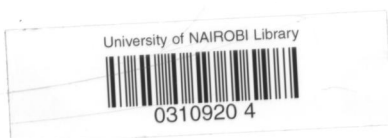


**COMBINING ABILITY AND HETEROTIC GROUPING OF EARLY
MATURING QUALITY PROTEIN MAIZE INBRED LINES**

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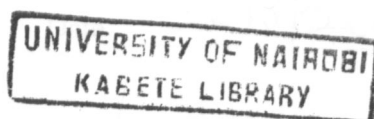
SUSAN NJERI GACHANJA

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN PLANT
BREEDING AND GENETICS**



**DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION
COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES
UNIVERSITY OF NAIROBI**

2011



DECLARATION

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

Susan Njeri Gachanja 

Date 25/11/11

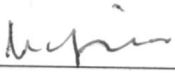
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DEDICATION

I dedicate this thesis to: My parents, Joakim and Ann; Brother, Duncan; Sisters, Mary and Lydia and friend Felix for their great support.

ACKNOWLEDGEMENTS

I am heartily thankful to my supervisors Dr Kiarie Njoroge, Dr Dan Makumbi and Dr George Chemining'wa whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject. I thank them all for their valuable advice which has nourished my intellectual maturity that I will benefit from for a long time to come. It is a pleasure to pay tribute also to Mr Silvano Assanga and Mr Joseph Kassango who always granted me their ears to my many questions. I hope to keep up our collaboration in the future. I convey special acknowledgement to all KARI staff at Kiboko, Kakamega, Kibos, and Embu, and to staff of NaCCRI Namulonge in Uganda for their great support in the field.

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Finally I thank my God for his grace each and every day.

ABSTRACT

Maize is the staple crop for most farmers in the arid and semi arid areas of the tropics. Drought and low soil fertility are major limiting factors in maize production in these areas. Research emphasis has been placed at developing early maturing quality protein maize (QPM) varieties that can yield well under water-limited conditions and low nitrogen stress experienced in drier mid-altitude areas of this region. The general objective of this study was to assess the general combining ability present in CIMMYT's early QPM maize lines and specific combining ability of single crosses under drought stress, low nitrogen and well-watered conditions and group the lines in known heterotic groups. Two studies were conducted.

In the first study, 13 inbred lines were crossed in a diallel. Hybrids were evaluated under managed drought, random stress and low nitrogen stress and well watered conditions at six locations. The objective was to evaluate their performance, estimate GCA and SCA effects and determine the phenotypic correlations between grain yield and agronomic traits. Inbred line 1 and 2 had high, positive and significant ($P < 0.05$) GCA effects for grain yield under all well-watered conditions and managed drought stress. This suggesting that these inbred lines have the potential to be used as parents for developing good hybrids for well-watered conditions as well as drought-stressed environments. Entry 42 was consistent in its top performance for grain yield under all conditions tested. Phenotypic correlations between grain yield across well-watered conditions were positive and significant ($P < 0.001$) for days to anthesis, plant height and ear height. Under the three stress conditions, the correlation between anthesis silking interval and ears per plant was negative and significant ($P < 0.05$) indicating a

reduced anthesis-silking interval which resulted in an increased number of ears under stress conditions.

In the second study, lines were crossed with two inbred line testers. The F_1 hybrids were evaluated under six locations to estimate general combining ability and specific combining ability effects under drought stress and well watered conditions, and group them into known heterotic groups. Inbred line 45 had high, significant and positive GCA effect for grain yield under managed drought stress and across well-watered conditions. Lines with good GCA in each heterotic group may be used in recycling inbred lines. Based on SCA effects for grain yield, the two inbred line testers grouped 29 lines into heterotic group B, 25 inbred lines into heterotic group A and 11 into heterotic group AB. Entries 55, 60, 87 and 113 were the top performers in terms of grain yield both under managed drought and across well-watered conditions.

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CHAPTER 1: INTRODUCTION

1.1 Maize production

Maize (*Zea mays* L.) is one of the world's most important cereal crops and is cultivated in a wider range of environments than either wheat or rice (Koutsika-Sotiriou, 1999). The area under maize in the world is estimated to be 150 million hectares with a yield of 4970.9 kg/ha (Tilman *et al.*, 2002). Although 68% of the world maize area is in developing countries, only 46% of the world's maize production is produced there (FAO, 2003).

In Kenya, maize is a staple food and therefore a lot of emphasis is laid on the crop's production. The area under production is approximately 1.6 million hectares (Bradford *et al.*, 1995). The maximum production in a good season is about 34 metric tonnes which drops to 18 metric tonnes during drought years (EPZA, 2005). Maize consumption is estimated at 103 kg per capita which is high compared to 81 kg per capita in the eastern and southern regions of the continent (Pingali, 2001). Maize production has not kept pace with increased consumption trends and this has often led to food insecurity accompanied by importation. Most tropical maize is produced under rain-fed conditions in areas where drought is widely considered the most important abiotic constraint to production (Pingali and Pandey, 2000). Drought is a major threat to maize production, food security and economic growth in eastern and southern Africa (Bänziger and Diallo, 2004). In addition to the adverse effects of drought, increased population pressure, high input costs, and extreme poverty force smallholder farmers in the region to implement low input farming systems (Bänziger *et al.*, 1999). These lead to low yields in resource poor farmers fields where on average 1.3 t ha^{-1} are produced (Bänziger and Diallo, 2004) in contrast to 6 to 9 t ha^{-1} attained in similar areas with adequate inputs (Loomis,

1997). Under circumstances in which the smallholder farmers cannot afford additional inputs, it would be desirable to increase the tolerance of the maize crop to stresses that occur in the fields (Bänziger *et al.*, 1999).

1.2 Nutritional role of maize

Normal maize has a biological nutritional value of 40% as compared to that of milk (Bressani, 1991) and therefore needs to be eaten with complementary protein sources. In Africa, maize supplies at least one fifth of total daily calories consumed as estimated by FAO food balance sheets (Krivanek *et al.*, 2007). Maize provides 50% of the calories in diets in southern Africa, 30% in eastern Africa and 15% in West and Central Africa (Prasanna *et al.*, 2001). It is also an important source of protein and accounts for 17 to 60% of people's total daily protein supply in this continent (Krivanek *et al.*, 2007). Maize provides as much protein as it provides carbohydrates (FAO, 2003). In fact, specific groups that include sick children, sick adults and children being weaned are more dependent on maize as a major source of dietary protein than on any other source (Millward and Rivers, 1989). Such dependence on maize as a protein source puts people at risk of dietary protein deficiency because maize protein is deficient in two essential amino acids, lysine and tryptophan (Vivek *et al.*, 2008). Due to the nutritional importance of maize, significant efforts have been made by breeders to improve its protein quality.

1.3 Quality protein maize (QPM) breeding

Quality protein maize (QPM) was derived from mutant maize with soft and opaque grains (Vietmeyer, 2000). It has a substantially higher amount of lysine and tryptophan than normal maize (Bressani, 1991). A double increase of lysine and tryptophan helps balance the leucine to isoleucine ratio. This ratio is considered beneficial as it helps to liberate more tryptophan for more niacin biosynthesis, thus helping to combat pellagra a protein deficiency nutritional disorder (Vasal, 1994). High protein maize is also vital to the growth of humans and non-ruminant livestock as it serves as a source of protein and calories. Thus, substituting normal maize with QPM improves the protein status and greatly reduces malnutrition problems of resource poor people who depend on maize as a staple crop (EARO and CIMMYT, 2001).

Unfortunately, the gene responsible for higher lysine and tryptophan content is also associated with reduced grain yield, increased susceptibility to ear rot, soft floury endosperm, and poor dry-milling properties (Vasal, 2000). However, after many years of research, plant breeders and biochemists have developed nutritionally improved hard-endosperm maize genotypes collectively called quality protein maize (QPM).

Quality protein maize has been used in feeding monogastric animals and humans (Vivek *et al.*, 2008) resulting in positive impact. In humans, studies have shown that QPM improves the nutritional status of vulnerable groups whose staple food is maize (Akuamoah-Boateng, 2002). In a study done in the Ethiopian Highlands, Akalu *et al.*, (2010) concluded that in major maize producing and consuming areas of Africa, home cultivation and use of QPM in children's diets could reduce or prevent growth faltering and may in some cases support catch up growth

in weight. Given the great number of farmers involved in maize production, the development, introduction, and adoption of improved QPM cultivars may have significant potential to reduce protein malnutrition, alleviate hunger, increase incomes, and improve livelihoods (Vivek *et al.*, 2008), of many people in developing countries of the world.

The QPM breeding program for East Africa is led by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with National Agricultural Research Systems (NARS) and small seed companies. Their approach includes testing inbred lines and conversion of popular cultivars to QPM. Inbred lines, both early generation and elite lines such as CIMMYT maize lines (CMLs), hybrids and open pollinated varieties (OPVs) developed from other breeding programs, are tested. The most adapted varieties are identified for direct release while inbreds are used as breeding material. Popular adapted cultivars are also converted to QPM through backcross-recurrent selection procedures. Considerable effort has also been dedicated to formation of drought tolerant (maize streak resistant) cultivars from QPM populations from CIMMYT-Mexico. CIMMYT work also aims to introgress Imidazoline Resistant (IR) gene to QPM cultivars for striga prone ecologies. The imazapyr resistant herbicide – coated maize seeds kills striga before it damages the crop. Currently, more than 20 early QPM OPVs have been developed and distributed for evaluation across the Sub-Saharan Africa and some have been released for commercial exploitation. Quality Protein Maize hybrids released include: KH500Q and KH631Q and WS104Q an OPV. (Krivanek *et al.*, 2007).

1.4 Constraints to maize production

Maize production is limited by a number of biotic and abiotic factors. One of the most important limiting abiotic factor is moisture stress which affects yields on an estimated 40% of the maize sown in lowland tropical environments (Edmeades *et al.*, 1989). Soil infertility is also an important abiotic factor affecting maize production.

Soils in the tropics are generally inherently infertile and most, especially those under subsistence agriculture have been mined of nutrients for years without replenishment with fertilizer (Smaling *et al.*, 1997). Nitrogen depletion rates average in excess of 20 kg N/ha/yr in most of the major maize producing countries in Eastern and Southern Africa, and >40 kg N/ha/yr in Ethiopia and Kenya (Smaling *et al.*, 1997). Tropical soils themselves vary greatly, giving rise to differences in moisture and nitrogen at a single site within the same year. In contrast to drought, low soil nitrogen tolerance is a more predictable stress, since often one has prior knowledge of the soil nitrogen status. Nitrogen status levels too can be more easily adjusted through controlled fertilizer applications (Vasal *et al.*, 1997). However, most small holder farmers in the Sub-Saharan Africa region use very little or no fertilizers at all because of prohibitively high prices. The development of drought and low nitrogen tolerant varieties requires appropriate strategies. These range from the establishment of an appropriate selection environment, like the establishment of off-season nurseries, ability to control water and fertility levels, well trained personnel, and adequate equipment to evaluate parameters related to stress tolerance (Edmeades *et al.*, 1999).

Diseases and pests also contribute to yield losses. Major diseases in Sub-Saharan Africa include northern leaf blight (*Exserohilum turcicum*), maize streak disease transmitted by hoppers (*Cicadulina spp*), gray leaf spot (*Cercospora zea maydis* and common leaf rust (*Puccinia sorghi*). Major insect pests of economic importance in sub-Saharan Africa include stem borers (*Chilo partellus*) and (*Busseola fusca*), grain weevils (*Sitophilus zeamays*), and the larger grain borer (*Prostephanus truncatus*). Parasitic weeds such as *Striga spp* can cause up to 100% yield loss. *Striga* infestation is common in areas with low soil fertility and affects an estimated 20- 40 M ha in Sub-Saharan Africa (Lagoke *et al.*, 1991).

1.5 Problem statement and justification

Quality protein maize is known to improve the nutritional status of resource poor farmers who depend on maize as the staple crop. Most of these farmers are in the arid and semi-arid mid-altitude areas of the tropics. In these areas, severe droughts have become more frequent due to climate change leading to maize production losses and affecting economies and livelihoods of millions of people. Initial efforts at developing improved QPM varieties were targeted at the moist mid-altitude areas of Eastern Africa. More recently, emphasis has been placed at developing early maturing QPM varieties that can yield well under water-limited conditions experienced in drier mid-altitude areas of this region. Several QPM inbred lines have been developed by breeders at the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with national partners in several East African countries. For some of the lines, the combining ability (breeding value) and heterotic grouping have not yet been determined. Such information will be useful in hybrid and/or open-pollinated variety development

program. This research was aimed at determining the breeding value of 65 QPM inbred lines and also their heterotic groupings using identified good inbred line testers.

1.6 Objectives

The general objective was to assess the relative importance of general combining ability of CIMMYT's early quality protein maize lines and specific combining ability of single crosses under drought stress, low nitrogen and well-watered conditions.

1.6.2 Specific objectives

1. To estimate the general combining ability (GCA) effects of the inbred lines, the specific combining ability (SCA) of the hybrids as well as evaluate their performance under well watered, managed drought stress and low nitrogen stress conditions.
2. To classify the 65 QPM inbred lines into heterotic groups based on SCA for grain yield with 2 inbred line testers.

1.6.3 Hypotheses

1. Prior determination of combining ability and heterotic grouping are essential in getting good hybrids
2. Identification of GCA is a good way of determining the potential of F₁ hybrids.
3. Screening under managed stress conditions reflects the conditions under natural states.

CHAPTER 2: LITERATURE REVIEW

2.1 Effect of drought stress on maize

Drought is a multidimensional stress affecting plants at various levels of their organization (Yordanov *et al.*, 2000) and is a major constraint to maize production worldwide. Heisey and Edmeades (1999) estimated that 20-25% of the global maize area is affected by drought in any given year. This leads to maize production losses, which prominently affect economies and livelihoods of millions of people (Bänziger and Araus, 2007). Drought in Eastern and Southern Africa results in a wide spread maize crop failure. Global climate change is expected to result in a long-term trend towards higher temperatures, greater evapo-transpiration, decreases in water use efficiency, changes in precipitation and increased incidence of drought specific regions (Jones, 2003). These conditions imply a need for breeding maize with improved levels of drought tolerance.

Drought affects maize starting from crop establishment up to grain filling. Bänziger *et al* (2000) reported that drought could affect maize production by decreasing plant population during the seedling stage. Additional reduction in production may come from increased energy and nutrient consumption of drought adaptive responses, such as increased root growth under drought. Drought has been reported to be devastating when it occurs at flowering and pollination time (Zaidi *et al.*, 2004). Maize is particularly sensitive to water stress one week before or two weeks after flowering (Denmead and Shaw, 1960; Grant *et al.*, 1989). One of the main causes of this, is thought to be a reduction in the flux of assimilates to the developing ear below some threshold level necessary to sustain grain formation and growth (Westgate and Bassetti, 1990; Schussler and Westgate, 1995). Drought stress also causes delayed silking and

female sterility (Moss and Downey 1971), reduction in amount of pollen and number of kernels per plant (Hall *et al.*, 1982), resulting into a large reduction in grain yield. Campos *et al.* (2004) reported 45-60% yield losses when drought occurred at silk emergence. Cakir (2004) reported that water stress occurring during vegetative and tasselling stages reduces plant height, as well as leaf area development. Water deficits during the rapid vegetation period caused 28-32% loss of final dry matter weight and much greater losses of 66-93% could be expected because of prolonged water stress during tasselling and ear formation stages (Mugo *et al.*, 2000). This is because water deficit causes a decline in photosynthesis per plant caused by reduced light interception due to reduced leaf expansion and to reductions in carbon fixation per unit area. (Mugo *et al.*, 2000). Water stress slows ear growth, and consequently silk emergence, more than tassel growth or anthesis, resulting in a widening interval between anthesis and silking (Bolaños and Edmeades, 1996). Under such conditions, pollen desiccates and lands on withered silks or on ovaries that have exhausted their starch reserves thus reducing grain yield (Saini and Westgate, 2000). Anthesis-silking interval has therefore been used as a secondary trait to enhance the rate of genetic improvement of maize populations under drought (Bolaños and Edmeades, 1996;).

In a study by Fischer *et al.* (1989), anthesis-silking interval was one component of a selection index used to identify superior full-sib families for recombination during recurrent selection for improved performance under drought in Tuxpeno which is one of the most productive and successful Mexican races of maize. The first three cycles of selection in this population resulted in a significant response of negative 2.1 days in ASI under drought, and ASI was significantly correlated with grain yield under drought in two trials ($r=-0.52$; $r=-0.36$; $P<0.01$,

n=250) of full-sib families (Fischer *et al.*, 1989). Concurrent with this change in ASI was an increase in the proportion of biomass invested in the developing ear and husks at flowering, suggesting that a change in partitioning of photo-assimilates favoring more rapid ear growth may have taken place.

Breeding drought tolerant varieties of maize has not been widely accepted due to a perception that drought tolerant varieties are low yielding in non-drought environments, implying that a yield penalty occurs when rainfall is adequate. Drought tolerant germplasm that is specifically adapted to low yield environments have been found. Moreno *et al.* (2005) reported that traits that confer drought tolerance lack positive relationship with high yield potential. Hybrids with high yield potential in both drought and non-drought conditions are desired. Possibly, such hybrids could be developed by combining drought tolerant lines with those that have been selected for high general combining ability (GCA) for grain yield potential under normal conditions. Earliest attempts to increase drought tolerance in maize revealed low genetic variance and heritability of grain yield under drought, and large genotype-by-environment effects and this fostered the notion that breeding progress for drought tolerance would be difficult to achieve (Johnson and Geadelmann, 1989). Secondary traits under such conditions have been used so as to increase selection efficiency, provided these traits have a clear adaptive value under stress, relatively high heritability, have a significant correlation with grain yield and are easy to measure (Falconer, 1960).

Over the past decade, experiences from selection experiments confirmed significant grain yield increases under drought in both temperate and tropical maize (Bänziger and Araus,

2007). Bolaños and Edmeades (1993a) evaluated eight cycles of selection for drought tolerance in lowland tropical maize and reported that selection under drought stress increased yield at the rate of 8.9% (30 kg ha^{-1}) per cycle. These authors also reported a significant gain of 9.4% for ears per plant and an increase in kernel number per fertile ear in early cycles of selection under drought stress conditions. Bolaños and Edmeades (1993a) further reported that about 25% of the gains that were recorded in those trials could be attributed to improved adaptation to the selection site.

Drought tolerance has been achieved through many approaches. Many breeders have focused on alleviating the effects of drought at flowering and during grain filling because maize is most vulnerable to drought at these stages. By evaluating maize that is moisture stressed during flowering, it is possible to identify maize genotypes capable of maintaining a short ASI, and achieving above-average grain yield. This approach is routinely used by the International Maize and Wheat Improvement Center (CIMMYT) to improve and develop drought tolerant maize populations, inbred lines and hybrids (Bänziger *et al.*, 2000). Other selection criteria, in addition to grain yield and ASI, may include number of ears per plant (EPP), ear aspect (EA) which is a visual assessment of quality, anthesis date (AD), leaf rolling (RL), rate of leaf senescence (SEN), and tassel size (Vasal *et al.*, 1997).

