	3.37	66.59	1.45	1.84	152.94	231.18	25.17	0.76	13.78	0.55	26.06	5.26
137	57x2	5.32	65.09	1.86	1.31	150.57	227.50	18.19	0.90	14.78	0.96	16.31	5.05
138	58x2	5.03	65.59	2.64	1.39	148.41	223.27	15.20	0.76	15.41	-0.06	17.86	5.79
139	59x2	4.52	66.10	2.05	1.74	153.89	233.65	17.14	0.87	15.66	0.90	2.09	3.70
140	60x2	5.27	65.82	1.17	1.30	150.41	236.84	6.39	0.93	16.39	0.32	12.51	3.83
141	61x2	3.99	66.02	1.65	2.04	140.48	218.18	8.72	0.87	14.89	2.01	25.17	4.50
142	62x2	5.67	66.19	1.21	0.74	149.26	226.05	13.88	0.93	16.51	1.31	16.13	2.50
143	63x2	4.39	67.53	1.56	1.95	171.51	244.99	19.96	0.80	14.76	0.16	10.81	4.64
144	64x2	3.89	65.19	0.95	2.15	153.95	230.85	10.60	0.84	15.07	0.33	22.48	6.62
145	65x2	4.53	66.25	1.63	1.47	154.94	233.39	14.35	0.89	15.54	0.22	13.47	4.01
146	66x2	4.62	66.32	1.84	1.90	151.98	230.66	9.16	0.87	14.78	0.93	26.96	5.16
147	67x2	5.30	67.47	1.59	1.51	148.51	219.64	9.06	0.89	16.79	2.50	10.34	3.55
148	68x1	4.20	67.40	0.91	1.43	154.04	230.74	15.94	0.90	16.30	1.24	25.33	4.06
149	69x2	2.13	64.51	3.58	2.26	133.78	220.20	8.96	0.74	14.26	1.40	30.46	6.57
150	70x2	3.13	64.13	1.09	1.59	127.99	206.52	11.44	0.90	14.71	1.41	40.38	5.15
151	71x2	2.78	63.56	2.10	2.32	138.49	221.30	15.53	0.76	12.74	-0.60	15.28	6.00
152	72x2	2.37	63.12	2.42	2.56	142.29	228.52	19.71	0.74	14.11	0.43	33.75	5.33
153	73x2	3.59	65.24	2.13	1.68	155.67	237.80	15.10	0.86	14.28	2.38	23.65	5.05
154	74x2	4.20	63.58	3.24	2.18	136.21	225.60	9.52	0.81	14.02	0.03	14.75	5.60
155	75x2	4.08	63.94	2.65	2.26	144.63	232.90	23.28	0.83	14.16	0.70	26.56	4.84
156	76x2	3.68	64.82	2.14	1.77	149.40	237.58	18.26	0.85	13.99	-0.32	21.32	5.70
157	77x2	3.16	65.07	1.89	1.90	140.06	230.28	16.03	0.82	14.45	0.73	24.87	5.25
158	78x2	3.94	65.26	2.15	1.62	134.97	214.88	12.07	0.83	15.44	0.39	22.06	5.64
159	79x2	3.93	63.48	1.32	1.81	143.71	235.52	13.23	0.95	15.41	1.24	24.21	5.25
160	80x2	3.03	65.09	2.63	2.43	142.77	230.24	21.21	0.68	13.61	-0.77	28.31	6.31
161	DK-8053	3.43	64.23	2.17	2.18	126.31	210.29	13.90	0.69	14.10	5.63	16.05	5.52
162	H513	2.16	64.38	2.96	3.25	152.23	226.50	18.24	0.63	12.24	0.95	8.22	6.78
163	PH3253	2.36	65.19	2.97	1.82	146.09	226.71	29.20	0.71	14.81	1.93	11.60	4.71
164	Local check 1	2.25	65.09	3.39	1.81	138.32	222.07	17.91	0.79	13.39	4.05	22.61	4.70
165	Local check 2	1.93	61.61	2.90	2.20	132.25	229.08	22.48	0.73	13.64	1.26	5.15	5.02
Grand mean of trial		**3.55**	**66.42**	**1.93**	**1.99**	**147.09**	**227.02**	**17.44**	**0.80**	**14.58**	**1.55**	**20.36**	**5.02**
Heritability		**0.29**	**0.64**	**0.23**	**0.14**	**0.73**	**0.59**	**0.21**	**0.10**	**0.00**	**0.00**	**0.15**	**0.00**
LSD		**1.92**	**2.98**	**2.31**	**1.05**	**12.51**	**16.58**	**15.04**	**0.22**	**2.72**	**5.19**	**24.89**	**1.91**

GY: Grain yield; AD: Anthesis date; ASI: Anthesis-Silking Interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; EA: Ear aspect; PA: Plant aspect; ER: Ear rot; RL: Root lodging; SL: Stem lodging.