2.2 Effects of low nitrogen stress on maize

Most of the maize in developing countries is produced under low nitrogen conditions because of continuous cropping and mono-cropping which have resulted in a decline in soil fertility. As a result, nitrogen continues to be a major nutrient limiting maize production in most

farmers' fields (CIMMYT, 1992). Population pressure has also exacerbated this problem by reducing fallow periods, leading to reduced soil fertility. Increased production of crops which have a higher monetary value leaves maize to be grown in less fertile areas. These changes imply that more maize will be grown in the marginal areas in the future. Poor weed control and leaching due to heavy rain in some seasons increase the incidence of nitrogen stress in many places.

Variation in nitrogen supply affects both growth and development of maize plants (McCullough *et al.*, 1994). Uhart and Andrade (1995b) reported that nitrogen deprivation reduced leaf area index, leaf area duration, radiation interception and radiation use efficiency. Low nitrogen also increases the anthesis silking interval (Jacobs and Pearson, 1991). Lack of nitrogen enhances kernel abortion (Pearson and Jacobs, 1987) and reduces final grain number (Lemcoff and Loomis, 1986).

One approach to reducing the impact of nitrogen deficiency is to select cultivars that are superior in the utilization of available nitrogen, due either to enhanced uptake capacity or more efficient use of absorbed nitrogen for grain production (Lafitte and Edmeades, 1994) or both. Blum (1988) suggested that selection for grain yield in the target environment (in this case low nitrogen environments) should be more efficient than selection for yield potential alone.

Breeding for low nitrogen stress tolerance has been an ongoing program at the International Maize and Wheat Improvement Center (CIMMYT) since 1986. It has been established that successful strategies to develop low nitrogen tolerant maize requires knowledge of the plant and its environment (Edmeades *et al.*, 1992). One such approach is the development of stress tolerant maize under carefully managed low nitrogen stress sites. Another approach to increasing the efficiency of selection in low nitrogen environments is the use of correlated secondary traits (Blum, 1988). These are improved N uptake by plants, high plant nitrate uptake and increasing nitrate reductase activity. Feil *et al.* (1993) reported positive correlations between nitrate reductase activity measured in growing plants in a growth cabinet and total N uptake and grain yield observed in the field. Other traits positively correlated with grain yield under limited nitrogen environments are large leaf area, high specific leaf N, total biomass and N at anthesis, plant height at anthesis and length of the duration of grain filling (Lafitte and Edmeades, 1988). Delayed senescence was proposed as indirect selection criteria for low nitrogen tolerance (Moll *et al.*, 1994).

2.3 Diallel analysis and combining ability

Diallel mating design is a method whereby all inbred lines or open-pollinated varieties are crossed in all possible combinations for field evaluation purposes. Theoretically, when the number of crosses per parent is $n-1$ among n inbreds, n^2 single crosses are possible, including n selfs and $[n(n-1)]/2$ F_1 s and reciprocals each. The diallel design has four methods. Method 1 is a full diallel set involving parents, F_1 s and reciprocals; method 2 is a half diallel set involving parents and F_1 s only; method 3 is a half diallel involving F_1 s and reciprocals; method 4 involves F_1 s only. Griffing's, (1956) suggested diallel analysis based on two models

associated with the type of materials (parents) involved in the mating and about which inferences are to be drawn. Model I often referred to as the fixed effects model, implies that the experimental material itself is the population about which inferences are to be drawn, and hence estimates obtained from the analysis apply to those genotypes alone. In an analysis based on this model, one is concerned with comparisons of the combining abilities of the actual parents used in the experiment with the identification of superior combinations (Baker, 1978). In model II (random model), the parents are assumed to be an unselected sample from some reference population. For an analysis based on random model, inferences are made about the population from which the parents were sampled and the inferences are made from estimates of components of variance (Baker, 1978; Hallauer and Miranda, 1988). Diallel analysis of cross-pollinated populations is used to study the genetic control of quantitative traits (Hayman, 1958), to assess general and specific combining abilities (Griffing, 1956) and perform heterosis analysis (Gardner, 1967).

Combining ability is the ability of parents or cultivars to combine amongst each other during hybridization so that favorable gene expressions are transmitted to their progenies. Combining ability is of two types: general and specific combining ability. General combining ability (GCA) is the average performance of a line in hybrid combinations, while specific combining ability (SCA) is the performance of a hybrid compared to the average performance of the parent-inbred lines of the hybrid (Sprague and Tatum, 1942). The performance of a hybrid is related to the general combining ability (GCA) and specific combining abilities (SCA) of the inbred lines involved in the cross. At the gene action level, GCA is associated with additive effects of the genes, while SCA is related to dominance and epistatic effects (non-additive

effects) of the genes. Combining ability plays an important role in selecting superior parents for hybrid combinations and in studying the nature of genetic variation (Koutsika-Sotiriou, 1999). General combining ability effect is an indicator of the relative value of the lines and their parental populations in terms of frequency of favorable genes and of its divergence, as compared to the other parents in the diallel. Thus, the analysis of GCA allows identification of superior parents, to be used in intra-population breeding programs. The SCA effect of two populations expresses the differences of gene frequencies between them and their divergence, as compared to the diallel parents. Therefore, the GCA and SCA effects should be considered in the selection of populations for hybrid production and for reciprocal recurrent selection programs.

Pixley and Bjarnason (1993) evaluated QPM inbred lines across four locations and reported that GCA effects across locations were significant for grain yield, protein concentration in grain and tryptophan concentration in grain. Bhatnagar *et al.* (2004) evaluated QPM hybrids in diallel experiments across 5 southern US environments and reported that GCA effects were non-significant for grain yield but highly significant for agronomic and kernel traits. Betrán *et al.* (2003b) evaluated inbred lines in 12 stress and non-stress environments and reported an increase in SCA variance under non-stressed conditions indicating a better expression of effects related to heterosis.

Vasal *et al.* (1993) evaluated 10 QPM parents in a diallel study across five environments and reported that GCA effects were highly significant for grain yield, time to silk, and endosperm hardness while SCA effects were highly significant for time to silk. Dhiliwayo *et al.* (2005)

studied the combining ability for resistance to maize weevil among 14 Southern African maize inbred lines using a diallel at four locations in Zimbabwe. These workers reported that GCA was more important than SCA for grain yield and thus indicating that grain yield was controlled mainly by additive gene action among these lines. Their results suggested that inbred lines with good GCA for weevil resistance should be used as female parents for hybrids or open pollinated cultivars for regions where farmers often store maize grain without chemical protection against weevils.

Giridharan *et al.* (1996) in a diallel study with maize inbred lines reported that grain yield was controlled by both additive and non-additive gene. Velasquez *et al.* (1996) performed diallel analysis on five elite maize inbred and concluded that number of kernels per row was controlled by additive type of gene action, while number of kernel rows per ear, 100-grain weight and grain yield per plant were conditioned by over dominance gene action. A study by Dutu (1999) showed that additive gene action was predominant in the inheritance of grain yield. In a complete set of diallel involving 6 inbred lines, Saleem *et al.* (2002) reported that number of days to tasseling, number of days to silking, number of kernel rows per ear, number of kernels per row, 100-grain weight and grain yield per plant were controlled by over dominance type of gene action, while number of days to silking showed partial dominance.

2.4 Line by tester analysis

The design is an extension of top cross analysis in the sense that instead of one tester as used in top crossing; more than one tester are employed under line by tester mating design (Kempthorne, 1957). Line x tester analysis is used to select the parental material for

hybridization from the germplasm and to identify their genetic worth. This mating design provides information about the general and specific combining ability of parents and estimates of other genetic parameters (Saleem *et al.*, 2009).

The mating plan involves “*l*” lines and “*t*” testers. All the “*l*” lines are crossed to each of the “*t*” testers and thus, “*l*” x “*t*” full-sib progenies are produced. Generally the lines are used as females and testers as male parents (Sharma, 1998). These progenies resulting from line x tester mating, along with or without the parents, can be tested in a replicated trial using a suitable field design (Singh and Choudhury, 1985).

A minimum of two tester parents are normally used as pollen source (males) in developing line by tester hybrids. The choice of a suitable tester should be based on simplicity in its use; its ability to classify the relative merit of lines, maximize genetic gain, and enhance the expected mean yield of a population generated using selected cultivars (Matzinger, 1953; Rawlings and Thompson, 1962; Allison and Curnow, 1966, Hallauer, 1975; Hallauer and Miranda, 1988; Russell *et al.*, 1992, Menz *et al.*, 1999).

Heterotic

A line by tester analysis including 23 partially inbred lines (s_2 to s_4) derived from seven late white CIMMYT populations and crossed to 4 synthetic testers was done to estimate the combining ability of the 23 inbred lines (Vasal *et al.*, 1999). Result showed that 12 lines had a positive GCA while across environments, 10 lines had positive and significant SCA effect for grain yield. Narrow *et al.* (2003) reported highly significant differences for line x tester and line x tester x environment interaction for grain yield indicating different response of top crosses across environments. Thus, top cross performance is not only a consequence of gamete segregation and recombination but also of the environmental effect where cultivars are

evaluated. Süleyman and Akgüni, (2007) using the line by tester mating design in wheat reported that grain yield per plant and most of the other studied traits were under control of non-additive gene effects. It was further reported by Akbar *et al.* (1997) that number of tillers per plant and spikelets per spike were controlled by additive type of gene action. In another study Singh *et al.* (2000) evaluated some breeding material using line by tester mating design and on analyzing their combining ability for number of grains per spike, 100-grain weight and grain yield per plant in bread wheat. The magnitude of additive genetic variance was higher than that of non-additive variance for all traits studied.

2.5 Heterotic grouping in maize germplasm

In hybrid breeding, classifying maize inbred lines into heterotic groups is the initial step in a maize breeding program, which would provide maximum exploitation of heterosis.

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 and heterotic response when crossed with genotypes from other genetically distinct germplasm groups. Heterotic groups are formed by isolation and selection (natural or human) for adaptedness over time and are critical in maximizing the expression of heterosis in hybrids (Pawali, 2000). It is commonly assumed that the combination of lines of different heterotic groups results in hybrids with higher chances of genetic expression of the target effects of hybridization (Troyer, 1999; Austin *et al.*, 2000; Birchler *et al.*, 2003; Tollenaar *et al.*, 2004; Ricci *et al.*, 2007).

The International Maize and Wheat Improvement Center (CIMMYT) has played an important role in maize breeding in tropical and subtropical regions. CIMMYT's breeding efforts in the early 1960s and 1970s were focused on intra-population improvement via recurrent selection. Therefore, more than 100 populations and 30 genetically broad-based backup pools were established disregarding known racial complexes (Vasal *et al.*, 1999).

Vasal *et al.* (1992) identified and formed two divergent tropical heterotic groups namely; tropical heterotic group A and tropical heterotic group B. In this study, lines that showed negative SCA with Tester 1 "Pop 21" (Tuxpeno-1) and positive SCA with Tester 3 "Pop 25" (Blanco Cristalino) were classified under tropical heterotic group "A". Those showing positive SCA with Tester 1 and negative with Tester 3 were classified under tropical heterotic group "B". Results from CIMMYT-Zimbabwe's regional trials conducted over several years, single cross testers CML312/CML442 (group A) and CML395/CML444 (group B) have proved useful in hybrid formation for subtropical and mid altitude environments and are currently in wide use. These single crosses are intermediate and late maturing respectively (Pswarayi and Vivek, 2007).

Some authors have demonstrated the efficiency of the identification of heterotic groups of maize lines using molecular procedures such as restriction fragment length polymorphism (RFLPs) (Warburton *et al.*, 2005). Conventional methods have also been used whereby testers are used to classify the performance of inbred lines by evaluating their combining abilities and defining their heterotic groups and patterns. Different types of testers have been used. When parental varieties are used as testers, they result in improved performance of the mean population (Rawlings and Thomson, 1962). Single crosses are also used as testers (Horner *et*

al., 1976). However inbred line testers are most commonly used in recurrent selection programs (Russell and Eberhart, 1975).

Fan *et al* (2009) classified 23 maize inbred lines into heterotic groups using four testers. He reported that using heterotic group's specific and general combining ability (HSGCA) increased maize breeding efficiency by 16.7% to 23.6% compared with simple sequence repeat (SSR) and specific combining ability combined with line pedigree and hybrid yield information (SCA-PY) methods, respectively. The HSGCA method could explain more variation in maize hybrid yield and produce more predictable yield information to the other two methods. He concluded that HSGCA method is superior to SSR and SCA-PY method in that it includes both GCA and SCA effect in assigning an unknown maize line to a known heterotic group. Riboniesa and Efren (2008) classified 11 inbred lines into heterotic groups using 2 testers representing the dent and flint heterotic pattern using SCA effects and test crosses mean grain yield. They reported highly significant GCA and SCA effects for grain yield among the inbred lines.

CHAPTER 3

GENETIC ANALYSIS OF AGRONOMIC TRAITS IN EARLY MATURING QUALITY PROTEIN MAIZE GERMPLASM UNDER STRESS AND NON-STRESS CONDITIONS

ABSTRACT

Development of early maturing quality protein maize (QPM) inbred lines have been developed and there have been efforts to develop early maturing QPM varieties that can yield relatively well under well-watered, water limited and low soil fertility (low N) conditions has been undertaken. From these efforts QPM inbred lines have been developed at CIMMYT. Information on combining ability and heterotic groups of these inbred lines is very crucial in developing high yielding hybrids. The aim of this study was to evaluate the performance of the hybrids in different conditions, to establish both the general combining ability (GCA) and specific combining ability (SCA) effects of the inbred lines and to determine phenotypic correlations between grain yield and other agronomic traits in the F₁ hybrids.

A diallel analysis of 13 QPM inbred lines under well-watered, random drought, managed drought and low nitrogen conditions was conducted. From the diallel, 78 F₁ hybrids were produced as $[n(n-1)]/2$; where n = number of inbred lines. These hybrids plus two checks (H513 (commercial hybrid) and CML144/159) formed a trial of 80 entries. The hybrids were evaluated in field trials during the April and October of 2009 at four locations: Embu, Kakamega, Kiboko (in Kenya) and Namulonge (in Uganda). Inbred line 1 and 2 had high, positive and significant ($P < 0.05$) GCA effects for grain yield under all well-watered conditions and managed drought stress, suggesting that these inbred lines have the potential to

be used as parents for developing good hybrids for well-watered conditions as well as drought-stressed environments. Entry 42, a hybrid between P4 x P13, was consistent in its top performance under test conditions. Phenotypic correlations between grain yield across well-watered conditions were positive and significant ($P < 0.001$) for days to anthesis, plant height and ear height. However, correlations between grain yield and anthesis silking-interval and ears per plant across well-watered conditions were non significant indicating that these traits are less useful under adequate moisture conditions. Under low nitrogen, managed and random drought conditions, correlations between grain yield and ears per plant were positive and significant ($P < 0.05$) while correlations between grain yield and anthesis-silking interval were negative and significant ($P < 0.001$). Under the three stress conditions, the correlation between anthesis silking interval and ears per plant was negative and significant ($P < 0.05$) indicating that a reduced anthesis-silking interval resulted in an increased number of ears under stress conditions.

3.1 Introduction

Drought and low soil fertility are among the most important stresses threatening maize production, food security and economic growth in Southern and Eastern Africa. Yield loss to drought in lowland tropical environments averaged 17% (Edmeades *et al.*, 1992), and reached 60% in severely drought affected regions (Rosen and Scott, 1992). Farmers in drought prone areas often reduce N fertilizer application (Mc Cown *et al.*, 1992). Low N and drought can result in average maize yield of only 1-2 t ha⁻¹ in developing countries (CIMMYT, 1994) compared to reported yields from research stations in the same countries of 4-12 t ha⁻¹ (CIMMYT 1995, 1996).

2000)

Drought has been estimated to cause annual maize yield loss of 24 million tons in the developing world (Edmeades *et al.*, 1992). Drought affects maize yields by restricting season length and through unpredictable stress that occur at any time during the cropping cycle but mostly during flowering (Saini and Westgate, 2000). Current breeding efforts have focused on improving tolerance to drought at flowering. By evaluating maize that is moisture stressed during flowering, it is possible to identify maize genotypes capable of maintaining a short anthesis-silking interval, and achieving above average grain yield. This approach is routinely used by CIMMYT to improve and develop drought tolerant maize populations, inbred lines and hybrids (Bänziger, 2000). The choice of a selection strategy is crucial when breeding for drought stress tolerance. Selection for drought avoidance or escape through earlier maturity can play a deciding role in whether a crop will yield anything, particularly in areas that have a very short growing season. Early maturity allows the crop to escape terminal drought, it may also avoid coincidence between flowering and a mid season dry spell, which often affects maize in the tropics. However, given adequate rainfall, yield is usually positively correlated with late maturity in determinate annual crops such as maize, sorghum and sunflower (Edmeades *et al.*, 1989), and therefore, earliness continues to carry a yield penalty when rainfall levels are above average (Bänziger *et al.*, 2000).

ability (SCA)

Low soil fertility is a major limiting factor in maize production in Eastern Africa as farmers rarely apply nitrogen fertilizers in their maize crop. Use of nitrogen fertilizers is constrained by high cost and lack of credit faced by small scale farmers. Kenya is one of the countries with low fertilizer application rates of 34 kg ha⁻¹ compared with ideal rates of 200kg ha⁻¹ (Pingali,

2000). Nitrogen use efficient varieties are estimated to increase the average maize yield from 1.2 to 1.5 t ha⁻¹ (Pingali, 2001).

Breeding strategies to develop stress tolerant maize inbred lines include screening and selection of inbreds under managed stress conditions, and multi-location testing of progenies in a representative sample of the target environments (Beck *et al.*, 1996). The CIMMYT maize breeding program has improved yields of maize under drought stress (Edmeades *et al.*, 1997, 1999) and low soil fertility (reduced soil nitrogen) conditions (Bänziger *et al.*, 1997, 1999). Improved performance under low N stress in germplasm selected for drought tolerance was reported by Bänziger *et al.* (2002). Their results showed that decreased ear abortion and increased assimilate supply during grain filling in maize germplasm selected for drought provide tolerance to low nitrogen stress.

Information about combining ability of experimental breeding materials is imperative to a breeding program aiming to develop high yielding hybrids and composite varieties. Such information can indicate the type of gene action involved in controlling quantitative characters, thereby assisting breeders in selecting suitable parent materials (Hallauer and Miranda, 1988). Significant values for general combining ability (GCA) and specific combining ability (SCA) may be interpreted as indicating the performance of additive and non-additive gene action, respectively (Sprague and Tatum, 1942). General combining ability enables breeders to exploit the existing variability in the breeding materials, to identify individual genotypes conferring desirable attributes and to distinguish relatedness among genotypes (Melani and Carena, 2005). Specific combining ability helps to determine heterotic patterns

among populations or inbred lines, to identify promising single crosses and to assign inbred lines into heterotic groups (Vasal *et al.*, 1992; Hede *et al.*, 1999; Parentoni *et al.*, 2001; Revilla *et al.*, 2002). Combining ability studies aiming to identify inbred lines with good GCA and SCA effects rely on the availability of genetic diversity among groups of genotypes involved in a breeding program.

A highlight

Development of maize germplasm tolerant to drought and low nitrogen stress is crucial if productivity of maize based farming system is to be sustained or increased. Promising early maturing quality protein maize inbred lines that can be utilized for the formation of QPM hybrids are available, but their combining abilities, heterotic groups and performance under stress and non-stress conditions are unknown. Several countries in sub-Saharan Africa will benefit from this germplasm by developing hybrids, synthetics and/or open pollinated varieties in their breeding programs in a bid to reduce malnutrition and improve self sufficiency in food production. The objectives of this study were to (i) estimate the general combining ability (GCA) effects of 13 QPM inbred lines under stress and non-stress conditions, (ii) estimate specific combining ability (SCA) effects and identify -the best QPM hybrids under stressed and non-stressed conditions, and (iii) determine phenotypic correlations between grain yield and other agronomic traits in the F₁ hybrids.

P5	...
P6	...
P7	...
P8	...
P9	...
P10	...
P11	...
P12	...
P13	...

Source: Data

3.2 Materials and methods

3.2.1 Pollination and hybrid generation

Thirteen QPM inbred lines developed at CIMMYT were used in this study (Table 3.1). Selection of these inbred lines was based on top cross performance, protein quality, and good kernel modification.

A highly significant correlation of $r=0.85$ between lysine and tryptophan content in quality protein maize has been obtained (Hernandez and Bates, 1969). On the basis of this result, it was recommended that the more rapid simpler tryptophan method be adopted in protein laboratories and that the co-variate lysine be estimated indirectly from the regression equation $Y=0.3601+4.0745X$, where Y and X represent the lysine and tryptophan content, respectively. Consequently, this method, with minor modifications, has been adopted by CIMMYT. For the lines used in this study, only the tryptophan content for the 13 lines was analyzed in the laboratory and the percentage content is presented in Table 3.1 (D. Makumbi, personal communication).

Table 3.1 Quality protein maize inbred lines used in the study

Parents	Pedigree	Typtophan %
P1	CML216/CML144//CML159//POOL15QPMSR-B-32-B-3-B	0.063
P2	CML312/CML144//CML159//POOL15QPMSR-B-16-B-B-B	0.078
P3	CML390/CML144//CML159//POOL15QPMSR-B-28-B-B-B	0.061
P4	LLSYNTH1/PL15QPMC7SRC1F2//POOL15QPMSR-B-17-B-B-B	0.077
P5	ECA-MOROSR(BC1)F2-6-ECAVEE6/PL15QPMC7SRC1F2//POOL15QPMSR-B-97-B-B-B	0.076
P6	LLSYNTH1/PL15QPMC7SRC1F2//POOL15QPMSR-B-1-B-B-B	0.076
P7	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-82-B-B-B	0.076
P8	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-52-B-B-B	0.074
P9	CML389/CML144//CML159//POOL15QPMSR-B-59-B-B-B	0.071
P10	ECA-MOROSR(BC1)F2-6-ECAVEE6/PL15QPMC7SRC1F2//POOL15QPMSR-B-35-B-B-B	0.069
P11	CML444/CML144//CML159//POOL15QPMSR-B-41-B-B-B	0.069
P12	Pool15QPMFS462-B-4-B-#-B-B-B	0.111
P13	Pool15QPMFS538-B-3-B-B-B-B-B	0.072

Source: Dan Makumbi, personal communication

The nursery for making the crosses was planted in December 2008 at KARI Kiboko Research Center (Table 3.2). The plots were 4 m long, 0.75 m between rows and 0.20 m between hills. Regent[®] 5g (active ingredient: Fipronil) was also applied before planting to control soil, germination and seedling pests. Five grams of Diammonium phosphate (DAP, 18:46:0) was applied at planting. Two seeds were planted per hill and later thinned to one plant per hill two weeks after emergence. An insecticide (Bulldock[®] active ingredient: Beta Cyfluphrin) was applied at 3 and 6 weeks after planting to control stem borers at Kiboko. Calcium Ammonium Nitrate (CAN) was top dressed four weeks after emergence. The nurseries were kept free from weeds by hand weeding to avoid unnecessary competition for nutrients.

The 13 inbred lines were crossed in a diallel mating design. Prior to initiation of flowering, the inbred lines were checked daily for signs of ear shoot emergence and pollen shed. Before the silks emerged, all shoots were covered with a shoot bag to avoid unwanted pollination. Tassels to be used as pollen sources were covered with a tassel bag to prevent foreign pollen from landing on the anthers a day before the pollen was to be used. On the day of pollination, pollen from plants in the same row was bulked and used to pollinate female parents whose silks had emerged. This was carried out very carefully to avoid contamination. Each inbred line was used both as female and male parent. Each pollinated ear was covered with a tassel bag until harvest. At harvest, selection was done for the best ears with viable seeds and showing no signs of ear rots. Seeds from each reciprocal cross were bulked to form a set of 78 F₁ hybrids as $n(n-1)/2 = 78$ where n = number of parents. This is method 4 of Griffing (1956), whereby only the F₁ hybrids are produced and evaluated.

3.2.2 Field evaluation of F₁ hybrids

The 78 F₁ hybrids, one experimental QPM single cross hybrid, and a commercial check were included in the trial. The trial was evaluated during the long rains and short rains of 2009 at Kiboko, Embu, Kakamega, and Namulonge (Table 3.2). The hybrids were evaluated under four growing conditions: well-watered, managed drought stress, random drought stress, and low nitrogen stress. Under well watered conditions trials were grown under rain fed conditions in Embu and Kakamega, and under irrigation in Kiboko. The moisture was sufficient throughout the growing season. For this sites, standard agronomic practices recommended in maize production were applied. At all locations, land was prepared by ploughing and harrowing followed by application of diammonium phosphate (DAP, 18:46:0) at a rate of 27 Kg N ha⁻¹ and 60 Kg P ha⁻¹. All experiments were planted using the alpha (0, 1) lattice design (Patterson and Williams, 1976) with two replicates of one row plot at each location. Incomplete blocks each comprising of eight plots giving ten blocks per replication were laid. The experimental unit was a 4 m row plot with inter row and intra row spacing of 0.75 m and 0.20 m respectively for the three trials in Kiboko, 5 m row plot with inter row spacing of 0.75 m for all trials and intra row spacing of 0.25 m, 0.30 m and 0.25 m in Kakamega, Namulonge and Embu respectively. Two seeds were planted per hill and later thinned to one plant per hill two weeks after emergence. . A second dose of 60 kg ha⁻¹ was side dressed as Calcium Ammonium Nitrate (CAN) four weeks after emergence.

The low N trial was planted at Kiboko in a managed low nitrogen stress block. The low nitrogen field had been depleted off nitrogen by growing unfertilized maize continuously removing crop biomass after each season for a minimum of 5 years (Worku *et al.*, 2007). This

was continued until yield of normal genotypes, not improved for either low nitrogen stress, averaged between 25 and 30% of the well fertilized field. In this trial no nitrogen fertilizer was applied (Bänziger *et al.*, 2000, Worku *et al.*, 2007). The land was ploughed and harrowed to loosen the soil. Planting, spacing, weeding and control of maize stalk borer were as under well watered condition in Kiboko. At harvest, the ears from plants at each side of the plot were discarded because of the border effect

The managed drought stress experiment was carried out at Kiboko during the dry season (June-October) which is rain free thus allowing for the control of drought stress by withdrawing irrigation water during and after flowering. Irrigation was applied at the beginning of the season to establish good plant stands. Afterwards drought stress was achieved by withdrawing irrigation water during two weeks before flowering until the end of the flowering period and throughout the grain filling stage. The land was ploughed and harrowed to loosen the soil. Planting, spacing, fertilizer application weeding and control of maize stalk borer were as under well watered condition in Kiboko. At harvest, the ears from plants at each side of the plot were discarded because of the border effect

Table 3. 2 Locations used to evaluate the F₁ hybrids

Site	Country	Longitude	Latitude	Elevation m asl †	Annual Rainfall (mm)	Soil type	Management
Kiboko	Kenya	36.37° E	3.18° S	975	530	Sandy clay	M DRT, L N, WW
Embu	Kenya	37.41° E	0.45° S	1480	1200-1500	Clay loam	WW
Kakamega	Kenya	34.45° E	0.16° N	1585	1995	Sandy loam	WW
Namulonge	Uganda	34.04° E	0.32° N	1150	1500	Sandy clay	R DRT

†m asl: meters above sea level; mm: millimeters; M DRT: Managed drought; R DRT: Random drought; L N: Low nitrogen; WW: Well-watered.

The choice of the experimental site was based on their unique ecological locations that represent some of the most common smallholder farming systems in East Africa.

3.2.3 Field measurements for agronomic traits

Under both well-watered and drought conditions, data were recorded for grain yield and other agronomic traits. Grain yield in tons ha⁻¹ was calculated using grain weight at harvest adjusted to 12.5% moisture content using the formula:

$$(Field\ weight/1000) * [(100-moisture\ content)/87.5 * (10/plot\ area)] * shelling\ percentage.$$

Data were recorded for the following traits:

1. Days to silking: day from planting to 50% extruded silks.
2. Anthesis date: number of days after planting when 50% of the plants shed pollen.
3. Plant height: Measured as height from the base of a plant to the first tassel branch of the same plant.
4. Ear height: height between the base of the plant to the insertion of the top ear of the same plant.
5. Root lodging: percentage of plants leaning at an angle >30° from the vertical.
6. Stalk lodging: percentage of plants with broken stalks at or below the main ear at maturity.
7. Husk cover: measured as percentage of plants with ears that are not completely covered by the husks.
8. Ear rots: percentage of ears that is rotten.

9. Ears per plant: number of ears with at least one fully developed grain divided by the number of harvested plants.

10. Ear aspect on a scale (1-5), 1= nice and uniform cobs with the preferred texture in the area; 5= ugly cobs with the undesirable texture in the area.

During the grain filling period, disease severity was rated for northern leaf blight (*Exserohilum turcicum*) and gray leaf spot (*Cercospora zeaе maydis*) on a 1-5 scale (1= clean, no infection to 5= severely diseased).

Under managed drought stress, leaf senescence and leaf rolling were scored. Leaf senescence, scored on a scale of 1-10 was taken during grain filling by estimating the percentage of dead leaf area and dividing it by 10; where 1=10% dead leaf area, 10=100% dead leaf area. Leaf rolling score was taken on a scale of 1 (unrolled, turgid leaves, desirable) to 5 (severely rolled leaves, undesirable) (Bänziger *et al.*, 2000).

3.2.4 Data analysis

Analysis of variance for each location and across well-watered environments was carried out using PROC GLM procedure of SAS (SAS, 2003). Adjusted entry means were computed using the PROC MIXED procedure of SAS (SAS, 2003) considering entries as fixed, with replications and blocks within replicates as random factors. Mean squares for grain yield were adjusted for anthesis date in the trial under managed drought stress. Entry means were separated using the least significant difference (LSD) method. The adjusted means were used to compute the phenotypic correlations between the traits.

For diallel analysis, the experimental single cross hybrids were excluded.

Combining ability analysis was carried out according to the following linear model:

$$X_{ijk} = \mu + r_k + g_i + g_j + s_{ij} + e_{ijk}$$

where X_{ijk} is the observed performance of the cross between i^{th} and j^{th} parents in the k^{th} replication, μ = the population mean, r_k = the replication effect, g_i = the GCA effect for the i^{th} parent, g_j = the GCA effect for the j^{th} parent, s_{ij} = the SCA effect for the cross between i^{th} and j^{th} parents, and e_{ijk} = the experimental error for the X_{ijk} observation (Hallauer and Miranda, 1988). General combining ability effects of the parents and Specific combining ability effects of the crosses, as well as their mean squares at each environment and across environment, were estimated following Griffing's method 4 model 1 (Griffing, 1956) using the DIALLEL-SAS05 program (Zhang *et al.*, 2005).

3.3 Results and discussion

3.3.1 Analysis of variance for grain yield and agronomic traits at individual sites

At Kakamega, significant mean squares ($P < 0.05$) were observed among all entries for all traits except ear rots (Table 3.3). Under well-watered conditions at Embu, highly significant mean squares ($P < 0.05$) were observed among the genotypes and F_1 hybrids for all traits except ears per plant, ear rots, root lodging and stem lodging (Table 3.4). At Kiboko, significant differences ($P < 0.05$) were observed among the genotypes for all traits except stem lodging (Table 3.5).

The analysis of variance for grain yield and other agronomic traits at Namulonge presented in Table 3.6 showed significant differences ($P < 0.05$) among the genotypes for all the traits except grain yield, ear aspect and ears per plant. This is similar to the work of Makumbi *et al.*, 2010 who reported that no significant differences were observed among hybrids across drought stress conditions. Under managed drought stress, genotypes mean squares were significantly different ($P < 0.05$) for all traits except ears per plant and root lodging implying variation for these traits among these entries (Table 3.7).

Variance due to genotypes and F₁ hybrids was significant for all traits except ear rots and root lodging under low nitrogen stress at Kiboko (Table 3.8). This is an indication that maize performs differently under low nitrogen due to the existence of genetic variability for the tolerance to nitrogen stress (Dencic *et al.*, 2000; Diallo *et al.*, 2004)

Variation within and between QPM genotypes has been reported (Vasal *et al.*, 1993 a,b; Bhatnagar *et al.*, 2004). These significant differences at the individual sites indicated that there was variation in performance between the genotypes and hybrids under different stresses for the above mentioned traits.

Table 3. 3 Analysis of variance for grain yield and agronomic traits under well-watered conditions at Kakamega

SOURCE	df	GY† t ha ⁻¹	MEAN SQUARES												
			AD days	SD days	ASI days	PH cm	EH cm	RL %	SL %	EPP #	HC %	ER %	ET 1-5	EA 1-5	PA 1-5
REP	1	0.15	1.60	0.63	4.23	26.41	100.81	585.23*	0.63	0.03	178.93	22.58	0.76***	0.26	0.03
GENOTYPES	79	5.46***	11.81***	12.54***	3.76**	447.98***	452.32***	738.46***	16.21**	0.03***	361.58***	10.36	0.47***	0.37***	0.47***
F1 HYBRIDS	77	5.02**	9.66***	10.60***	3.83*	418.92*	451.63***	755.43***	16.52**	0.03***	366.80***	10.60	0.462***	0.345***	0.468**
GCA	12	11.80***	30.20***	48.65***	10.31***	1415.33***	1726.91***	3012.67***	20.01**	0.077***	951.70***	27.18**	2.119***	1.454***	0.562**
SCA	65	3.76*	4.21*	3.58***	2.63	234.97	216.19	338.71**	15.88**	0.02**	258.82***	7.53	0.156***	0.14	0.451**
ERROR	79	2.39	2.54	2.26	1.97	260.51	162.26	184.41	8.02	0.01	96.68	9.34	0.06	0.11	0.22

†GY: Grain Yield; AD: Anthesis Date; SD: Silking Date; ASI: Anthesis-silking Interval; PH: Plant Height; EH: Ear Height; RL: Root Lodging; SL: Stem Lodging; EPP: Ears per Plant; HC: Husk Cover; ER: Ear Rot; ET: *E. Turcicum*; EA: Ear Aspect; PA: Plant Aspect

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

Table 3. 4 Analysis of variance for grain yield and agronomic traits under well watered conditions at Embu

SOURCE	df	GY† t ha ⁻¹	MEAN SQUARES												
			SD days	AD days	ASI days	EPP #	PH cm	EH cm	ER %	ET 1-5	HC %	PA 1-5	EA 1-5	RL %	SL %
REP	1	68.78***	0.63	0.01	0.51	0.06*	7636.93***	532.90*	33.95*	0.13*	164.63*	0.45*	20.66***	2100.33***	39.10
GENOTYPES	79	2.30***	10.63***	9.16***	2.65**	0.01	459.77**	252.95***	9.58	0.03**	147.14***	0.48***	0.37***	185.21	29.91
F1 HYBRIDS	77	2.14**	10.23***	8.85***	2.63**	0.01	430.25**	288.90***	9.68	0.03*	149.87***	0.43***	0.35**	187.69	30.38
GCA	12	6.24***	47.36***	45.91***	6.27**	0.01	1624.82***	1124.54***	25.02**	0.05*	313.38***	2.11***	0.78***	394.01**	30.83*
SCA	65	1.38	2.10*	2.01*	1.97**	0.01	209.72	63.55	6.85	0.03*	119.69***	0.12	0.26*	149.60	28.83
ERROR	79	1.08	1.15	1.28	1.43	0.01	237.25	76.68	9.81	0.02	52.86	0.10	0.17	147.28	22.85

†GY: Grain yield; SD: Silking Date; AD: Anthesis Date; ASI: Anthesis-silking Interval; EPP: Ears per Plant; PH: Plant Height; EH: Ear Height; ER: Ear rot; ET: *E. Turcicum*; HC: Husk Cover; PA: Plant Aspect; EA: Ear Aspect; RL: Root Lodging; SL: Stem Lodging

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

Table 3. 5 Analysis of variance for grain yield and agronomic traits under well watered conditions at Kiboko

SOURCE	Df	MEAN SQUARES													
		GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	ER %	RL %	SL %	HC %	PA 1-5	EA 1-5	
REP	1	1.90	27.23***	32.40***	0.23	0.002	119.03	169.13*	5.18	152.88	10.25	373.02*	0.09	0.01	
GENOTYPES	79	3.53***	7.02***	7.52***	1.68*	0.01*	396.42***	438.00***	15.59*	173.97**	4.82	390.63***	0.84***	0.39***	
F1 HYBRIDS	77	3.40***	5.61***	22.07	1.67*	0.01*	366.79***	418.17***	15.88*	177.95**	4.82	397.66***	0.82***	0.39***	
GCA	12	15.05***	23.48***	43.72*	6.66***	0.01	1593.28***	2201.8***	21.58*	316.45***	5.30	1174.02***	3.51***	1.80***	
SCA	65	1.26*	2.31	18.07	0.75	0.01*	140.36**	88.90***	14.83*	152.38*	4.73	254.33***	0.32***	0.13	
ERROR	79	0.73	1.59	1.59	1.00	0.01	177.01	39.83	0.13	96.36	4.98	64.12	0.13	0.13	

† GY: Grain yield; SD: Silking Date; AD: Anthesis Date; ASI: Anthesis-silking Interval; EPP: Ears per plant; PH: Plant Height; EH: Ear Height; ER: Ear rot; RL: Root Lodging; SL: Stem Lodging; HC: Husk Cover; PA: Plant Aspect; EA: Ear Aspect

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

Table 3. 6 Analysis of variance for grain yield and agronomic traits under random drought stress at Namulonge

SOURCE	Df	MEAN SQUARES													
		GY† t ha ⁻¹	SD days	AD days	ASI Days	EPP #	EH cm	PH Cm	ER %	ET 1-5	HC %	EA 1-5	PA 1-5		
REP	1	13.98***	532.90***	313.60***	28.90***	0.04	4141.23***	15563.03***	9.75	19.95***	11.29	9.75***	0.23		
GENOTYPES	79	0.60	49.58***	20.36**	14.27**	0.06	349.10**	840.48***	124.74*	0.13*	266.36***	0.80	0.29*		
F1 HYBRIDS	77	0.57	40.50	16.51*	13.27***	0.05	346.42**	833.11***	126.88*	0.13*	269.64***	0.75	0.28*		
GCA	12	0.74	102.44***	34.31***	41.53***	0.09*	839.77***	2254.45***	138.80*	0.34***	586.71***	1.09	0.61***		
SCA	65	0.54	29.07*	13.22	8.05	0.04	255.33	570.71*	124.68*	0.09	211.10*	0.69	0.22		
ERROR	79	0.49	20.86	10.12	7.91	0.06	204.43	394.58	80.55	0.08	126.36	0.69	0.18		