Appendix VIII: Mean grain yield and other agronomic traits of DH maize testcrosses evaluated across five sites under random drought conditions.

Entry	Cross	GY	AD	ASI	EA	PA	EH	PH	ER	EPP	MOI	RL	SL	GLS	ET
1	1x1	4.08	74	2.1	2.1	2.1	119	211	11.9	0.9	20.4	2.4	11.2	0.4	0.4
2	2x1	4.85	73	0.7	1.8	1.5	111	208	12.3	0.9	19	2	13.5	0.5	0.3
3	3x1	4.09	73	1.8	2	2.1	113	208	6.7	0.9	19.2	2.8	10.6	0.5	0.5
4	4x1	5.41	70	-0.1	1.8	1.9	120	224	7.1	1	18.7	8	16.4	0.6	0.5
5	5x1	4.37	72	0.3	2	1.9	111	206	8.8	1	17.6	3.9	11.7	0.4	0.3
6	6x1	3.98	74	1.1	1.7	1.8	115	215	8.2	0.9	19.3	3.6	4.6	0.3	0.3
7	7x1	4.71	70	0.3	2	1.5	111	215	7.2	1	17.1	5.3	14.8	0.5	0.5
8	8x1	4.24	73	0.5	2	1.9	115	209	9.3	0.9	17.5	3.4	21.6	0.4	0.3
9	9x1	4.69	71	0.5	1.8	1.6	105	205	3.5	0.9	18.3	3.2	11.7	0.3	0.4
10	10x1	4.86	71	0.4	1.8	1.7	118	214	8.7	0.9	19.1	8.1	12.4	0.4	0.3
11	11x1	4.83	71	-0.1	1.9	1.7	115	217	7.7	0.9	19.6	2.5	8	0.4	0.4
12	12x1	5.19	72	-0.3	2	2.1	126	226	9.3	1	19.3	5.7	16.9	0.4	0.4
13	13x1	4.59	71	1.1	1.8	1.8	116	218	14.6	0.9	19.3	4.9	11.9	0.3	0.4
14	14x1	3.98	71	0.5	2.2	1.4	107	201	8.1	1	17.9	3.3	10.1	0.2	0.3
15	15x1	3.65	75	0.8	2.2	1.9	118	208	9.1	0.9	18.3	3	9	0.5	0.3
16	16x1	3.84	74	1.1	2	1.9	115	209	8.9	0.9	19.4	7.1	6.8	0.6	0.4
17	17x1	3.91	72	0.5	2.1	2	120	213	6.8	1	17.8	6.7	12.1	0.3	0.3
18	18x1	4.84	71	-0.4	1.9	1.7	120	225	7.8	1	17.5	6.3	11	0.4	0.4
19	19x1	5.27	73	-0.4	1.7	2	125	224	8.7	1	18.8	1.6	4	0.3	0.3
20	20x1	3.83	73	0.7	2	2	119	224	9.6	0.9	18.1	2.3	11	0.4	0.3
21	21x1	4.19	74	0.6	2	1.8	116	216	8.4	1	17.8	5.5	13.5	0.4	0.4
22	22x1	6.72	70	0.9	1.4	1.4	110	209	6.3	1	21.1	4.5	11.1	0.4	0.4
23	23x1	5.74	71	0.1	1.6	1.7	118	222	7.8	1	18.6	2.3	22.7	0.3	0.4
24	24x1	5.52	64	0.5	1.7	1.7	105	213	7.9	0.9	17.2	3.7	12.6	0.5	0.5
25	25x1	6.3	67	0.2	1.6	2	114	227	9.4	1	17.5	4	13.1	0.5	0.3
26	26x1	6.43	68	-1	1.5	1.9	113	223	7.9	1	16.9	3.6	8.9	0.3	0.4
27	27x1	6.06	73	-0.3	1.6	1.9	130	231	8.2	1	21.5	2.7	11.7	0.4	0.3
28	28x1	5.98	68	1.8	1.6	1.4	110	217	6.4	1	19.2	3.5	5.8	0.3	0.3
29	29x1	5.98	70	0.6	1.6	1.6	108	213	5.2	1	18	3	12.7	0.3	0.4
30	30x1	4.69	75	1.2	2	2.3	127	228	11.2	0.9	19.2	11.8	4.8	0.3	0.3
31	31x1	4.48	74	0.4	2	1.6	108	206	9.8	0.9	18.9	1.8	8	0.3	0.3
32	32x1	4.39	73	1.5	2	1.8	110	201	9.7	1	17.3	9.5	8.8	0.3	0.3
33	33x1	3.97	72	1.6	1.8	1.8	113	209	4	1	18.9	5.3	7.7	0.3	0.4
34	34x1	4.51	72	1.9	1.8	1.6	106	201	9.1	1	20.5	3.8	12.5	0.3	0.3
35	35x1	4.34	72	0.2	1.9	1.7	110	207	11.1	0.9	18.2	2.9	7.3	0.5	0.3
36	36x1	5.25	73	-0.2	1.8	1.9	123	221	9.8	1	18.7	12.4	10.7	0.3	0.2
37	37x1	4.9	73	0.5	1.7	1.7	107	200	6	0.9	18.3	8.6	11.3	0.3	0.4
38	38x1	4.52	72	1.7	2.1	1.9	110	200	11	1	18.9	5.3	10.7	0.3	0.4
39	39x1	4.55	72	1.4	2	2.2	121	219	12.1	0.9	18.9	15	12.4	0.3	0.3
40	40x1	4.83	74	0.7	2	2	123	215	11	0.9	19.2	7	15.5	0.4	0.4
41	41x1	4.73	73	0.3	1.9	1.5	106	200	9.4	0.9	18.9	4.7	9.2	0.3	0.3
42	42x1	4.47	72	1.8	2	1.7	111	211	12.2	0.9	18.8	10.1	11	0.2	0.3
43	43x1	4.55	73	0.5	2.1	1.9	115	217	11.2	0.9	18.8	2.8	5.6	0.4	0.3
44	44x1	5.11	73	0.3	1.9	1.5	105	207	8.3	1	19	0.9	8.3	0.3	0.2
45	45x1	4.65	73	1.1	2.1	1.6	106	204	8.7	0.9	20.6	1.7	11.2	0.3	0.2
46	46x1	4.09	74	0.2	2.2	1.6	112	204	4.9	0.9	18.8	3.7	6.3	0.3	0.4
47	47x1	4.07	73	0.1	2	1.7	107	205	9.8	1	18.3	4.9	6.8	0.5	0.5
48	48x1	4.59	73	0.6	2	1.7	111	205	6.9	1	20.3	1	5.8	0.3	0.4
49	49x1	3.84	73	0	1.9	1.7	114	219	9.3	0.9	18.4	11.4	16.3	0.3	0.2
50	50x1	4.44	74	0.9	1.9	1.7	105	207	9.3	0.9	19.4	6.2	4.8	0.3	0.5
51	51x1	3.89	74	0.3	2.1	1.9	114	208	8.3	0.9	20	5.4	5.8	0.3	0.4
52	52x1	3.88	74	0.4	1.9	1.7	109	207	7.1	0.9	19.2	3.1	7.3	0.2	0.3
53	53x1	3.65	74	0.2	2	2	120	213	8.8	1	19.1	5.5	11.1	0.3	0.2
54	54x1	5.83	71	1.2	1.7	1.5	116	224	11.9	1	19.3	8.3	4.8	0.4	0.3
55	55x1	4.22	72	0.1	2	1.9	110	204	8.1	0.9	19.1	1.3	4.9	0.2	0.4
56	56x1	4.77	73	0.2	1.8	1.9	118	217	8	0.9	19	4.9	5.6	0.3	0.3
57	57x1	5.53	69	0.2	1.6	1.8	114	222	7.1	1	18.9	4.6	6.8	0.4	0.3

Entry	Cross	GY	AD	ASI	EA	PA	EH	PH	ER	EPP	MOI	RL	SL	GLS	ET
58	58x1	3.53	74	0	2	2	112	210	8.2	1	19.2	3.1	10.1	0.3	0.3
59	59x1	4.78	75	0.6	1.8	1.7	117	212	11.1	0.9	19.5	1.9	4.8	0.4	0.2
60	60x1	4.3	73	1.2	1.9	1.7	107	206	8.9	0.9	19.2	4.5	6	0.3	0.3
61	61x1	3.65	73	0.5	2	1.6	100	199	10.6	1	19	2.8	10	0.4	0.4
62	62x1	4.68	73	0.3	2	1.6	110	201	6.8	1	19.3	5.7	3.1	0.3	0.4
63	63x1	3.66	74	0.3	2	1.9	123	211	6	0.9	19	3.6	6	0.3	0.3
64	64x1	4.79	72	0.2	2	1.6	114	213	8.5	1	18.9	4.7	7.9	0.2	0.3