† GY: Grain yield; SD: Silking Date; AD: Anthesis date; ASI: Anthesis-silking Interval; EPP: Ears per plant; EH: Ear Height; PH: Plant Height; ER: Ear rot; ET: *E. turcicum*; HC: Husk Cover; EA: Ear Aspect; PA: Plant Aspect

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

Table 3. 7 Analysis of variance for grain yield and agronomic traits under managed drought at Kiboko

SOURCE	Df	GY† t ha ⁻¹	MEAN SQUARES										
			SD days	AD days	ASI Days	EPP #	PH cm	EH Cm	SL %	RL %	HC %	SEN 1-10	EA 1-5
REP	1	19.81***	60.03**	11.03***	19.60*	0.66***	220.90	89.25	1249.37*	2.05	87.91*	0.14***	7.23***
GENOTYPES	79	0.84*	25.31***	8.13***	13.79***	0.06	375.40***	254.69***	447.27**	10.77	49.63***	0.02*	0.52**
F1 HYBRID	77	0.81*	18.01***	5.5***	15.56***	0.06	368.52***	242.29***	450.50**	9.64	50.70***	1.52*	0.49**
GCA	65	2.72**	73.86***	23.92***	65.87***	0.13**	1581.04***	1254.38***	1324.02***	11.83	155.47***	3.96***	1.66***
SCA	12	0.84	7.70*	2.10**	6.27	0.05	144.66	55.44	289.23	9.23	31.35*	1.07	0.27
ERROR	79	0.89	5.84	0.89	5.22	0.05	145.88	51.99	249.97	12.45	20.18	0.01	0.29

†GY: Grain yield; SD; Silking Date; AD: Anthesis date; ASI: Anthesis-silking Interval; EPP: Ears per plant; PH: Plant Height; EH: Ear Height; SL: Stem Lodging; RL: Root Lodging; HC: Husk Cover; SEN: Senescence; EA: Ear Aspect

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

Table 3. 8 Analysis of variance for grain yield and agronomic traits under low nitrogen at Kiboko

SOURCE	df	GY† t ha ⁻¹	MEAN SQUARES												
			SD days	ASI days	AD days	EA 1-5	EH cm	EPP #	ER %	HC %	PH cm	RL %	SL %		
REP	1	0.14	104.73**	40.53*	18.23***	0.10	718.26***	0.01	0.96	216.46*	184.9	16.26*	0.02		
GENOTYPES	79	0.86***	78	34.02***	25.94***	79	7.89***	0.43**	203.27***	0.04***	12.39	209.03***	450.35***	3.73	13.31*
F1HYBRID	77	0.87***	76	33.16***	32.00***	77	9.70***	0.43**	201.84***	0.04***	12.64	212.53***	447.93***	3.82	13.52*
GCA	12	3.18***	12	23.48*	32.79*	12	32.79***	1.04***	999.73***	0.12***	151.47	612.86***	2169.47***	3.56	31.37***
SCA	65	0.44	65	2.310***	5.44	65	5.44*	0.32*	54.53*	0.03*	821.54	138.63*	130.10*	3.87	10.22
ERROR	79	0.35	76	12.63	10.00	79	1.12	31.99	0.02	10.71	76.04	79.69	3.95	8.94	

†GY: Grain yield; SD; Silking Date; ASI: Anthesis-silking Interval; AD: Anthesis date; EA: Ear Aspect; EH: Ear Height; EPP: Ears Per Plant; ER: Ear rots; HC: Husk Cover; PH: Plant height; RL: Root Lodging; SL: Stem Lodging.

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

3.3.2 Performance of hybrids under well-watered conditions

The mean yields for the trials at well-watered sites were 8.63, 5.74, and 8.87 t ha⁻¹ for Kakamega, Embu, and Kiboko, respectively (Tables 3.9, 3.10, 3.11). The highest yielding entries at the three well-watered sites were entries 21, 42, 1, 12, 18 and 78. These hybrids have the ability to perform remarkably well under well watered conditions and should be investigated for further breeding work. Lower yields in Embu compared to other well-watered sites could have been due to reduced rainfall at this site during grain filling. High yields in Kakamega could be attributed to high rainfall experienced during the season leading to proper synchronization of male and female flowering (short anthesis-silking interval) and high prolificacy displayed by the hybrids at this site. At Kiboko, there was adequate irrigation water supplied and hence synchronization between male and female flowering. Hybrids at Kiboko flowered earlier than in Kakamega and Embu with average anthesis and silking dates of 56 and 57 days respectively (Table 3.11). Earlier flowering at Kiboko could be attributed to the high temperatures which were experienced in June through October 2009 when the trial was grown.

Mean anthesis and silking dates for the hybrids in Kakamega were 69 and 70 days respectively. This was significantly earlier than the average of the commercial and experimental checks used in this study, whose average anthesis and silking dates were 75 and 74 days, respectively (Table 3.9).

Low percentages of stem and root lodging in Kiboko (0.4% and 3.2%, respectively) might have been due to the shorter plant and ear heights recorded for this site compared to Kakamega and Embu. Among the top 20 hybrids which appeared at all the three sites, entry 78 had the lowest percentage of root and stem lodging (Table 3.9, 3.10 and 3.11).

Diallel hybrids differed for turcicum leaf blight (*Exserohilum turcicum*) disease reaction. At Kakamega which is a hotspot for this disease, entries 15, 5, 18, 43 and 46 had low scores for turcicum leaf blight ranging from 1.5 to 1.9 probably because of natural infestation and low disease pressure. The best performing parents in various hybrid combinations were P1, P2 and P13 indicatively, these lines have potential to be used as parents for hybrids to be grown under well-watered conditions.

Small percentages of ear rots (less than 3%) were recorded at all the three well-watered sites, suggesting that some of the diallel hybrids might have tolerance to fungal ear rots (Table 3.9, 3.10 and 3.11).

Differences in performance for grain yield were reported among ten CIMMYT tropical latematurity QPM pools and populations (Vasal *et al.*, 1993a), and among CIMMYT subtropical QPM pools and populations grown in 8 environments in Mexico and in the USA (Vasal *et al.*, 1993b). Bhatnagar *et al.* (2004) reported a disparity in performance among and between seven white and nine yellow QPM inbred lines for grain yield, root lodging and stalk lodging in five southern US environments.

Table 3. 9 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Kakamega

NO.	ENTRY	CROSS	GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH Cm	RL %	SL %	HC %	ER %	GLS 1-5	ET 1-5	EA 1-5
1	21	2x11	13.39	69.9	70.0	0.0	1.0	237.7	117.7	7.3	0.0	5.2	2.7	1.5	2.3	1.5
2	15	2x5	11.66	66.0	69.0	-3.0	1.3	209.1	108.9	49.6	0.0	8.2	0.0	1.7	1.9	2.0
3	8	1x9	11.47	69.5	71.5	-2.2	1.2	220.0	118.5	4.8	0.0	10.6	4.0	1.5	2.5	2.3
4	17	2x7	11.25	69.0	70.0	-1.2	1.0	240.0	129.7	40.1	0.0	10.6	2.3	1.5	2.5	2.3
5	42	4x13	11.06	68.9	69.0	-0.1	1.1	242.5	145.2	38.9	0.0	35.1	0.0	1.5	2.5	2.0
6	5	1x6	10.99	66.5	67.0	-0.8	1.5	207.7	119.9	2.6	5.2	20.3	0.1	1.5	1.8	1.8
7	1	1x2	10.84	71.7	71.5	0.0	1.0	227.1	124.8	41.5	0.0	30.7	6.1	1.7	2.3	1.8
8	20	2x10	10.66	69.8	70.0	0.1	1.1	230.0	119.5	0.7	0.0	2.7	0.0	1.5	2.5	1.5
9	51	6x7	10.66	65.1	65.0	-0.1	1.1	198.2	105.9	19.1	0.0	9.5	2.2	1.5	2.0	2.7
10	12	1x13	10.51	73.8	74.0	0.0	1.1	241.6	138.7	10.3	0.0	0.0	0.5	1.5	2.5	1.8
11	13	2x3	10.37	69.8	70.0	0.0	1.0	222.5	122.1	5.2	0.0	17.7	0.2	1.5	2.0	2.0
12	58	7x8	10.22	70.6	70.5	0.1	1.1	219.3	109.0	42.2	2.8	16.0	5.2	1.5	2.2	3.0
13	18	2x8	10.19	72.8	73.0	-0.1	1.1	233.9	124.9	18.5	0.0	27.5	0.0	1.7	1.8	2.4
14	63	7x13	10.12	67.6	71.5	-4.1	1.1	215.9	124.5	0.0	2.7	2.8	0.0	1.5	2.5	2.1
15	78	12x13	10.11	69.9	70.0	0.0	1.0	239.1	137.0	5.9	0.0	7.5	0.0	1.5	2.3	1.7
16	77	11x13	9.99	70.4	71.5	-0.9	1.0	239.1	140.5	38.5	0.0	2.7	0.0	1.5	2.5	1.4
17	43	5x6	9.96	65.0	65.0	0.3	1.5	226.5	121.6	42.1	0.0	0.0	0.1	1.5	1.5	2.0
18	9	1x10	9.94	70.0	70.0	-0.1	1.1	207.3	121.5	1.1	0.0	0.0	0.0	1.8	2.8	2.2
19	46	5x9	9.60	67.6	67.5	0.3	1.2	207.8	118.7	22.5	2.7	5.6	6.7	1.5	1.8	2.5
20	40	4x11	9.57	67.4	67.5	-0.3	1.0	237.5	116.8	38.2	0.0	17.8	0.3	1.5	3.0	2.5
79		CML144/CML159	10.69	76.4	78.0	-1.5	1.1	261.8	134.3	26.4	0.0	0.0	3.1	1.8	1.7	1.5
80		H513	12.85	72.5	73.0	-0.3	1.2	210.1	133.6	9.8	0.0	7.5	1.9	1.5	1.8	1.8
Mean of top 20 hybrids			10.63	69.06	69.67	-0.60	1.13	225.15	123.27	21.40	0.67	11.50	1.44	1.55	2.25	2.07
Mean of checks			11.77	74.44	75.47	-0.88	1.14	235.98	133.99	18.11	0.00	3.75	2.54	1.62	1.76	1.65
Mean of trial			8.63	68.50	69.20	-0.70	1.12	222.60	121.00	19.00	1.40	11.80	1.80	1.50	2.40	2.40
LSD (0.05)			3.06	2.80	3.20	2.60	0.20	29.00	22.40	24.60	5.70	19.40	5.90	0.20	0.50	0.60
CV			17.76	2.00	2.30	182.8	8.72	6.50	9.30	64.90	203.0	82.10	164.9	7.70	9.30	12.90

† GY= Grain yield; SD= Silking Date; AD= anthesis date; ASI= anthesis-silking interval; EPP= Ears Per Plant; PH: Plant Height; EH: Ear Height; RL: Root Lodging; SL: Stem Lodging; HC: Husk Cover; ER: Ear Rots; GLS: Grey Leaf Spot; ET: *E. Turcicum*; EA: Ear Aspect.

Table 3. 10 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Embu

NO.	ENTRIES	CROSS	GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	HC %	ER %	ET 1-5	EA 1-5	PA 1-5
1	23	2x13	8.20	70.3	71.0	-0.5	1.0	258.8	135.6	0.4	0.4	8.0	2.8	1.5	2.0	3.2
2	14	2x4	8.03	67.5	67.0	0.3	1.2	239.7	109.7	0.0	0.0	9.8	0.4	1.5	2.5	2.5
3	1	1x2	7.90	70.0	69.0	1.0	1.0	240.4	121.9	0.0	0.0	16.7	0.2	1.4	2.5	2.5
4	33	3x13	7.55	67.9	67.0	1.0	1.0	252.2	142.2	0.0	0.0	12.3	0.1	1.5	2.1	3.3
5	42	4x13	7.44	66.0	65.5	0.5	1.0	260.7	127.4	2.5	8.3	22.5	-0.8	1.5	2.7	2.9
6	78	12x13	7.33	67.3	67.0	0.5	1.0	259.1	129.3	4.1	12.3	7.9	0.2	1.5	2.1	3.0
7	18	2x8	7.04	68.9	66.5	2.5	1.0	258.9	107.3	6.7	1.8	30.3	7.7	1.5	3.2	2.1
8	58	7x8	7.04	68.2	65.5	2.6	1.0	244.5	114.3	8.7	0.6	2.3	0.0	1.5	2.8	2.1
9	77	11x13	6.94	66.7	68.0	-1.1	1.0	243.5	122.0	0.0	0.0	0.0	0.0	1.5	2.8	3.2
10	76	11x12	6.82	65.2	64.5	0.5	1.0	244.9	105.7	0.0	0.0	0.0	0.0	1.7	2.5	2.4
11	68	8x13	6.77	68.8	68.5	0.5	1.0	246.8	124.7	6.7	0.9	16.7	0.3	1.6	2.7	3.3
12	7	1x8	6.64	67.1	66.0	1.1	1.0	246.6	121.8	15.4	3.3	0.1	2.5	1.7	2.8	2.8
13	62	7x12	6.59	67.9	65.5	2.5	1.0	233.6	111.1	4.3	1.2	5.9	0.3	1.5	2.1	2.3
14	12	1x13	6.56	70.4	69.5	1.0	1.0	235.0	129.7	12.2	8.2	0.0	0.4	1.8	2.2	3.2
15	37	1x13	6.49	67.4	66.5	1.0	1.0	256.6	115.7	5.3	0.1	0.9	0.0	1.7	3.0	2.6
16	50	4x8	6.49	67.6	64.0	3.4	1.0	251.2	140.0	10.8	2.6	0.0	2.4	1.6	2.1	3.4
17	63	5x13	6.46	67.6	68.5	-1.0	1.0	240.2	127.6	2.0	2.7	0.5	0.0	1.5	2.6	2.5
18	21	2x11	6.44	68.6	68.0	0.5	1.0	241.5	113.6	1.7	0.2	1.7	2.6	1.5	2.9	2.2
19	75	10x13	6.42	68.5	67.0	1.4	1.0	249.3	131.4	0.4	12.2	3.2	0.0	1.5	2.3	3.5
20	16	2x6	6.40	64.1	63.5	0.5	1.1	239.7	102.0	3.5	1.6	15.4	0.0	1.5	2.8	1.9
79	79	CML144/CML159	3.92	67.0	68.0	-1.0	1.0	234.1	121.3	0.0	0.0	0.0	0.0	1.5	3.1	2.9
80	80	H513	7.31	71.1	69.5	1.6	1.0	265.7	143.0	0.0	0.1	2.3	0.0	1.5	1.8	3.7
Mean of top 20 hybrids			6.98	67.80	66.90	0.91	0.98	247.16	121.64	4.24	2.82	7.71	0.96	1.55	2.53	2.75
Mean of checks			5.61	69.08	68.75	0.31	0.89	249.88	132.15	0.00	0.05	1.15	0.00	1.47	2.47	3.32
Mean of trial			5.74	66.1	65.6	0.40	0.95	236.90	114.80	6.70	2.40	5.70	1.50	1.60	2.80	2.40
LSD (0.05)			1.56	2.00	2.30	2.30	0.21	21.50	14.30	23.70	8.70	14.10	6.00	0.20	0.70	0.50
CV			13.55	1.50	1.70	277.60	11.02	4.50	6.20	178.0	182.8	122.5	203.2	7.80	13.60	11.30

† GY= Grain yield; SD: Silking Date; AD= Anthesis date; ASI= Anthesis-silking interval; EPP: Ears Per Plant; PH: Plant Height; EH: Ear Height; RL: Root Lodging; SL: Stem Lodging; HC: Husk Cover; ER: Ear Rots; ET: *E. Turcicum*; EA: Ear Aspect; PA: Plant Aspect.

Table 3. 11 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Kiboko

NO.	ENTRY	CROSS	GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	HC %	ER %	EA 1-5	PA 1-5
1	12	1x13	11.97	59.7	58.3	1.5	1.0	210.3	124.0	1.3	0.0	0.0	2.6	1.5	1.4
2	2	1x3	11.90	58.0	56.2	2.0	1.0	208.3	108.7	0.4	0.0	33.5	0.0	1.6	1.5
3	1	1x2	11.82	57.6	56.7	1.0	1.1	211.3	111.6	2.9	0.0	0.0	2.5	1.4	1.4
4	23	2x13	11.49	59.3	59.0	0.5	1.0	221.5	112.2	0.1	0.0	7.1	0.0	1.6	1.9
5	7	1x8	11.19	58.6	56.7	1.5	1.1	218.0	118.8	0.0	0.0	0.6	0.1	2.2	1.6
6	68	8x13	10.71	58.1	57.3	0.5	1.0	227.5	129.2	0.0	0.0	19.9	2.7	2.4	3.1
7	27	3x7	10.71	56.3	55.9	1.0	1.0	207.0	103.9	0.0	0.0	23.0	4.7	2.0	1.4
8	50	5x13	10.58	58.0	56.7	1.5	1.1	231.8	145.1	0.8	0.0	0.2	0.0	2.1	2.6
9	18	2x8	10.40	56.2	55.9	0.5	1.0	217.5	90.6	2.0	0.0	62.6	2.5	2.4	2.9
10	3	1x4	10.22	57.1	54.4	2.5	1.1	224.5	119.7	17.7	0.0	15.8	0.0	1.9	1.4
11	9	1x10	10.20	58.8	57.2	1.5	1.0	209.0	110.2	0.0	0.0	0.2	2.7	1.7	1.2
12	21	2x11	10.11	57.6	56.7	1.0	1.0	214.5	98.0	0.0	0.0	2.9	7.1	2.2	1.9
13	4	1x5	10.06	58.2	57.9	0.0	1.1	235.3	126.9	59.0	0.0	3.4	0.0	1.6	1.0
14	13	2x3	10.04	58.0	56.6	1.5	1.0	224.0	100.2	1.4	0.0	32.8	12.2	2.0	1.4
15	46	5x9	9.95	55.9	54.9	1.0	1.1	217.0	112.1	6.1	2.7	10.5	0.0	2.1	1.4
16	25	3x5	9.91	57.2	56.7	0.5	1.2	227.8	128.6	0.0	0.0	7.3	1.9	2.2	1.2
17	78	12x13	9.82	59.1	57.1	1.5	1.0	229.3	122.5	3.1	0.0	19.6	2.5	2.2	2.4
18	57	6x13	9.74	57.0	56.1	1.0	1.0	200.8	110.6	0.0	0.0	5.6	0.0	2.0	2.2
19	42	4x13	9.65	57.1	55.5	1.5	1.2	249.3	135.8	45.5	0.0	2.6	2.4	2.4	3.2
20	14	4x13	9.56	56.5	54.6	2.5	1.0	231.5	104.8	0.8	0.0	0.7	0.0	2.2	2.5
79	79	CML144/CML159	10.76	62.5	63.2	0.0	1.0	242.5	124.8	0.8	2.5	0.2	0.0	2.1	2.6
80	80	H513	11.53	60.9	59.0	2.0	1.0	236.0	131.7	0.2	0.0	12.7	2.6	1.6	1.0
	Mean of top 20 hybrids		10.50	57.71	56.53	1.23	1.04	220.79	115.69	7.06	0.14	12.42	2.20	1.98	1.88
	Mean of checks		11.14	61.73	61.10	1.00	1.00	239.25	128.22	0.50	1.25	6.45	1.30	1.88	1.83
	Mean of trial		8.87	57.10	55.90	1.30	1.01	212.10	104.50	3.20	0.40	10.80	2.10	2.40	1.80
	LSD (0.05)		1.38	2.00	1.90	2.00	0.15	17.50	12.00	18.20	4.50	15.30	6.40	0.60	0.60
	CV		7.78	1.80	1.70	77.9	7.21	4.10	5.70	284.30	588.20	70.90	153.10	12.30	17.10

† GY= Grain yield; SD: Silking Date; AD= anthesis date; ASI= Anthesis-silking interval; EPP: Ears Per Plant; PH: Plant Height; EH: Ear Height; RL: Root Lodging; SL: Stem Lodging; HC: Husk Cover; ER: Ear Rots; EA: Ear Aspect; PA: Plant Aspect.