65	65x1	4.08	74	-0.4	2	1.6	111	202	10.9	0.9	19.5	8.7	9.7	0.4	0.3
66	66x1	4.07	72	0.1	2.2	1.8	123	214	9.3	1	18.2	2.9	10.3	0.3	0.3
67	67x1	4.16	74	0.8	2.2	2.1	117	213	9.1	1	18.9	6.3	11.5	0.4	0.3
68	68x1	3.6	74	0.6	2.3	2.1	106	190	6.3	0.9	19.5	0.5	7.7	0.3	0.3
69	69x1	6.28	69	-0.2	1.5	1.7	111	226	7.1	1	19.2	2.8	12.3	0.3	0.4
70	70x1	6.33	69	-0.3	1.8	1.4	107	209	6.7	1.1	17.5	3	9.2	0.3	0.3
71	71x1	5.55	70	0.2	1.5	1.5	109	211	8.6	1	19.6	5.9	8.5	0.3	0.3
72	72x1	4.5	71	1.1	1.8	1.8	117	222	13.3	0.9	18.8	17.2	13.2	0.4	0.4
73	73x1	4.29	72	0.5	1.8	1.9	116	210	11.3	0.9	18.2	7.6	10.5	0.3	0.5
74	74x1	5.56	69	0.6	1.6	1.7	117	219	8.3	1	18.6	6.7	7	0.4	0.4
75	75x1	4.8	71	1.2	1.8	1.7	114	218	12.1	0.9	17.4	10.8	9.2	0.3	0.4
76	76x1	4.28	73	1.1	2	1.8	108	208	6.8	0.9	19	8.2	7.2	0.3	0.3
77	77x1	4.52	72	-0.2	1.8	1.9	114	218	6.3	0.9	18.1	3.4	12	0.5	0.5
78	78x1	5.41	70	0.2	1.6	1.6	113	221	10.7	1	18.1	3.6	9.5	0.4	0.4
79	79x1	5.02	69	-0.1	1.7	1.8	110	220	9.4	1	17.9	6	5.4	0.6	0.4
80	80x1	4.55	73	0.5	1.7	1.7	117	224	6.8	0.9	18.4	3.8	3.1	0.3	0.3
81	1x2	6.61	68	1.1	1.5	1.5	110	212	8	1	19.1	-0.4	15.4	0.3	0.4
82	2x2	5.63	70	0.6	1.9	1.5	105	210	8.4	1	19.4	3.9	19.2	0.5	0.4
83	3x2	5.92	69	1.9	1.8	1.8	115	223	14.3	0.9	19.7	1.6	11.3	0.4	0.3
84	4x2	6.44	67	3	1.8	1.7	109	215	6.5	1.1	18.7	6.7	16.1	0.5	0.4
85	5x2	5.98	69	0.7	1.7	1.4	98	201	4.9	1	17.8	3.3	11.7	0.4	0.5
86	6x2	5.72	70	1.5	1.7	1.6	108	215	11.5	1	19.9	5.5	12.9	0.4	0.3
87	7x2	6.14	66	0.9	1.6	1.5	96	204	4.1	1.1	16.7	1.8	11.7	0.6	0.4
88	8x2	5.38	69	0.7	1.6	1.6	113	217	3.5	1	17.8	5.7	9.6	0.4	0.4
89	9x2	5.87	68	0.1	1.4	1.1	97	199	7.8	1	18.3	0.6	16.2	0.5	0.5
90	10x2	6.35	66	1.3	1.6	1.3	106	210	6.2	1	19.1	1.2	14	0.4	0.2
91	11x2	6.39	69	0.7	1.6	1.5	112	225	8.5	1	19.9	2.3	20.3	0.3	0.3
92	12x2	5.71	68	1.1	1.6	1.7	113	216	7.2	1	19.2	2.6	18.8	0.2	0.3
93	13x2	6.06	68	1.4	1.7	1.3	114	218	8.4	1	18.5	2.1	11.9	0.3	0.3
94	14x2	6.36	67	0	1.7	1.4	113	219	5.5	1	18.5	1.6	8.8	0.4	0.5
95	15x2	5.99	70	0.1	2	1.7	116	224	5.5	1	17.6	2.4	16.3	0.3	0.3
96	16x2	6.36	68	0.8	1.9	1.6	116	218	6.3	1	18.7	2.5	11.3	0.3	0.6
97	17x2	5.62	70	0	1.5	1.6	121	226	3.4	1	17.4	2.7	22.3	0.4	0.4
98	18x2	5.85	68	-0.1	1.7	1.3	107	216	7.3	1	17.5	0.7	20.3	0.6	0.5
99	19x2	5.96	69	-0.1	1.8	1.7	113	218	6.6	1	17.7	3.1	11.7	0.4	0.3
100	20x2	5.27	69	0.6	1.8	1.9	114	221	9	1	17.3	7	16.8	0.5	0.3
101	21x2	5.64	69	-0.2	1.8	1.7	111	217	2.3	1	17.6	3.6	23.5	0.5	0.4
102	22x2	4.81	68	2.1	1.9	1	92	185	4.8	1	19.2	3.5	24.6	0.3	0.4
103	23x2	4.61	69	0.7	1.8	1.5	98	196	7.4	0.9	17.9	2	15	0.6	0.4
104	24x2	4.15	63	0.5	2.2	1.8	88	197	14.4	1	15.9	6.2	16.1	0.5	0.5
105	25x2	4.26	66	2.1	2.1	1.9	96	199	11	1	16.7	7.3	5.7	0.5	0.4
106	26x2	4.34	67	0.1	2.2	1.7	95	199	7	1	14.6	6.3	24.2	0.5	0.3
107	27x2	3.63	72	0.3	2.1	2	103	193	8.9	0.9	19.7	2.2	23.2	0.3	0.4
108	28x2	4.88	68	1.3	2.1	1.4	88	184	7.8	1	18.3	2.1	16.5	0.4	0.4
109	29x2	4.61	67	1.4	1.9	1.5	87	183	7.2	1	16.7	7.4	18.5	0.4	0.3
110	30x2	6.34	70	1.1	1.8	2.1	123	226	9.8	0.9	19.8	10.7	10.2	0.3	0.4
111	31x2	6.36	68	0.8	1.6	1.3	108	211	6.8	1	19.4	3.1	17.9	0.3	0.3
112	32x2	5.86	68	1.3	1.9	1.6	104	206	13.7	0.9	17.9	2.4	10	0.3	0.3
113	33x2	5.47	67	2.7	1.6	1.5	101	207	4.6	1	19.3	7	7.3	0.2	0.3
114	34x2	6.01	69	2.2	1.8	1.4	106	211	8.5	1	20.3	7.4	13.6	0.3	0.3
115	35x2	6.38	67	1	1.8	1.5	101	211	10.4	1	19.4	3.5	13.2	0.4	0.4

Entry	Cross	GY	AD	ASI	EA	PA	EH	PH	ER	EPP	MOI	RL	SL	GLS	ET
116	36x2	6.43	70	-0.4	1.8	1.7	124	232	9.5	1	18.5	4	18	0.5	0.3
117	37x2	6.16	68	0.9	1.5	1.3	97	203	8.1	1	19	2	11.5	0.4	0.4
118	38x2	5.26	68	1.7	2.1	1.4	102	199	8.9	1	19.6	4.6	12.4	0.2	0.4
119	39x2	5.23	69	1.4	1.8	1.7	117	225	9.8	1	18.5	3.8	15.6	0.3	0.3
120	40x2	6.38	71	1.1	1.6	1.8	109	213	10.3	1	20.1	9.4	12.8	0.5	0.6
121	41x2	5.71	68	0.8	1.6	1.2	94	190	6.6	1	19	0.2	7	0.3	0.2
122	42x2	6.12	69	1.7	1.8	1.7	110	214	9.3	1	18.7	4	14.6	0.3	0.5
123	43x1	5.73	70	0.5	1.8	1.8	110	218	8.6	1	18.7	5.2	9.7	0.3	0.4
124	44x2	6.02	67	1	1.7	1.5	103	210	6.8	1	19.6	3.1	10.3	0.2	0.3
125	45x2	6.24	67	1.6	1.6	1.4	98	201	5	0.9	20.6	2.5	3.1	0.4	0.3
126	46x2	6.08	70	0	2	1.4	105	209	4.6	0.9	18.4	3.6	16.8	0.3	0.3
127	47x2	5.46	70	0.1	2	1.7	110	216	7.6	1	18.6	2.9	15.6	0.3	0.5
128	48x2	6.18	70	1.2	1.8	1.4	103	205	3.8	1	19.8	1.6	7.2	0.3	0.3
129	49x2	6.03	69	0.5	1.9	1.5	111	223	8.1	1	18.5	3.8	13.7	0.3	0.4
130	50x2	5.42	69	0.2	1.7	1.2	98	207	7.1	1	17.4	2.3	15.2	0.5	0.3