3.3.3 Performance of hybrids under managed drought stress

The mean yield of the hybrids in this trial was 2.35 t ha⁻¹ (Table 3.12). However, based on the lsd, the yields of the best 20 hybrids were not significantly different. The Anthesis-silking interval for the best 20 entries varied from -1.5 to 3 days whereas the QPM check had an ASI of 8 days (Table 3.12). Most of the higher yielding genotypes had shorter Anthesis-silking interval and also higher number of ears per plant. These results confirmed that high grain yield performance of the maize hybrids under drought is associated with smaller Anthesis-silking interval and number of ears per plant. This agrees with earlier findings by Bolaños and Edmeades, (1993b) and Edmeades *et al.* (2000). Betrán *et al.* (2003c) also found that high yield under a range of stress intensities was associated with a short ASI, earlier flowering, increased plant and ear heights and increased number of ears per plant. The mean value for ears per plant for the trial was 0.75 (Table 3.12). This is an indication of bareness for some plants which is expected under managed drought stress. The top performing hybrids had a mean value of 0.88 for ears per plant and this was reflected in the high yields. All top performing hybrids except entry 28 showed low percentages of poor husk cover (Table 3.12).

3.3.4 Performance of hybrids under random drought stress

Mean grain yield and agronomic traits for the top 20 F₁ hybrids plus the 2 checks under random stress are presented in Table 3.13. Mean yield for the hybrids under random drought was 2.20 t ha⁻¹ and 0.66 t ha⁻¹ for the checks used in this trial (Table 3.13). The higher yields for the experimental hybrids could be attributed to reduced ASI compared to the checks (Table 3.13). Short ASI has been found to contribute to high ratio of ear setting to grain under

drought conditions (Ribaut *et al.*, 1997). Mean plant and ear height for the trial was 110.1 cm and 55.2 cm respectively. Average plant height at this site was shorter compared to all other sites possibly due to the reduced amount of rainfall experienced at Namulonge. Entries 1, 14, 23 and 42 performed well both under random and managed drought stress (Tables 3.12 and 3.13). Inbred line 2 was a parent in three of the entries (1, 14 and 23). This inbred line may be having good alleles for drought tolerance.

As recommended by Edmeades *et al.* (2006), it is more efficient to select for improved yield under stress when stressed yields are less than 50 to 60% of the potential. Secondary traits are valuable adjuncts in increasing the efficiency of selection for grain yield under stress (Banziger and Lafitte, 1997). Improvement in drought tolerance of maize for better anthesis-silking synchrony was found to be closely associated with improved N use efficiency (Muza *et al.*, 2004). The highest grain yielding genotypes under low N and drought tend to show lower anthesis-silking interval, delayed senescence, and a higher number of ears per plant (Moll *et al.*, 1994; Banziger and Lafitte, 1997; Diallo *et al.*, 2004). An increase in anthesis-silking interval in maize indicates that pollen shed is essentially over by the time silks emerge (Banziger and Lafitte, 1997; Edmeades *et al.*, 2006). Edmeades *et al.* (1993) found that delayed silking is related to less assimilate being partitioned to growing ears around anthesis, which results in lower ear growth rates, increased ear abortion, and more barren plants.

Table 3. 12 Grain yield and agronomic traits of the top 20 entries under managed drought stress at Kiboko

NO.	ENTRY	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI Days	PH cm	EH cm	EPP #	HC %	SEN 1-10	EA 1-5
1	40	4x11	3.82	62.6	65.6	3.0	248.4	122.4	1.03	3.4	0.8	3.1
2	1	1x2	3.78	64.7	65.5	1.0	229.1	119.0	0.89	0.4	0.8	2.6
3	21	2x11	3.76	65.1	66.0	1.0	233.1	117.0	0.86	0.0	0.8	2.7
4	15	2x5	3.44	65.2	64.0	-1.0	240.5	121.6	0.92	0.0	0.7	2.1
5	66	8x11	3.41	63.0	63.6	0.5	238.4	112.3	0.94	0.0	0.9	3.9
6	38	4x9	3.36	62.3	65.4	3.0	238.3	114.5	0.85	0.1	0.8	2.9
7	76	11x12	3.30	64.3	66.6	2.5	232.3	112.4	0.95	5.1	0.6	3.2
8	7	1x8	3.30	63.7	65.5	2.0	243.8	127.2	0.85	3.5	0.9	3.2
9	50	5x13	3.18	66.4	66.0	-0.5	239.2	137.4	0.53	0.0	0.8	2.1
10	33	3x13	3.17	66.0	68.0	2.0	240.8	138.9	1.05	0.0	0.8	3.0
11	14	2x4	3.16	61.5	64.4	3.0	236.8	110.4	0.71	2.6	0.8	2.3
12	72	9x13	3.16	67.8	66.5	-1.5	226.0	121.6	0.85	0.3	0.7	2.9
13	68	8x13	3.14	65.4	68.5	3.0	242.1	126.1	0.88	10.9	0.7	2.8
14	13	2x3	3.02	65.4	66.5	1.0	239.9	115.2	0.85	2.7	0.8	2.5
15	28	3x8	3.02	62.1	65.0	3.0	223.1	103.9	1.04	23.4	0.8	2.9
16	4	1x5	2.98	65.7	66.5	1.0	221.9	129.3	1.10	0.8	0.8	2.1
17	23	2x13	2.95	67.9	68.0	0.0	238.4	126.0	0.61	1.8	0.7	2.3
18	42	4x13	2.93	65.3	67.5	2.0	253.0	148.7	0.78	0.3	0.8	2.8
19	48	5x11	2.89	65.0	65.0	0.0	220.1	122.6	0.97	0.0	0.8	2.7
20	34	4x5	2.81	62.7	63.5	0.5	250.5	143.0	0.90	1.1	0.8	2.6
21	79	CML144/CML159	0.68	75.1	83.0	8.0	218.3	121.0	0.39	0.0	0.7	4.3
22	80	H513	2.88	67.8	72.5	4.5	248.7	142.6	0.62	3.5	0.7	2.5
Mean of top 20 hybrids			3.23	64.61	65.88	1.28	236.79	123.47	0.88	2.53	0.77	2.73
Mean of checks			1.78	71.43	77.73	6.25	233.50	131.80	0.50	1.46	0.72	3.370
Mean of trial			2.35	64.10	66.70	2.60	223.90	116.90	0.75	2.90	0.80	3.00
LSD (0.05)			1.45	1.60	4.80	4.60	23.70	13.90	0.410	8.10	0.20	0.90
CV			30.78	1.20	3.60	88.60	5.30	5.90	27.17	139.7	10.10	14.40

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; HC: Husk cover; SEN: Senescence; EA: Ear aspect

Table 3. 13 Grain yield and agronomic traits of the top 20 entries under random drought stress at Namulonge

NO.	ENTRY	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	HC %	ER %	ET 1-5	TEX 1-5	EA 1-5	PA 1-5
1	3	1x4	2.85	62.0	66.3	3.7	102.4	57.4	1.00	2.6	0.0	1.8	1.5	3.1	3.4
2	46	5x9	2.65	60.4	57.9	-2.1	138.7	71.7	1.09	0.3	6.5	1.4	1.0	2.1	2.9
3	8	1x9	2.63	65.0	64.9	-0.1	119.4	56.7	1.55	0.3	0.0	1.7	1.0	2.5	3.3
4	19	2x9	2.50	60.5	61.6	1.0	128.7	65.9	1.03	25.3	23.8	2.1	2.0	2.5	2.9
5	10	1x11	2.46	64.1	65.2	1.8	79.8	47.4	1.28	0.0	4.2	1.9	1.2	3.1	3.5
6	66	8x11	2.39	63.2	66.7	2.7	156.5	69.3	1.00	0.0	0.0	2.2	2.0	3.3	3.5
7	62	7x12	2.38	61.6	64.9	3.0	114.0	52.5	1.01	4.3	0.0	2.4	1.0	2.5	3.2
8	14	2x14	2.28	62.0	67.5	5.1	130.7	73.9	1.07	0.5	3.3	1.6	1.7	2.8	3.1
9	41	4x12	2.15	63.6	66.7	2.6	124.9	58.5	0.95	3.7	0.0	1.8	1.5	3.5	3.6
10	58	7x8	2.11	62.8	64.5	2.7	125.0	70.5	0.88	0.0	5.3	1.7	1.2	2.7	3.0
11	78	12x13	2.09	65.1	67.0	2.6	126.9	71.7	0.85	0.0	0.0	2.3	1.0	2.2	3.0
12	45	5x8	2.08	62.2	62.8	0.2	137.4	67.8	0.97	1.2	0.3	1.5	1.0	2.8	3.1
13	5	1x6	2.05	61.7	65.2	3.1	80.1	40.7	1.06	0.0	0.0	1.6	1.8	3.0	3.6
14	23	2x3	2.01	66.0	66.5	0.5	131.2	68.3	0.84	1.0	0.4	1.8	1.5	2.3	3.1
15	71	9x12	1.99	60.7	60.7	-0.7	130.0	23.6	1.05	6.5	0.0	1.5	1.3	2.5	3.2
16	35	4x6	1.97	55.4	59.2	3.6	120.0	55.7	1.04	0.5	8.0	1.8	1.5	3.2	3.3
17	25	3x5	1.92	60.4	61.7	1.8	128.0	73.2	0.91	11.2	3.6	1.9	1.2	2.3	3.0
18	44	5x7	1.90	63.6	63.8	-0.3	98.1	46.1	0.98	0.0	0.0	2.3	1.0	2.3	3.6
19	42	4x13	1.82	63.2	69.6	6.8	153.0	83.0	0.93	0.0	0.0	1.7	1.5	2.9	3.2
20	1	1x2	1.82	64.6	69.1	3.4	88.4	49.5	1.33	30.9	30.9	1.7	2.0	4.1	3.6
79	79	CML144/159	0.77	74.6	84.5	10.0	117.6	74.5	0.99	0.0	0.0	1.8	1.8	4.2	3.6
80	80	H513	0.56	69.7	73.5	4.7	85.8	56.2	1.71	16.7	6.3	1.7	2.0	4.3	3.9
Mean of top 20 hybrids			2.20	62.40	64.60	2.10	120.70	60.20	1.00	4.20	4.30	1.80	1.40	2.80	3.20
Mean of checks			0.70	72.20	79.00	7.30	101.70	65.40	1.40	7.50	3.20	1.80	1.90	4.30	3.80
Mean of trial			1.49	63.60	66.60	3.10	110.10	55.20	1.01	7.40	5.40	1.90	1.50	3.30	3.50
LSD (0.05)			1.33	5.50	7.40	5.50	34.90	22.80	0.50	21.80	17.60	0.50	0.60	1.50	0.60
CV			44.48	4.30	5.60	88.70	15.90	20.60	24.89	147.60	163.00	13.30	20.00	22.60	8.70

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; HC: Husk cover; ER: Ear rot; ET: *E. Turcicum*; Tex: Texture; EA: Ear aspect; PA: Plant aspect

3.3.5 Performance of hybrids under managed low nitrogen stress

The mean yield for the trial under low nitrogen was 1.8 t ha^{-1} (Table 3.14). This average yield is 20 % of the mean yields of the hybrids under well-watered conditions at the same location. This mean yield is within the recommended limits by Bolaños and Edmeades (1996) who concluded that average yield under drought or low N stress have to be 20-30% of the average yield at the same location under optimal management to be able to select varieties that perform reasonably well under both optimum and stress conditions. Entries with shorter Anthesis-silking interval had higher values of ears per plant which led to high yields. The results are similar to a study by Lemcoff and Loomis (1986), who observed that under low nitrogen, yield was significantly correlated with ears per plant. The diallel hybrids performed better compared to the checks under managed low nitrogen stress. However, there is need to evaluate these hybrids across several other low nitrogen sites in order to obtain more conclusive results. The number of ears per plant for most hybrids was less than 1 suggesting that some hybrids had some barren plants.

Consideration of secondary traits could improve selection efficiency under low N stress conditions. Banziger and Lafitte (1997) noted that the use of secondary traits increased selection efficiency for grain yield when broad-sense heritability of grain yield was low under low N. Moll *et al.* (1987) found that selection for ears per plant improved the identification of superior genotypes under low N. Banziger and Lafitte (1997) used ears per plant and leaf senescence to discriminate superior genotypes under low N.

Table 3. 14 Grain yield and agronomic traits of the top 20 entries under managed low nitrogen stress at Kiboko

NO.	ENTRY	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	HC 1-5	TEX 1-5	EA 1-5
1	40	4X11	3.3	53.5	57.6	3.2	215.8	101.6	1.0	0.1	4.3	3.0
2	41	4X12	3.0	53.5	57.6	4.5	212.9	100.7	1.0	4.2	2.4	2.4
3	31	3X11	3.0	54.8	57.8	2.5	196.5	90.0	1.0	8.9	3.1	2.7
4	5	1X6	2.8	54.7	59.2	4.4	191.9	87.9	0.8	1.0	4.2	3.2
5	55	6X11	2.8	53.1	54.2	1.1	176.4	81.1	1.0	1.4	4.0	3.0
6	25	3X5	2.7	55.1	55.3	0.0	198.2	104.6	1.0	0.0	2.7	2.6
7	45	5X8	2.7	55.5	55.0	0.0	203.7	98.2	0.9	8.2	2.9	2.9
8	43	5X6	2.6	53.2	54.2	1.1	181.7	87.6	1.0	4.2	3.4	2.8
9	14	2X4	2.5	54.4	58.8	4.4	228.5	102.3	0.9	13.4	3.0	2.9
10	15	2X5	2.5	55.9	55.1	-1.0	203.3	100.7	0.9	2.4	2.7	2.8
11	48	5X11	2.4	56.4	55.9	-0.9	209.4	104.4	1.0	2.9	3.5	2.9
12	42	4X13	2.4	56.1	61.3	5.0	240.7	124.8	1.0	10.7	2.3	3.0
13	26	3X6	2.4	53.4	56.5	3.7	179.9	82.2	1.0	10.8	2.8	3.2
14	33	3X3	2.4	57.4	59.9	2.7	223.5	107.4	1.1	11.7	1.8	2.9
15	28	3X8	2.4	53.4	57.3	3.6	191.3	86.8	0.9	0.5	3.0	3.1
16	35	4X6	2.4	52.3	56.1	4.3	188.4	86.7	1.0	5.1	3.7	3.9
17	52	6X8	2.3	53.6	60.8	7.6	191.6	85.6	0.8	43.7	4.0	3.6
18	2	1X3	2.3	55.4	59.8	4.0	203.5	100.8	0.9	5.2	3.7	3.0
19	34	4X5	2.2	54.0	55.1	1.0	215.4	117.2	1.0	7.4	3.6	3.3
20	76	11X12	2.2	54.8	58.1	3.6	212.6	95.6	0.9	0.0	2.6	2.9
21	79	CML144XCML159	1.14	63.0	68.2	5.0	219.2	100.3	0.9	1.7	2.2	3.6
22	80	H513	1.97	58.8	63.7	5.5	216.9	110.3	1.0	6.2	1.9	2.8
Mean top 20 hybrids			2.6	54.5	57.3	2.7	203.3	97.3	1.0	7.0	3.2	3.0
Mean of checks			1.6	60.9	65.9	5.2	218.1	105.3	0.9	4.0	2.0	3.2
Mean of trials			1.8	55.5	60.9	5.5	201.3	93.9	0.9	11.4	2.7	3.3
LSD (0.05)			1.04	1.3	6.5	6.2	16.7	10.2	0.25	16.1	0.7	0.9
CV			29.49	1.2	5.3	56.9	4.2	5.4	14.66	70.3	12.0	12.8

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; HC: Husk cover; TEX: Texture; EA: Ear aspect

3.3.6 Analysis of variance for agronomic traits across well-watered sites

Significant differences ($P < 0.001$) due to environment were observed for all traits except for ear rot (Table 3.15) meaning the environments were unique as desired. Significant differences ($P < 0.05$) were observed among the genotypes and F_1 hybrids for all traits across well-watered sites. Genotype x environment interaction was significant ($P < 0.05$) for all traits except ASI, plant height, and ear rots. F_1 hybrid x environment interaction was significant ($P < 0.05$) for all traits except anthesis date, ASI, plant height, and ear rots (Table 3.15). This suggested that for these traits, the hybrids did not perform consistently across well-watered sites due to the influence of the environments in which they were grown and therefore, selection for the best hybrids for these traits could be effective.

3.3.7 Analysis of variance for GY and other agronomic traits across all sites

Mean squares due to environment were significantly different ($P < 0.001$) for all traits. Highly significant differences ($P < 0.001$) were observed among the F_1 hybrids and genotypes for all traits across all sites (Table 3.16). This implied that the entries performed differently due to the influence of the unique environments. Genotype x environment and F_1 hybrid x environment mean squares were significant ($P < 0.01$ and $P < 0.05$, respectively) for all traits (Table 3.16). This suggested that the hybrids did not perform consistently across sites and stresses. Researchers have also indicated additive effects in the inheritance of different agronomic traits in maize (Zehui *et al.*, 2000; Bayisa *et al.*, 2008). Variation within and between QPM cultivars for grain yield and other agronomic traits has been reported by Pixley and Bjarnason (2002) and Xingming *et al.* (2004) observed variation among yellow QPM hybrids for grain yield. Data from CIMMYT QPM trials conducted in eastern and southern Africa have shown variation in performance among QPM hybrids for grain yield, anthesis-silking interval, anthesis date, ear rots and ear aspect (CIMMYT, 2003).