131	51x2	5.61	70	0.3	1.8	1.6	109	209	7.8	1	19.1	1.9	8.8	0.3	0.3
132	52x2	5.83	71	-0.1	1.9	1.3	108	218	8	1	19.1	4.4	11	0.3	0.4
133	53x2	5.98	72	0	1.8	1.6	117	220	10.3	1	20.6	1.8	13.4	0.4	0.3
134	54x2	5.46	67	0.5	1.9	1.5	103	213	5.5	1	18.2	1.5	10.2	0.4	0.4
135	55x2	5.85	69	0.1	1.7	1.4	109	210	7.1	1	19.2	6.3	9.3	0.5	0.4
136	56x2	6.39	70	0.2	2	1.7	121	225	6.1	1	17.7	0.5	13.9	0.4	0.4
137	57x2	4.62	68	0.1	1.9	1.7	103	211	8.2	1	19.1	3.1	12.6	0.6	0.4
138	58x2	5.25	71	1.1	1.8	1.8	110	214	6.3	1	20	3.2	14.3	0.4	0.3
139	59x2	5.8	70	0.3	1.8	1.4	107	207	9.2	1	18.4	1.2	9.1	0.4	0.4
140	60x2	5.95	70	0.6	1.9	1.4	106	209	5.3	1	19.7	2.8	10.4	0.3	0.2
141	61x2	5.36	69	0.5	1.8	1.1	97	203	5.1	1	18	2.3	13.2	0.3	0.4
142	62x2	5.62	70	-0.5	1.8	1.5	105	206	4.9	1.1	19	3	11.1	0.3	0.3
143	63x2	6.04	71	0	1.8	2	117	217	6.2	1	18.6	2.4	11.4	0.3	0.4
144	64x2	6.53	67	0.6	1.7	1.4	117	221	7.2	1	17.8	2.2	13	0.3	0.4
145	65x2	5.57	69	0.5	2	1.7	108	205	7.9	1	18.1	1.7	10.9	0.3	0.4
146	66x2	6.02	69	0.2	1.9	1.6	121	224	8.1	1	17.5	5.6	16.6	0.6	0.4
147	67x2	5.48	70	0	1.8	1.8	110	209	7.9	1	18.7	7.1	14.4	0.4	0.4
148	68x1	6.32	70	-0.1	1.7	1.7	119	216	7	1	19.4	1.9	10.8	0.2	0.4
149	69x2	5.73	68	-0.5	1.7	1.5	98	208	5.9	1	17.6	2.9	18.4	0.5	0.5
150	70x2	5.45	67	0.1	1.9	1.2	91	192	11.8	1	17.3	3.2	15	0.3	0.4
151	71x2	5.83	66	0.9	1.9	1.4	97	204	8.7	1	18.5	5.1	11.3	0.4	0.4
152	72x2	6.01	67	0.7	1.8	1.9	105	215	13.6	1	17.5	3	6.9	0.4	0.3
153	73x2	6.17	68	1.3	1.6	1.7	117	219	9.3	1	19.1	3.8	12	0.4	0.4
154	74x2	5.3	67	1.3	1.8	1.7	104	203	9.3	1	18.6	9.3	14.8	0.5	0.4
155	75x2	5.67	66	1.1	1.8	1.5	107	215	7.5	1	17.9	4	16.4	0.3	0.3
156	76x2	6.17	69	1.5	1.8	1.4	109	214	7	0.9	19.2	2.4	16.3	0.4	0.3
157	77x2	5.35	64	1.3	1.7	1.6	99	207	7.8	0.9	18.2	3	17.2	0.2	0.5
158	78x2	6.1	68	0.6	1.7	1.4	103	211	7.1	1	19.2	10.4	12.2	0.4	0.5
159	79x2	6.03	66	0.5	1.6	1.4	101	209	5.1	1	18.1	6	10.2	0.5	0.5
160	80x2	5.7	69	1	1.8	1.8	107	217	4.4	0.9	18.7	3.2	8.9	0.4	0.3
161	DK-8053	5.32	67	1	1.7	1.7	96	202	9.6	1	17	3.8	-0.3	0.3	0.3
162	H513	6.32	66	0.8	1.8	1.8	114	218	15.1	1	17.5	9.2	5.9	0.5	0.6
163	PH3253	5.09	68	1.5	2.1	1.7	103	214	17.8	0.9	16.7	11.6	6.9	0.3	0.5
164	Local check 1	4.52	66	1.3	1.9	1.7	102	209	12.4	0.9	17.1	6.3	5.5	0.6	0.4
165	Local check 2	4.81	67	1.1	1.9	1.6	102	209	12.2	1	16.5	12.7	9.7	0.4	0.4
Mean of Trial		**5.21**	**70**	**0.7**	**1.8**	**1.7**	**110**	**212**	**8.3**	**1**	**18.6**	**4.5**	**11.5**	**0.4**	**0.4**
Location variance		**3.3**	**141**	**0.2**	**0.3**	**1**	**692**	**1399**	**207**	**0**	**5.5**	**50.3**	**202**	**0.7**	**0.7**
Loc x Entry variance		**0.21**	**1**	**0.3**	**0**	**0**	**25.7**	**32.4**	**11.7**	**0**	**0.5**	**9.2**	**25.3**	**0**	**0**
Heritability		**0.81**	**1**	**0.4**	**0.5**	**0.6**	**0.8**	**0.8**	**0.1**	**0.3**	**0.7**	**0.1**	**0.3**	**0**	**0**
LSD (0.05)		**1.01**	**2**	**1.4**	**0.4**	**0.4**	**9.6**	**12.1**	**6.5**	**0.1**	**1.4**	**7.5**	**10.6**	**0.3**	**0.2**

Appendix IX: Heterotic grouping of DH lines based on specific combining ability estimates for grain yield under well-watered conditions.

Line	CML312/CML 442 (HGA)	CML395/CML 444 (HGB)	Heterotic Group	Line	CML312/CML442 (HGA)	CML395/CML 444 (HGB)	Heterotic Group
1	0.54*	-0.54*	B	**41**	-0.24	0.24	A
2	-0.28	0.28	A	**42**	0.52*	-0.52*	B
3	0.32	-0.32	B	**43**	0.83**	-0.83**	B
4	-0.78**	0.78**	A	**44**	-0.19	0.19	A
5	0.02	-0.02	AB	**45**	0.02	-0.02	AB
6	0.11	-0.11	B	**46**	0.54*	-0.54*	B
7	-0.16	0.16	A	**47**	0.15	-0.15	B
8	0.56*	-0.56*	B	**48**	0.52*	-0.52*	B
9	-0.21	0.21	A	**49**	0.34	-0.34	B
10	0.74**	-0.74**	B	**50**	0.48	-0.48	B
11	0.56*	-0.56*	B	**51**	0.42	-0.42	B
12	0.23	-0.23	B	**52**	0.41	-0.41	B
13	0.3	-0.3	B	**53**	0.57*	-0.57*	B
14	0.07	-0.07	AB	**54**	-0.41	0.41	A
15	0.66**	-0.66**	B	**55**	0.81**	-0.81**	B
16	0.80**	-0.8**	B	**56**	-0.01	0.01	AB
17	0.72**	-0.72**	B	**57**	-0.95***	0.95***	A
18	0.02	-0.02	AB	**58**	0.53*	-0.53*	B
19	-0.06	0.06	AB	**59**	0.24	-0.24	B
20	-0.21	0.21	A	**60**	-0.1	0.1	A
21	0.21	-0.21	B	**61**	0.21	-0.21	B
22	-1.49***	1.49***	A	**62**	0.24	-0.24	B
23	-2.10***	2.10***	A	**63**	0.74**	-0.74**	B
24	-1.35***	1.35***	A	**64**	0.23	-0.23	B
25	-1.78***	1.78***	A	**65**	0.23	-0.23	B
26	-1.91***	1.91***	A	**66**	0.71**	-0.71**	B
27	-1.73***	1.73***	A	**67**	0.19	-0.19	B
28	-2.25***	2.25***	A	**68**	0.66**	-0.66**	B
29	-2.14***	2.14***	A	**69**	-1.27***	1.27***	A