Table 3. 15 Analysis of variance for grain yield and other agronomic traits across well-watered sites

SOURCE	MEAN SQUARES													
	df	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	PH cm	EH cm	SL %	RL %	HC %	ER %	EA 1-5	PA 1-5
ENV	2	484.62***	7620.98***	5707.06***	159.01***	1.20***	24813.72***	11069.92***	158.04***	11054.58***	1680.12***	14.16	6.74***	24.91***
REP(ENV)	3	23.68***	11.34***	9.49**	1.65	0.03*	2594.12***	267.61*	16.66	946.14***	238.86*	20.57	6.98***	0.19
GENOTYPES	79	5.72***	23.78***	24.62***	4.83***	0.02***	884.30***	907.46***	17.58*	438.05***	585.55***	15.02***	0.60***	0.65***
F1 HYBRIDS	77	5.15***	20.11***	21.46***	4.80***	0.02***	846.69***	864.18***	17.87*	447.07***	593.34***	15.35**	0.57***	0.63***
GCA	12	22.43***	56.84***	109.45	17.81***	0.04***	4110.23	4708.14***	19.34	1684.22	1704.00	51.79***	2.60***	2.39
SCA	65	1.96*	2.63***	5.21	2.4**	0.02**	244.19	154.52**	17.60	218.67	388.30	8.62	0.19*	0.31
GENOTYPES X ENV	158	2.79***	2.35*	2.78**	1.63	0.02***	209.94	117.90*	16.67*	329.79***	156.90***	10.25	0.26***	0.57***
F1 HYBRIDS X ENV	154	2.71***	2.11	2.49*	1.67	0.02***	184.64	117.26*	16.93*	336.48***	160.46***	10.42	0.26***	0.55***
GCA*ENV	24	5.30	2.31***	8.73	2.72*	0.03***	261.6	172.56*	22.40	1018.85	367.42	11.05	0.72***	1.89***
SCA*ENV	130	2.23	0.95	1.34	1.47	0.01*	170.43	107.05	15.92	210.51	122.25	10.31	0.17*	0.29***
ERROR	237	1.40	1.80	1.87	1.47	0.01	191.59	92.92	11.94	142.68	70.21	9.80	0.14	0.15

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

†GY=Grain yield; AD=Anthesis date; SD=Silking date; ASI=Anthesis-silking interval; EPP: Ears per plant; PH=Plant height; EH=Ear height; ER=Stem lodging; RL=Root lodging; HC=Husk cover; ER=Ear rot; EA=Ear aspect; PA: Plant aspect.

Table 3. 16 Analysis of variance for grain yield and other agronomic traits across all sites

SOURCE	MEAN SQUARES													
	df	GY† t ha ⁻¹	AD days	PH cm	EH cm	EPP #	EA 1-5	SD days	ASI Days	ER 1-5				
ENV	5	1862.84***	4839.14***	341253.93***	96069.93***	2.88***	26.78***	3002.97***	748.52***	4	467.08***			
REP(ENV)	6	17.49***	62.81***	3958.53***	958.53***	0.13***	6.34***	121.02***	15.66**	5	14.48			
GENOTYPES	79	3.94***	46.33***	1725.01***	1307.10***	0.05***	0.80***	77.44***	22.60***	79	41.77***			
F1 HYBRIDS	77	3.73***	34.43***	1723.20***	1264.27***	0.04***	0.78***	60.75***	22.69***	77	42.41***			
GCA	12	15.42***	171.75***	8824.47***	6951.97***	0.13***	2.73***	284.40***	105.62	12	99.24***			
SCA	65	1.57**	9.08***	412.19***	214.23***	0.03*	0.42**	20.395***	6.74**	65	31.91*			
GENOTYPES X ENV	395	1.99***	3.71**	249.07**	128.64***	0.03**	0.42***	12.31***	7.90***	316	31.72**			
F1 HYBRIDS X ENV	385	1.88***	3.48*	228.46*	124.99***	0.03***	0.39***	11.45***	7.72***	308	34.41**			
GCA*ENV	60	4.85***	5.08***	362.79***	239.03***	0.06***	1.02***	3.76	3.11	60	25.08			
SCA*ENV	325	1.33**	3.19	203.67	103.94	0.03*	0.28	4.85	2.38***	325	27.03			
ERROR	474	0.99	2.90	199.15	94.53	0.03	0.27	7.46	4.55	395	24.13			

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

†GY=Grain yield; AD=Anthesis date; PH=Plant height; EH=Ear height; EPP: Ears per plant; EA: Ear aspect; SD: Silking date; ASI: Anthesis-silking interval; ER: Ear rots.

3.3.8 Combining ability analysis for grain yield and agronomic traits at individual sites

At Kakamega mean squares for general combining ability (GCA) were highly significant ($P < 0.01$) for all traits while mean squares for specific combining ability (SCA) were significant ($P < 0.05$) for all traits except ASI, plant height, ear height, ear rots, and ear aspect (Table 3.3). Significant GCA and SCA mean squares imply there was variability to allow selection among the entries for grain yield and other agronomic traits.

Mean squares for GCA at Embu were significantly different ($P < 0.05$) for all traits except ears per plant suggesting the importance of additive gene effects for these traits. Mean squares for SCA were significant ($P < 0.05$) for silking date, anthesis date, ASI, turicum leaf blight, husk cover, and ear aspect thus non-additive gene effects were important for these traits (Table 3.4).

Mean squares for GCA were highly significant ($P < 0.01$) for all traits except ears per plant and stem lodging at Kiboko under well-watered condition indicated that additive gene action was important for these traits (Table 3.5). Mean squares for SCA were significant ($P < 0.05$) for all traits except silking date, anthesis date, ASI, stem lodging and ear aspect (Table 3.5) suggesting the importance of non-additive genetic effects in control of the inheritance of these traits.

The GCA/SCA variance ratio exhibited the predominance of additive effects in the inheritance of these traits. Several researchers also have indicated additive effects in the inheritance of different agronomic traits in maize (Zehui *et al.*, 2000; Bayisa *et al.*, 2008).

Under random drought stress at Namulonge, mean squares for GCA were significant ($P < 0.05$) for all traits except grain yield and ear aspect (Table 3.6) suggesting the importance of additive gene effects for these traits in this germplasm. Mean squares for SCA were significant for silking date, plant height, ear rots and husk cover.

Mean squares for GCA were highly significant ($P < 0.01$) for all traits except root lodging while mean squares for SCA were significant for only silking date, anthesis date, and husk cover (Table 3.7) at Kiboko under managed drought stress. General combining ability was more important than SCA for grain yield. This is in agreement with results obtained by Betrán *et al.* (2003c) who reported that additive genetic effects are more important than non-additive genetic effects under stress conditions. Analysis of variance under managed low nitrogen stress showed significant ($P < 0.05$) mean squares for GCA for all the traits except ear rots and root lodging suggesting that additive effects were important in controlling the majority of the traits (Table 3.8). Mean squares for SCA were significant ($P < 0.05$) for all traits except grain yield, ASI, ear rots, stem lodging and root lodging. Significant differences for entry, GCA and SCA mean squares suggest that there is scope for selecting for these traits among the entries under nitrogen stress. The relative importance of additive vs. non additive effects for grain yield in diallel crosses is an indicator of the type of gene action (Baker, 1978). The more

important type of gene action for grain yield has been variable, depending on the parents and the environment under consideration in other studies. For example, additive genetic effects were prevalent in CIMMYT's lowland tropical late and subtropical QPM germplasm (Vasal *et al.*, 1993) and subtropical and temperate intermediate maturity germplasm (Beck *et al.*, 1996). In contrast, GCA effects for grain yield across environments were non-significant, while SCA effects were highly significant among the high lysine QPM inbreds (Bhatnagar *et al.*, 2004).

3.3.9 General and Specific combining ability effects at individual sites

General combining ability effects under well-watered environments, managed drought, random drought and managed low nitrogen stress are presented in Tables 3.17 to 3.22. Parents 1 and 2 had positive and significant GCA effects for grain yield at the three well-watered sites (Kakamega (1.08 t ha⁻¹, 1.39 t ha⁻¹), Embu (0.40 t ha⁻¹, 0.49 t ha⁻¹) and Kiboko (1.51 t ha⁻¹, 0.67 t ha⁻¹)) respectively.

Parent 2 had the highest positive and significant GCA effect for grain yield (0.49 t ha⁻¹) followed by P1 (0.44 t ha⁻¹) under managed drought stress. This suggests that these two inbred lines have good alleles for both well-watered and managed drought stress conditions and may have the potential to be used as parents to develop hybrids for well-watered and drought stress conditions.

Parent 13 also had positive and significant GCA effects for grain yield (1.12 t ha⁻¹ and 1.22 t ha⁻¹) for Embu (well-watered) and Kiboko (well-watered) respectively. Under managed low

nitrogen stress, P3, P4, P5 and P11 had positive and significant GCA effects for grain yield of 0.44 t ha⁻¹, 0.46 t ha⁻¹, 0.43 t ha⁻¹ and 0.42 t ha⁻¹ respectively (Table 3.22). Parents 1 and 9 had the highest GCA effects (0.23 t ha⁻¹) for grain yield under random drought stress (Table 3.21).

Specific combining ability effects for grain yield were highest and significant for the crosses P2xP11 (3.43 t ha⁻¹) at Kakamega, P7xP10 (1.36 t ha⁻¹) at Embu, P1xP4 (1.11 t ha⁻¹) at Namulonge, P1xP2 (1.11 t ha⁻¹) at Kiboko under managed drought stress, P10xP12 (1.63 t ha⁻¹) at Kiboko under well-watered condition, and P1xP6 (0.68 t ha⁻¹) at Kiboko under managed low nitrogen stress.

Estimates of GCA effects for anthesis date and silking date varied between the lines (Tables 3.17 to 3.22). Parents 4 and 6 had significant negative GCA effects for anthesis date in all environments, implying it possesses alleles for earlier maturity compared to other parents. Parent 6 had the highest negative GCA effects for anthesis at Kakamega well-watered (-2.79 days), Embu well-watered (-3.15 days), Namulonge drought (-1.99 days) and Kiboko low nitrogen (-1.89 days). The inbred lines with negative GCA effects have the potential to be used as parents for developing early maturing hybrids. Early maturing hybrids may be needed in the short rainy season as they enable farmers to get harvest when the total rainfall is lower than normal.

Table 3. 17 General combining ability effects for grain yield and agronomic traits under well-watered conditions Kakamega

P	GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	HC %	ER %	ET		GLS		EA	PA
												1-5	1-5	1-5	1-5		
P1	1.08***	2.40***	1.30***	1.09***	0.06**	1.18	750.00**	-1.57	1.91**	-0.72	0.21	0.06	0.06*	0.06*	0.06*	-0.28***	-0.01
P2	1.39***	1.72***	1.71***	0.00	-0.05*	5.05	-3.73	2.72	-0.16	3.55*	-0.69	-0.42***	0.03	-0.42***	0.03	-0.42***	-0.28**
P3	-0.98**	-0.19	-0.38	0.19	-0.07**	1.09	-4.09	-4.66*	-0.85	11.74***	2.18***	0.15**	0.01	0.26***	0.01	0.26***	0.15
P4	-0.50	-0.87**	-1.47***	0.59*	0.00	8.68**	2.50	21.46***	0.42	10.79***	-0.34	0.03	-0.01	0.22**	-0.01	0.22**	0.29**
P5	0.08	-1.19***	-0.33	-0.86**	0.13***	-1.18	8.63**	20.74***	0.21	-9.15***	-0.12	-0.28***	0.01	-0.01	0.01	-0.01	0.01
P6	0.56*	-2.42***	-2.79***	0.37	0.06**	-17.68***	-12.96***	-3.79	-1.09*	1.94	-1.10*	-0.56***	-0.03	-0.19**	-0.03	-0.19**	-0.03
P7	-0.40	-0.19	0.21	-0.41	-0.08***	-6.09*	-2.05	11.39***	-0.02	-5.08*	0.00	0.26***	-0.01	0.24***	-0.01	0.24***	0.10
P8	-0.27	1.31***	0.58	0.73*	0.01	5.95*	-2.05	-5.11*	0.10	1.06	0.94	-0.15**	0.01	0.26***	0.01	0.26***	-0.10
P9	-0.59*	-1.64***	-0.38	-1.27***	0.00	-9.50**	-16.82***	-13.26***	-0.28	-3.34*	1.38*	-0.03	-0.03	0.20**	-0.03	0.20**	0.06
P10	-0.34	-0.06	-0.29	0.23	-0.01	-6.86*	1.04	-13.66***	-0.32	-7.75***	-1.52*	0.31***	-0.01	0.01	-0.01	0.01	-0.15
P11	0.03	-0.87**	-0.10	-0.77*	-0.07**	5.05	0.91	-3.29	-0.59	-5.75**	0.34	0.60***	-0.01	-0.08	-0.01	-0.08	-0.24*
P12	-0.77*	-0.10	-0.47	0.37	0.01	4.27	3.86	-13.13***	1.75**	5.19*	0.41	0.10*	0.01	0.20**	0.01	0.20**	0.06
P13	0.71	2.13***	2.40***	-0.27	0.00	10.05**	17.27***	2.17	-1.08*	-2.46	-1.68**	-0.06	-0.01	-0.42***	-0.01	-0.42***	0.13

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

† GY= Grain yield; SD=Silking date; AD= Anthesis date; ASI= Anthesis-silking interval; EPP= Ears per plant; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: ear rots; ET: *E. Turcicum*; GLS: Grey leaf spot; EA: Ear aspect; PA: Plant aspect.

Table 3. 18 General combining ability effects for grain yield and agronomic traits under well-watered conditions at Embu

P	GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	HC %	ER %	ET		EA	PA
												1-5	1-5		
P1	0.40*	2.02***	1.58***	0.45*	-0.02	-4.89	3.70*	-0.79	1.28	-0.30	0.01	0.02	0.02	-0.06	0.07
P2	0.49*	2.16***	2.31***	-0.14	-0.02	6.27*	-2.62	-5.67*	-2.20*	5.19***	0.31	-0.04	-0.04	0.03	-0.07
P3	-0.34	0.61**	0.31	0.31	0.02	5.97*	1.95	9.82***	1.55	1.68	-0.02	-0.04	-0.04	0.08	0.02
P4	0.22	-0.70**	-1.60***	0.90***	0.03	8.77**	1.42	-3.29	0.21	2.61*	-1.21*	0.00	0.17*	0.07	0.07
P5	-0.56*	-1.34***	-0.33	-1.01***	-0.01	-2.19	9.01***	3.92	0.40	-5.53***	-0.36	-0.02	-0.02	-0.06	0.27***
P6	-0.61**	-3.43***	-3.15***	-0.28	0.03	-16.52***	-10.62***	2.38	-1.54	-3.41*	-0.39	-0.04	-0.04	0.10	-0.50***
P7	0.08	0.43*	0.22	0.22	-0.02	-8.78**	-2.94	0.90	-0.83	-4.85**	-0.90	0.02	0.02	-0.08	-0.23***
P8	0.30	0.70**	0.35	0.36	0.02	9.65**	-1.08	0.70	-1.72*	0.76	1.88**	0.05	0.17*	0.00	0.00
P9	-0.65**	-1.29***	-0.47*	-0.83**	-0.02	-4.23	-10.08***	3.87	0.27	-2.91*	1.32*	0.12***	0.15*	-0.39***	-0.39***
P10	-0.28	-0.65**	-0.83***	0.17	-0.02	-8.46**	-1.6451	-1.74	0.84	3.85	-0.52	0.00	0.00	-0.08	-0.07
P11	-0.47*	-0.65**	-0.19	-0.46*	-0.03	-3.37	-3.49*	-2.77	-0.64	-4.20**	1.87**	0.00	0.00	0.24**	-0.09
P12	0.29	0.26	-0.06	0.31	0.01	7.59*	0.06	-3.55	0.19	4.51**	-0.97	-0.02	-0.02	-0.24**	0.18**
P13	1.12***	1.85***	1.85***	-0.01	0.02	10.20**	16.33***	-3.76	2.19*	2.60*	-1.01	-0.04	-0.04	-0.44***	0.75***

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

† GY= Grain yield; SD=Silking date; AD= Anthesis date; ASI= Anthesis-silking interval; EPP= Ears per plant; PH : Plant height; EH: Ear height; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: Ear rots; ET: *E. turcicum*; EA: Ear aspect; PA: Plant aspect.

Table 3. 19 General combining ability effects for grain yield and agronomic traits under well-watered conditions at Kiboko

P1	GY† t ha ⁻¹	SD days	AD days	ASI days	EPP cm	PH cm	EH days	RL %	SL %	HC %	ER		EA		PA
											1-5	1-5	1-5	1-5	
P1	1.51***	0.88**	1.31	0.19	0.02*	-3.01	7.57***	4.06*	-0.39	-6.95***	-1.15*	-0.55***	-0.45***	0.05	
P2	0.67***	1.01**	1.46	-0.08	-0.03*	7.28***	-5.77***	-3.31	-0.39	5.61**	1.05	-0.26***	-0.19*	-0.25***	
P3	0.47**	-0.85*	-2.68**	-0.17	-0.01	-1.78	-4.02**	-3.13	-0.17	9.56***	1.25*	0.20**	0.43***	-0.50***	
P4	-0.27	-1.26***	-1.63*	0.74**	0.01	7.08***	1.05	6.30**	0.08	1.36	0.32	-0.17*	0.14*	-0.45***	
P5	0.34*	-0.71*	0.87	-1.22***	0.03*	9.97	16.00***	7.63***	0.33	-5.86**	0.20	0.20**	0.14*	-0.45***	
P6	-0.64***	-2.08***	-1.77*	0.06	-0.02	-17.13***	-14.33***	-3.57*	-0.39	-5.93***	0.12	0.20***	0.14*	-0.45***	
P7	-0.50**	0.92**	1.37	-0.08	0.01	-7.06***	0.66	0.15	0.99*	-1.93	-1.40*	-0.03	-0.45***	0.09	
P8	0.31*	-0.17	0.19	0.01	-0.01	2.99	-3.08*	-2.72	0.97*	11.43***	1.03	0.27***	0.66***	0.09	
P9	-0.91***	-0.12	0.19	0.06	-0.02	-6.10**	-11.84***	-2.05	0.08	-4.49*	0.90	0.22**	0.06	-0.29***	
P10	-0.69***	0.01	0.41	-0.03	0.01	-3.87*	2.44*	-0.98	-0.17	-1.98	-1.39*	0.06	0.22**	0.36***	
P11	-0.32*	-0.08	0.50	-0.21	-0.02	-7.19***	-4.93***	-0.63	-0.16	-8.17***	0.70	0.22**	0.40***	-0.29***	
P12	-1.19***	1.29***	0.50	1.147***	-0.01	6.19**	-4.52**	-3.13	-0.39	12.20***	-0.68	0.40***	-0.29***	0.49***	
P13	1.22***	1.15***	1.91*	-0.40*	0.01	12.65**	20.76***	1.39	-0.39	-4.85**	-0.96	-0.37***	0.49***	0.09	

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

† GY= grain yield; SD=silking date; AD= anthesis date; ASI= Anthesis-silking interval; EPP= Ears Per Plant; PH= plant height; EH= Ear Height; RL= Root Lodging; SL= Stem Lodging; HC: Husk Cover; ER: Ear Rots; EA: Ear Aspect; PA: Plant Aspect.