30	0.86***	-0.86***	B	**70**	-0.94***	0.94***	A
31	0.63**	-0.63**	B	**71**	-1.22***	1.22***	A
32	0.32	-0.32	B	**72**	0.52*	-0.52*	B
33	0.68**	-0.68**	B	**73**	0.09	-0.09	AB
34	0.49	-0.49	B	**74**	0.26	-0.26	B
35	0.16	-0.16	B	**75**	-0.01	0.01	AB
36	-0.12	0.12	A	**76**	0.6*	-0.6*	B
37	-0.11	0.11	A	**77**	0.25	-0.25	B
38	-0.35	0.35	A	**78**	0.15	-0.15	B
39	0.001	-0.001	AB	**79**	0.21	-0.21	B
40	0.87***	-0.87***	B	**80**	0.88***	-0.88***	B

Appendix X: Heterotic grouping of DH lines based on specific combining ability estimates for grain yield under managed drought conditions.

Line	CML312/CML 442 (HGA)	CML395/CML 444 (HGB)	Heterotic Group	Line	CML312/CML 442 (HGA)	CML395/CML 444 (HGB)	Heterotic Group
1	-0.26	0.26	B	**41**	-0.13	0.13	B
2	-0.25	0.25	B	**42**	0.14	-0.14	A
3	-0.15	0.15	B	**43**	0.05	-0.05	AB
4	0.04	-0.04	AB	**44**	-0.25	0.25	B
5	-0.03	0.03	AB	**45**	-0.61	0.61	B
6	0.02	-0.02	AB	**46**	-0.32	0.32	B
7	-0.41	0.41	B	**47**	-0.38	0.38	B
8	-0.15	0.15	B	**48**	0.66	-0.66	A
9	-0.43	0.43	B	**49**	-1.52**	1.52**	B
10	-0.47	0.47	B	**50**	-0.12	0.12	B
11	-0.18	0.18	B	**51**	0.71	-0.71	A
12	-0.15	0.15	B	**52**	-0.36	0.36	B
13	0.39	-0.39	A	**53**	-0.13	0.13	B
14	0.8	-0.8	A	**54**	-0.08	0.08	AB
15	-0.12	0.12	B	**55**	0.09	-0.09	AB
16	-0.22	0.22	B	**56**	-0.39	0.39	B
17	-0.02	0.02	AB	**57**	-0.92	0.92	B
18	0	0	AB	**58**	-0.29	0.29	B
19	-0.79	0.79	B	**59**	-0.82	0.82	B
20	-0.38	0.38	B	**60**	-0.31	0.31	B
21	-0.33	0.33	B	**61**	-0.03	0.03	AB
22	-0.18	0.18	B	**62**	0.27	-0.27	A
23	0.25	-0.25	A	**63**	-0.24	0.24	B
24	0.09	-0.09	AB	**64**	-0.16	0.16	B
25	0.03	-0.03	AB	**65**	0.5	-0.5	A
26	0.57	-0.57	A	**66**	0.47	-0.47	A
27	-0.17	0.17	B	**67**	0.38	-0.38	A
28	1.41**	-1.41**	A	**68**	-0.25	0.25	B
29	0.82	-0.82	A	**69**	-0.29	0.29	B
30	-0.36	0.36	B	**70**	-0.77	0.77	B
31	-0.19	0.19	B	**71**	0.2	-0.2	A
32	0.7	-0.7	A	**72**	-0.58	0.58	B
33	0	0	AB	**73**	-0.07	0.07	AB
34	-0.01	0.01	AB	**74**	0.32	-0.32	A
35	0.05	-0.05	AB	**75**	1.26**	-1.26**	A
36	0.51	-0.51	A	**76**	0.88	-0.88	A
37	0.65	-0.65	A	**77**	0.78	-0.78	A
38	-0.13	0.13	B	**78**	0.06	-0.06	AB
39	0.37	-0.37	A	**79**	0.03	-0.03	AB
40	0.39	-0.39	A	**80**	0.49	-0.49	A