Table 3. 20 General combining ability effects for grain yield and agronomic traits under managed drought stress at Kiboko

P1	GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	HC %	EA		SEN
											1-5	1-10	
P1	0.44*	0.83*	0.78***	-0.07	0.06	-4.71*	2.60*	0.12	4.15	-1.97*	-0.28*	-0.36*	-0.47*
P2	0.49*	0.38	0.78***	-0.52	-0.01	7.09**	-4.15**	0.98	-5.34	-1.65*	-0.37**	0.25*	0.49*
P3	-0.10	0.33	-0.91***	1.11	0.04	-1.94	-1.26	-0.86	3.82	2.55**	0.25*	-0.05	0.20
P4	0.26	-1.08*	-1.27***	0.07	0.06	13.22***	7.40***	-0.36	-4.39	2.01*	-0.46***	0.56**	0.30
P5	0.27	-2.17***	0.64**	-2.93***	0.12**	3.99	10.67***	-0.87	6.40*	-3.19**	0.13	0.06	-0.55**
P6	-0.35*	-3.08***	-1.86***	-1.34*	0.00	-13.14***	-11.42***	-0.64	-11.92***	-1.18	0.06	0.10	0.06
P7	-0.70***	3.29***	0.23	3.75***	-0.19***	-11.05***	-3.81***	1.07	-10.52**	-1.02	0.34**	0.10	0.06
P8	0.03	0.33	-0.36*	0.57	0.00	3.06	-4.40***	0.13	-7.82*	4.72***	-0.03	0.06	0.33*
P9	-0.04	-1.44**	0.14	-1.71**	0.01	-2.12	-9.97***	-0.61	12.31***	-0.74	0.18	0.38*	-0.61**
P10	-0.26	-0.49	-0.31	-0.30	0.00	-12.12***	2.17	-0.34	3.66	-1.75*	0.22*	0.38*	-0.61**
P11	0.28	-1.17*	-0.22	-1.07*	0.03	2.20	0.08	-0.07	4.06	-1.97*	0.22*	0.38*	-0.61**
P12	-0.37*	2.56***	0.09	2.35***	-0.09*	5.04*	-2.56*	0.11	-3.94	4.97***	0.22*	0.38*	-0.61**
P13	0.06	1.70***	2.28***	0.11	-0.03	10.47***	14.67***	1.34*	9.52**	-0.77	-0.32**	-0.44*	-0.61**

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

† GY= Grain yield; SD=Silking date; AD= Anthesis date; ASI= Anthesis-silking interval; EPP= Ears per plant; PH= Plant height; EH=Ear height; RL=Root lodging; SL=Stem lodging; HC: Husk Cover; EA: Ear aspect; SEN: Senescence.

Parents 4, 5, 6, and 11 had significant negative GCA effects for silking dates at most of the sites. P6 showed the highest, significant and negative GCA effect ranging from -2.26 days to -3.42 days for SD at all sites except under random drought at Namulonge. The negative GCA effects suggest that these lines carry alleles for early silking compared to the other parents.

Significant GCA effects were recorded for ASI. Parent 5 showed significant negative GCA effects for ASI at all the six sites (Tables 3.17-3.20). Parent 5 also had the highest negative GCA effect under drought (-2.93 days) and managed low nitrogen stress (-5.62 days). Parent 9 had negative GCA effects at all sites except Kiboko (well-watered) and under managed low nitrogen stress. Parent 11 showed significant negative GCA effects at all sites except Kiboko (well-watered) and under random drought stress at Namulonge. A shorter ASI indicates increased partitioning of assimilates to the developing ears under stress. Parents 5, 9 and 11 crossed with other lines produced high yielding hybrids (Tables 3.9-3.14). A cross between parent 5 and 9 was among the higher hybrids in Kakamega (well-watered), Kiboko (well-watered) and Namulonge (random drought) with yields of 9.60 t ha⁻¹, 9.95 t ha⁻¹ and 2.65 t ha⁻¹ respectively (Tables 3.9, 3.11 and 3.13).

Under managed drought and low nitrogen stress, parent 5 showed the highest positive and significant GCA effect for ears per plant. This parent also had positive GCA effects for ears per plant under well-watered conditions at Kakamega (Table 3.17) and Kiboko (Table 3.19), indicating its ability to maintain a higher number of ears under both optimum and stress conditions. Number of ears per plant is an important secondary trait used to select germplasm under drought and low nitrogen stress (Bänziger *et al.*, 2000). As reported by Unhart and

Andrade (1995), stress affects kernel number primarily by increasing kernel abortion and secondarily by affecting the number of ovules. This eventually leads to few or no seed formation in the cobs.

Parent 2 had the highest and significant negative GCA effect for turcicum leaf blight at Kakamega. Other parents with significant negative GCA effects for turcicum leaf blight were parents 5, 6 and 8. Significant negative GCA effects meant that these parents had good alleles for tolerance to the disease. Kakamega is a hot spot for turcicum leaf blight during the long rainy season. The trial was grown during the long rainy season (March-September) when natural inoculum is abundant.

The estimate of GCA effects of a parent in the diallel is an important indicator of its potential for generating superior breeding genotypes. High positive GCA and SCA effects are desirable for grain yield, ears per plant, thousand kernel weight, number of rows per ear, kernels per row and kernels per ear, and thousand kernel weight while high negative effects are desirable for the other traits. Low absolute values of GCA effects indicate that the mean of a parent in crossing with the others does not differ greatly from the grand mean of the crosses. On the other hand, high absolute values of GCA estimate indicate that the parental mean is superior or inferior to the grand mean. SCA effect estimates the deviation of individual crosses from the average performance of the parents involved (Hallauer and Miranda, 1988).

Table 3. 21 General combining ability effects for grain yield and agronomic traits under random drought stress at Namulonge

GY† tha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	HC %	ER %	ET %	GLS %	EA 1-5	PA 1-5
P1	0.23	2.24*	1.01	1.22*	0.08*	-17.10***	-5.49*	-1.49	-0.46	-0.02	-0.02	0.07
P2	0.05	1.01	0.97	0.04	0.05	2.70	3.56	5.36*	3.68*	-0.02	0.07	-0.07
P3	-0.32*	1.24	-0.44	1.68**	-0.01	-5.02	-2.21	11.9***	4.26*	-0.02	0.25	0.18*
P4	0.11	-0.67	-1.71**	1.04*	-0.03	7.20*	6.65*	-0.68	-0.84	-0.02	0.04	-0.02
P5	0.14	-3.44**	-1.03	-2.41***	-0.01	9.52*	8.97**	-3.14	-0.01	-0.02	-0.3*	-0.11
P6	-0.23	-2.26*	-1.99**	-0.28	-0.03	-11.84**	-8.71***	-6.23**	2.21	-0.02	0.34*	0.16*
P7	-0.15	0.06	-0.03	0.09	-0.01	-12.89**	-5.76*	0.39	0.27	0.02	-0.05	0.14
P8	0.14	1.37	0.74	0.63	0.05	7.52*	2.42	2.72	-0.71	0.07*	-0.05	-0.16*
P9	0.23	-3.90***	-0.80	-3.09***	0.11*	7.84*	-3.9	3.55	-0.27	0.07*	-0.41*	-0.27**
P10	-0.15	2.28*	1.33*	0.95*	-0.13**	-8.39*	-5.85	-5.71*	-4.91**	-0.02	0.13	0.25**
P11	-0.06	-0.35	0.06	-0.41	-0.02	-2.16	-1.8	-1.91	1.15	-0.02	0.29*	0.14
P12	0.16	-0.44	-0.44	0.00	0.02	9.20*	1.33	-6.31**	-3.31*	0.02	-0.18	-0.18*
P13	-0.14	2.87**	2.33***	0.54	-0.08*	13.38**	10.79***	1.55	-1.07	-0.02	-0.12	-0.13

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

† GY= Grain yield; SD=Silking date; AD= Anthesis date; ASI= Anthesis-silking interval; EPP: Ears per plant; PH: Plant height; EH: Ear height; HC: Husk cover; ER: Ear rots; ET: *E. turcicum*; GLS: Grey leaf spot; EA: Ear aspect; PA: Plant aspect.

Table 3. 22 General combining ability effects for grain yield and agronomic traits under managed low nitrogen stress at Kiboko

GY† t ha ⁻¹	SD days	AD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	HC %	ER %	EA 1-5
P1	0.19	0.66	1.20**	-0.3	0.04	-4.43*	-0.51	0.67	-4.60*	0.06	0.07
P2	-0.43***	3.10	1.38**	0.46	-0.09**	6.57***	-2.15*	-0.58	2.42	0.64	0.30**
P3	0.44***	-2.16*	-0.39	-1.53*	0.09**	-2.16	-0.85	-0.58	0.65	1.49*	-0.45***
P4	0.46***	-2.52**	-1.34**	-0.94	0.03	10.03***	7.67***	3.60***	-0.53	0.12	0.01
P5	0.43***	-5.70***	0.16	-5.62***	0.12***	-3.27*	5.85***	-0.04	-6.43***	0.42	-0.29**
P6	0.21*	-1.34	-1.89***	0.79	0.02	-17.04***	-10.79***	-0.58	-0.72	0.94	0.08
P7	-0.52***	2.21*	-0.16	2.66	-0.08**	-14.91***	-5.56***	-0.34	0.42	0.03	0.19*
P8	-0.03	-0.02	-1.48***	1.61**	-0.08**	3.02	-3.15*	-0.84	12.48***	-1.03	0.19*
P9	-0.47***	1.57*	-0.62	2.43**	-0.09**	-1.04	-7.35***	-0.84	0.52	-1.10	-0.02
P10	-0.36**	1.78	-0.30	0.69	-0.05*	-7.09***	-1.06	0.60	4.70*	-0.16	0.17*
P11	0.42**	-2.11*	0.88*	-2.75**	0.05*	2.55	0.67	-0.84	-8.02***	-0.31	-0.17*
P12	-0.06	2.16*	0.20	2.20*	-0.04	9.41***	1.40	0.12	-3.72*	-0.24	-0.20*
P13	-0.28*	14.67***	2.34***	0.06*	0.06*	18.34***	15.24***	-0.36	2.84	-0.86	0.12

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

† GY= Grain yield; SD=Silking date; AD= Anthesis date; ASI= Anthesis-silking interval; EPP: Ears per plant; PH= Plant height; EH= Ear height; RL=Root lodging; SL=Stalk lodging; HC: Husk cover; ER=Ear rot; EA=Ear aspect.

Table 3. 23 Specific combining ability effects for grain yield at Kakamega well-watered (upper diagonal) and Embu well-watered (lower diagonal)

Lines	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1		-0.12	-0.34	-0.02	-1.10	0.82	-0.72	-0.10	2.47*	0.62	-2.01*	0.35	0.17
P2	1.25*		1.39	-2.13*	1.64	-3.3**	1.72*	0.49	-1.30	1.05	3.43***	0.33	-3.20*
P3	-0.52	-0.54		1.29	0.31	0.57	-1.96*	-1.44	-1.23	1.17	-0.65	0.11	0.77
P4	0.29	1.13	-1.22*		-0.97	0.30	0.11	-0.02	0.50	-1.70*	1.47	-1.07	2.25*
P5	0.52	-1.84**	0.65	-0.51		0.82	-0.37	-1.79*	1.57	-0.33	0.00	0.85	-0.63
P6	-0.24	0.35	-0.59	0.15	0.51		1.95*	-0.78	0.38	-0.17	0.36	0.37	-1.32
P7	-1.02	0.12	0.58	-0.57	-0.32	0.66		2.33*	-1.50	-0.35	-1.23	-1.27	1.30
P8	0.28	0.22	0.24	0.48	0.28	0.40	1.18*		0.42	-0.03	0.80	0.30	-0.18
P9	0.99	0.12	0.88	0.31	-1.05	-0.66	-0.78	-0.07		0.73	-0.49	-0.23	-1.32
P10	0.94	-0.69	-0.41	0.11	-0.58	-0.82	1.36*	-1.32*	0.64		-0.94	0.12	-0.17
P11	-1.71*	0.65	0.26	0.26	1.14*	-0.26	-0.87	-0.24	-1.06	0.50		-0.75	1.46
P12	-0.37	-1.51*	-0.51	-1.03	0.78	0.77	0.41	-0.88	0.70	0.57	1.33		1.62
P13	-0.41	0.73	1.18*	0.60	0.42	-0.26	-0.75	-0.59	-0.01	-0.30	-1.5*	-0.43	

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

Table 3. 24 Specific combining ability effects for grain yield at Namulonge random drought stress (upper diagonal) and Kiboko under managed drought stress (lower diagonal)

Lines	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1		0.34	-0.16	1.11*	-0.98*	0.59	-0.91*	-0.58	0.57	-0.36	0.71	-0.26	-0.07
P2	1.11*		-0.81*	0.64	-0.09	-0.37	0.11	-0.13	0.63	0.15	-0.45	-0.56	0.54
P3	-0.45	0.35		0.25	0.47	-0.14	-0.25	-0.18	0.06	0.64	0.13	-0.11	0.10
P4	-0.56	0.04	-1.17*		-0.32	0.53	-0.49	-0.60	-0.86*	-0.77*	-0.26	0.51	0.25
P5	0.17	0.77	-0.14	-0.24		-0.06	0.42	0.29	0.77*	0.13	0.30	-0.61	-0.32
P6	0.00	-0.80	0.24	-0.07	-0.34		0.30	0.05	-0.17	-0.08	-0.85	-0.29	0.49
P7	0.65	-0.80	-0.16	0.73	0.11	0.89		0.20	1.00	0.75	0.77	0.10	-0.52
P8	0.91	-0.54	0.76	-0.30	0.08	-0.54	-0.40		-0.12	0.34	0.92*	0.10	-0.68
P9	-0.22	-0.47	0.52	0.01	-0.20	0.57	-0.48	-0.66		-0.17	-0.86*	0.01	0.14
P10	-0.29	-0.89	-0.15	0.04	0.32	0.50	0.65	-0.39	1.08*		0.48	-0.04	-0.17
P11	-0.88	1.02*	-0.39	1.10*	0.03	-0.34	-0.49	0.77	-0.56	-0.33		-0.25	-0.01
P12	0.17	0.17	-0.94	0.70	-0.67	-0.09	-0.19	-0.28	-0.26	0.07	0.07		0.49
P13	-0.62	0.03	1.52*	-0.29	0.10	-0.03	-0.48	0.59	0.66	-0.62	-1.13*	0.19	

* Significant at $P < 0.05$ probability level

Table 3. 25 Specific combining ability effects for grain yield under well-watered conditions (upper diagonal) and managed low nitrogen stress (lower diagonal) at Kiboko

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1	0.42	0.77	0.91	0.18	0.19	-0.31	-0.07	0.50	-1.37*	0.47	-1.03*	-0.86	0.59
P2	0.00	-0.03	0.52	0.19	0.10	-0.09	0.08	0.78	-0.65	-1.75**	0.56	-1.07*	0.57
P3	-0.62	0.60	-0.53	-1.12*	0.12	0.45	1.25*	-1.13*	0.38	-0.43	-0.59	1.21	-1.59**
P4	-0.29	0.47	0.25	-0.62	-0.14	0.10	0.17	-0.53	0.34	0.23	-0.25	1.06*	-0.24
P5	0.68*	-0.55	-0.23	-0.29	0.13	-0.06	0.31	-1.10*	1.60**	-0.39	-0.38	-0.38	0.12
P6	0.36	-0.28	-0.35	0.48	-0.19	0.28	-0.10	0.40	-0.38	-0.72	-0.03	0.49	0.24
P7	0.67*	0.29	0.37	-0.70*	0.67*	0.40	-0.08	-0.39	0.64	-0.37	0.54	-1.24*	-0.83
P8	-0.49	0.13	-0.34	-0.26	0.42	0.14	-0.03	-0.32	0.35	0.73	0.36	0.05	-0.02
P9	0.25	-0.83*	0.14	0.12	-0.45	-0.23	0.20	-0.38	0.96	-0.10	-0.12	-1.4*	0.72
P10	-1.08**	-0.41	0.27	0.75*	0.02	0.45	-0.13	-0.36	0.28	0.17	1.31*	1.63**	-0.59
P11	0.30	0.52	-0.11	0.67*	-0.40	0.07	-0.35	-0.73*	-0.44	-0.21	0.05	-0.37	0.46
P12	-0.18	-0.31	0.57	0.40	-0.03	-0.85*	0.07	0.19	-0.02	0.27	-0.42	0.27	0.95*

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

3.3.10 Combining ability analysis across well-watered sites

General combining ability (GCA) mean squares were significant ($P < 0.001$) for all traits except silking dates, plant height, stem lodging, root lodging, husk cover and plant aspect. Specific combining ability (SCA) mean squares were significant ($P < 0.05$) for silking date, plant height, stem lodging, root lodging, husk cover, ear rots and plant aspect. There was significant ($P < 0.05$) GCA x environment interaction for anthesis date, ASI, ears per plant, ear height, ear aspect and plant aspect. Specific combining ability (SCA) x environment interaction was significant ($P < 0.05$) for all traits except ears per plant, ear aspect and plant aspect (Table 3.15). Lack of significant GCA x environment and SCA x environment for grain yield suggests that the GCA and SCA for grain were consistent across environments. The larger magnitude of GCA mean squares compared to GCA x environment mean squares for all traits suggests that interaction effects maybe of minor importance for these traits.

3.3.11 Combining ability analysis across all sites

General combining ability mean squares were highly significant at ($P < 0.001$) for all traits except ASI. Mean squares for SCA were significant at ($P < 0.05$) for all traits (Table 3.16). The significant differences for GCA and SCA mean squares imply that there was variability to allow selection among the entries for these traits. Variation within and between QPM cultivars for grain yield and other agronomic traits has been reported by Pixley and Bjarnason (2002). Xingming *et al.* (2004) observed variation among yellow QPM hybrids for grain yield. Data from CIMMYT QPM trials conducted in eastern and southern Africa have shown variation in performance among QPM hybrids for grain yield, anthesis-silking interval,

anthesis date, ear rots and ear aspect (CIMMYT, 2003). There was a highly significant ($P < 0.001$) GCA x environment interaction for all traits except silking date, ASI, and ear rots implying that GCA of lines was variable at different environments for grain yield, anthesis date, plant height, ear height, ears per plant and ear aspect. Interaction between SCA and environment was significant at ($P < 0.05$) for all traits except grain yield, ears per plant and ASI (Table 3.16).

3.3.12 General and specific combining ability effects across well-watered sites

General combining ability effects for grain yield and other agronomic traits are presented in Table 3.26. Significant and positive GCA effects for grain yield were observed for parents 1 (1.00 t ha^{-1}), 2 (0.85 t ha^{-1}), and 13 (1.01 t ha^{-1}) across well-watered sites. However, for these three lines 1, 2, and 13, the GCA effects for anthesis date were 1.09, 1.71, and 1.93 days respectively. This implies that these lines matured later than others and are likely to contribute alleles for late maturity to their progeny. Parents 4 and 6 had negative GCA effects for AD implying that they carry alleles for early maturity. Parents 7, 10 and 13 had negative and significant GCA effects for ear rots of -0.77, -1.14 and -1.22 respectively (Table 3.26). This is an indication that the parents had alleles for ear rot resistance which is a desirable trait in QPM germplasm. Parents 2 and 6 had negative and significant GCA values for turicum leaf blight implying that the lines carry some alleles for resistance to the disease.

Specific combining ability effects for grain yield across optimum sites presented in Table 3.27 was highest for the cross between parents 2 x 11 (1.54 t ha^{-1}).

3.3.13 General and specific combining ability effects across all sites

Estimates of GCA effects across all environments are presented in Table 3.27. General combining ability effects for GY ranged from -0.40 t ha^{-1} to 0.78 t ha^{-1} . Parent 1 had the highest and significant GCA effect for GY (0.64 t ha^{-1}) across all sites. Other lines with high and positive GCA effects include lines 2, 8 and 13.

Specific combining ability effects for grain yield across all sites were not significant (Table 3.28). The cross P2xP11 recorded the highest SCA effect for grain yield (0.80) followed by the cross P1xP2 ($\text{SCA} = 0.62 \text{ t ha}^{-1}$).

Parents 4 and 6 had significant negative GCA effects for days to anthesis and silking, suggesting they carry alleles for early maturity. Parents 5, 9 and 11 had significant negative GCA effects for ASI indicating that the parents had a shorter ASI across all sites compared to other parents. A shorter ASI indicates increased partitioning of assimilates to the developing ears under stress (Edmeades *et al.*, 1993). Thus, the lines may be selected for use as parents in breeding for drought and low nitrogen stress tolerance.

Specific combining ability effects significantly different from zero were observed among some lines for ears per plant. Parents 1 and 5 had positive and significant GCA effects across all sites indicating their ability to maintain the number of ears under both stress and non-stressed conditions. Ears per plant is an important secondary trait used to select for drought tolerant germplasm. Bolaños and Edmeades (1993) reported that selection for drought

tolerance in lowland and tropical maize populations resulted in a significant gain in the number of ears per plant. Thus, these lines might be good sources of useful alleles for some secondary traits useful in selecting for drought tolerance.

Parents 2 and 6 had negative and significant GCA effects for turcicum leaf blight. These lines may be having tolerance to the disease and could be used as sources of resistance in breeding for turcicum leaf blight resistance in quality protein maize.

Parents 10, 12 and 13 showed significant negative GCA effects for ear rots (Table 3.27) with parent 13 having the highest negative GCA effect of -1.09%. This is an indication that these lines carry some of the alleles for tolerance/resistance to ear rots, which is a desirable trait in QPM breeding.

Estimates of GCA effects showed that parents 1, 5, 6, and 11 had negative highly significant ($P < 0.01$) GCA effects for husk cover, suggesting that these lines have good alleles for husk cover (Table 3.27). Open tips (poor husk cover) may lead to incidences of ear rots in maize and therefore maize germplasm that combines good husk cover and ear rot tolerance/resistance is desirable. Parents 1, 7, and 10 showed good GCA effects for both husk cover and ear rots across locations (Table 3.27).

Table 3. 26 General combining ability effects for grain yield and agronomic traits across well-watered sites

P1	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	ET		GLS 1-5	HC %	ER #	EA 1-5	VA 1-5
										1-5	0.04					
P1	1.00***	1.19	1.77**	0.58**	0.02	-2.24	6.26***	0.58	0.96*	0.03	2.66*	-0.31	-0.30***	-0.13*		
P2	0.85***	1.71*	1.63*	-0.07	-0.03*	6.20**	-4.04**	-2.11	-0.92*	0.02	4.78***	0.23	-0.21***	-0.10		
P3	-0.28	-0.25	-0.14	0.11	-0.01	1.76	-2.06	0.69	0.17	0.05	7.66***	1.14**	0.05	-0.03		
P4	-0.19	-1.69*	-0.94	0.74***	0.02	8.18**	1.66	8.14***	0.24	0.02	4.92***	-0.41	0.20**	0.26***		
P5	-0.05	-0.05	-1.08	-1.03***	0.05**	2.20	11.22***	10.78***	0.30	-0.15*	0.01	-6.85***	-0.08	-0.07		
P6	-0.23	-2.69***	-2.64***	0.05	0.02	-17.11***	-12.64***	-1.67	-1.00*	-0.30***	-0.02	-2.47*	0.04	-0.13*		
P7	-0.27	0.48	0.39	-0.09	-0.03*	-7.31***	-1.44	4.13*	0.04	0.14	-3.95**	-0.77*	0.04	-0.19*		
P8	0.11	0.25	0.62	0.37*	0.00	6.20***	-2.07	-2.36	-0.21	-0.05	4.41***	1.28***	0.23***	0.19*		
P9	-0.71**	-0.34	-1.02	-0.68***	-0.02	-6.61**	-12.91***	-3.82*	0.02	0.04	-3.58**	1.20**	0.19**	-0.08		
P10	-0.43*	-0.36	-0.23	0.12	0.00	-6.40**	0.61	-5.48**	0.11	0.15*	-1.96	-1.14**	0.00	-0.17**		
P11	-0.25	-0.05	-0.53	-0.48**	-0.04**	-1.84**	-2.58*	-2.25	-0.45	0.30***	-0.01	-6.04***	0.97*	0.01		
P12	-0.56*	-0.13	0.48	0.61***	0.00	6.02	-0.20	-6.59**	0.52	0.04	7.30***	-0.41	0.12*	-0.02		
P13	1.01***	1.93*	1.71**	-0.22	0.01	10.96***	18.12***	-0.06	0.23	-0.05	-1.57	-1.22**	-0.41***	0.46***		

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

† GY= Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking date; EPP: Ears per plant; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Stem lodging; ET: *E. turcicum*; GLS: Grey leaf spot; HC: Husk cover; ER: Ear rots; PA: Plant aspect; EA: Ear aspect.

Table 3. 27 General combining ability effects for grain yield and agronomic traits across all sites

P1	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	PH cm	EH cm	RL %	SL %	ET		GLS 1-5	HC %	ER %	PA 1-5	EA 1-5
										1-5	0.01					
P1	0.64*	1.06*	1.54***	0.51*	0.04*	-5.49	2.66	0.27	1.54	0.01	-2.67***	-0.27	-0.19**	-0.19**		
P2	0.45	1.34**	1.36**	-0.11	-0.03	5.82	-2.47	-1.12	-1.73	-0.19**	0.00	3.41***	0.99*	-0.11*		
P3	-0.14	-0.38	-0.13	0.29	0.01	-0.64	-1.75	0.34	0.75	0.06	0.00	6.34***	1.82***	0.03		
P4	0.04	-1.60***	-1.15**	0.48*	0.02	9.16*	4.44*	4.92***	-0.01	-0.02	-0.01	2.59**	-0.4	0.10*		
P5	0.12	-0.10	-2.39***	-2.26***	0.06***	2.81	9.86***	6.35***	1.45	-0.16*	0.00	-5.55***	0.02	-0.21***		
P6	-0.18	-2.33***	-2.40***	-0.03	0.01	-15.56***	-11.47***	-1.23	-3.10*	-0.25***	-0.02	-2.58**	0.35	0.10*		
P7	-0.36	0.21	1.17**	0.86**	-0.06***	-10.13**	-3.24	2.64*	-2.15	0.18**	0.00	-2.01*	-0.41	0.06		
P8	0.78	0.05	0.64	1.54*	0.00	5.37	-1.88	-1.44	-1.86	-0.05	0.03	5.53***	0.42	0.20**		
P9	-0.40	-0.27	-1.10*	-0.80***	0.00	-2.53	-9.99***	-2.36*	2.31	0.06	0.01	-1.23	0.47	0.02		
P10	-0.35	-0.09	0.27	0.29	-0.03	-7.80*	-0.48	-3.36***	0.92	0.09	-0.01	-1.44	-0.71***	0.08		
P11	-0.02	0.12	-0.84*	-0.93***	-0.01	-0.49	-1.43	-1.46	0.37	0.25***	-0.01	-5.00***	0.74	0.14*		
P12	-0.33	-0.12	0.99*	1.14***	-0.02	6.95*	-0.07	-3.82***	-0.45	0.05	0.01	2.81***	-0.96*	0.03		
P13	0.45	2.09***	2.05***	-0.01	-0.01	12.52**	15.84***	0.28	1.07	-0.03	-0.01	-0.18	-1.09*	-0.26***		

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

† GY= Grain Yield; AD: Anthesis Date; SD: Silking Date; ASI: Anthesis-silking Date; EPP: Plant Height; EH: Ear Height; ; RL: Root Lodging; SL: Stem Lodging; ; ET: *E. turcicum*; GLS: Grey Leaf Spot; HC: Husk Cover; ; ER: Ear rots; PA: Plant Aspect; EA: Ear Aspect.

Table 3. 28 Specific combining ability effects for grain yield across well-watered sites (upper diagonal) and across all sites (lower diagonal)

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
P1	0.64												
P2	0.62	0.64											
P3	-0.10	0.14	0.46										
P4	0.07	0.07	-0.42	0.00									
P5	-0.25	0.18	0.28	-0.47	0.17								
P6	0.26	-0.79	0.05	0.12	0.17	0.17							
P7	-0.29	0.16	-0.14	0.07	-0.01	0.67	0.84						
P8	0.28	0.18	-0.23	-0.27	-0.26	-0.01	0.53	1.04					
P9	0.33	-0.26	0.04	0.00	0.53	-0.03	-0.36	-0.06	0.24				
P10	0.27	-0.50	0.15	-0.32	-0.23	-0.25	0.23	-0.17	0.51	0.42			
P11	-1.00	0.80	-0.16	0.51	0.19	-0.11	-0.35	0.36	-0.47	0.20	0.29		
P12	-0.12	-0.34	-0.06	0.14	-0.07	0.22	-0.32	-0.24	-0.27	0.36	0.01	0.07	
P13	-0.08	-0.26	0.43	0.49	-0.06	-0.29	-0.20	-0.12	0.03	-0.27	-0.19	0.51	0.71

3.3.14 Phenotypic correlations among traits

Phenotypic correlations among traits across optimal sites are presented in Table 3.29. Correlations between grain yield and anthesis date, ASI, plant height, ear height, and ears per plant across well-watered sites were positive. Positive correlation for grain yield with anthesis date is an indication that grain yield potential is proportional to crop maturity under well-watered conditions. Correlations between grain yield and ASI, and grain yield and ears per plant were small. This indicates that ASI and ears per plant have less influence on grain yield of maize grown under adequate moisture conditions compared to maize which is moisture stressed. Similar results were reported by Bolaños and Edmeades, (1996). A significant negative correlation between grain yield and turicum leaf blight (-0.33**) was observed, indicating the importance of tolerance to the disease for increased grain yield in these materials.

Phenotypic correlations among traits under managed drought stress are presented in Table 3.30. Grain yield was negatively correlated with ASI (-0.51***) (Table 3.30). A shorter ASI would lead to an increase in yield as a result of proper synchronization of pollen shedding and silks emergence. This suggests that ASI would be useful as a secondary trait to improve grain yield when selecting under drought stressed conditions. There are instances where selection for reduced ASI has been more effective than selection for grain yield under drought stress conditions.

Bolaños and Edmeades, (1996) reported an average genetic correlation of -0.48 between grain yield and ASI and noted that grain yield decreased to less than 20% of its well-watered levels as ASI increased from 0 to 5 days, and then declined asymptotically to almost zero yields as ASI increased.

Correlations between grain yield and ears per plant were positive and highly significant under managed drought stress (0.64***). This shows that under drought stress, grain yield becomes more associated with ears per plant confirming previous results where ears per plant have been reported to be an important secondary trait when selecting for drought tolerance and high yielding potential in maize. Bolaños and Edmeades (1997), working with inbred progenies adapted to the lowland tropics reported similar results that grain yield was more correlated to ears per plant under drought stress than under well-watered conditions.

Phenotypic correlation between ASI and ears per plant under drought stress was negative. Similar results were reported by Edmeades *et al.* (1993) who reported that short ASI under stress conditions was found to be associated with increased partitioning of photo-assimilates to developing ears at reproductive phase. Selection for tolerance to drought likely improves sink capacity of reproductive parts, particularly developing ears, through constitutive changes that contribute to increased tolerance to drought and other abiotic stresses (Westgate and Boyer, 1986).

Phenotypic correlations under random drought stress at Namulonge are presented in Table 3.31. The number of days to 50% pollen shed (AD) was negatively correlated with grain yield. This may have been due to early termination of the rains during that season, subjecting the hybrids to drought and especially during grain filling. Earlier maturing lines produced higher yields as they completed their development before drought stress became more severe. Correlation between grain yield and ASI was also negative which is an indication of higher yield with reduced ASI.

Under low nitrogen stress conditions, the phenotypic correlation between grain yield, anthesis date and ASI was negative and significant (Table 3.32). This indicates that increased ASI results in a reduced GY. Phenotypic correlation between ASI interval and ears per plant was negative and highly significant (-0.54***). This conforms to previous findings that selection for reduced ASI and increased ears per plant would lead to better performance under drought and nitrogen stress (Bänziger *et al.*, 2000). Both traits reflect the ability of hybrids to produce grain under stress. A greater ASI is related to less assimilate being partitioned to developing ears, resulting in slower ear growth, increased kernel abortion and decreased kernel growth (Edmeades *et al.*, 1993).

Table 3. 29 Phenotypic correlations between grain yield and agronomic traits across optimal sites

	GY [†]	AD	ASI	PH	EH	RL	SL	EPP	HC	ER	GLS	ET
AD	0.51***											
ASI	0.13	-0.13*										
PH	0.38***	0.45***	0.20*									
EH	0.50***	0.50*	0.00	0.60***								
RL	0.14	-0.12	-0.14	0.08	0.28*							
SL	0.04	0.11	0.08	0.1	0.26*	0.18						
EPP	0.11	-0.13	0.01	0.01	0.19*	0.24*	0.09					
HC	0.06	-0.03	0.41***	0.27*	-0.05	-0.12	0.06	-0.1				
ER	-0.13	0.01	-0.13	0.07	-0.34	-0.07	-0.05	-0.19*	0.13			
GLS	0.22*	0.16	0.14	0.05	0.20*	0.01	0.11	-0.07	0.13	-0.19*		
ET	-0.33**	0.11	0.00	-0.04	-0.02	-0.19	0.08	-0.28*	-0.15	0.06	0.18	

†GY: Grain yield; AD: Anthesis date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Stem lodging; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; ET: *E. Turcicum*.

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

Table 3. 30 Phenotypic correlations between grain yield and agronomic traits under managed drought at Kiboko

	GY [†]	AD	ASI	RL	SL	EPP	HC	SEN	EA
AD	0.11								
ASI	-0.51***	0.00							
RL	-0.14	0.20*	0.42***						
SL	0.33**	0.07	-0.48***	-0.26*					
EPP	0.64***	-0.16	-0.59***	-0.33**	0.47***				
HC	-0.16	-0.16	0.25*	0.03	-0.11	-0.03			
SEN	0.08	-0.38***	-0.49***	-0.31**	0.25*	0.37***	-0.20*		
EA	-0.43***	-0.31*	0.35**	0.03	-0.33**	-0.24*	0.27*	0.08	

†GY: Grain yield; AD: Anthesis date; ASI: Anthesis-silking interval; RL: Root lodging; SL: Stem lodging; EPP: Ears per plant; HC: Husk cover; SEN: Senescence; EA: Ear aspect.

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

Table 3. 31 Phenotypic correlations between yield and agronomic traits under random drought at Namulonge

	GY†	AD	ASI	PH	EH	EPP	HC	ER	GLS	ET
AD	-0.35**									
ASI	-0.39***	0.31**								
PH	0.46***	-0.27*	-0.28*							
EH	0.43***	-0.17	-0.13	0.80***						
EPP	0.28*	-0.11	-0.22*	0.06	-0.04					
HC	-0.07	-0.06	-0.05	-0.03	0.04	0.26*				
ER	-0.06	-0.24*	0.01	-0.09	-0.02	0.18	0.55			
GLS	0.09	-0.12	-0.09	-0.09	-0.15	0.06	0.11	-0.02		
ET	-0.01	-0.04	-0.01	-0.12	-0.11	0.01	0.13	0.17	0.38***	

†GY: Grain yield; AD: Anthesis date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height;; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; ET: *E. Turcicum*.

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

Table 3. 32 Phenotypic correlations between yield and agronomic traits under managed low nitrogen stress at Kiboko

	GY†	AD	ASI	PH	EH	RL	SL	EPP	HC	ER	EA
AD	-0.22*										
ASI	-0.62***	0.01									
PH	0.15	0.48***	-0.11								
EH	0.31**	0.40***	-0.34**	0.76***							
RL	0.06	-0.10	-0.10	0.15	0.15						
SL	0.15	-0.25*	-0.08	0.09	0.26*	0.21*					
EPP	0.69***	-0.09	-0.54***	0.10	0.39***	0.07	0.01				
HC	-0.32**	-0.11	0.27*	0.05	-0.06	0.05	-0.02	-0.13			
ER	0.22*	-0.13	-0.18	-0.11	-0.05	0.07	-0.15	0.19*	-0.09		
EA	-0.75***	0.14	0.37***	-0.15	-0.22*	-0.04	-0.08	-0.55***	0.30**	-0.07	

†GY: Grain yield; AD: Anthesis Date; ASI: Anthesis-silking Interval; PH: Plant Height; EH: Ear height; RL: Root lodging; SL: Stem lodging; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; EA: Ear aspect.

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

3.4 Conclusions and recommendations

Thirteen inbred lines were crossed in a diallel mating design and the resulting hybrids evaluated under well-watered, managed and random drought stress, and managed low nitrogen stress at four locations. General combining ability and SCA mean squares for grain yield were consistent across well watered environments. The larger magnitude of GCA mean squares compared to GCA X environment mean squares for all traits across well watered environments suggests that interaction effects maybe of minor importance for these traits.

Six hybrids were consistent in their top grain yield performance at the three well-watered sites in Kakamega, Embu and Kiboko. These include entries 1, 12, 18, 21, 42 and 78. Entries 1, 14, 23, 42 and 66 performed well both under managed and random drought stress. Under random drought, managed drought and low nitrogen, only entries 14 and 42 were consistent in their top performance for grain yield. Entry 42 which was a hybrid between parent 2 and 13 was the only one which was among the best 20 hybrids at all well-watered sites, managed drought stress, random drought stress and low nitrogen. This entry should be tested further and can be used as a parent in three way crosses or double cross hybrids in mid and low altitude ecologies. The experimental hybrids performed as well as the checks under well-watered conditions. Under managed drought the hybrids performed significantly better compared to the QPM check CML144/CML159. Under random drought and low nitrogen, the hybrids performed better in terms of grain yield compared to the two checks. However, further

testing under stressed conditions should be done in order to come up with more conclusive reports.

Parents 1 and 2 had positive and significant GCA effects for grain yield at the three well-watered sites. Parent 2 had the highest positive and significant GCA effect for grain yield followed by P1 under managed drought. This suggests that the lines have the potential to be used as parents to develop good hybrids under well-watered as well as drought conditions. Under low nitrogen condition, P3, P4, P5 and P11 had positive and significant GCA effects for grain yield. Parents 1 and 9 had the highest GCA effects of 0.23 under random drought. Parents 4 and 6 had significant GCA effects for anthesis date in all environments. Parent 6 showed the highest, significant and negative GCA effects for silking date except under random drought in Namulonge. These lines have the potential to be used as parents for developing early maturing hybrids. These hybrids are important in areas with two growing seasons and also help escape terminal drought at the end of the cropping season. Parent 2 had the highest and significant negative GCA effect for turicum leaf blight at Kakamega meaning it had good alleles for tolerance to the disease. The line should be tested further for potential use as a parent in breeding for turicum disease resistance.

Positive correlation for grain yield and anthesis date under well watered environments was an indication that grain yield potential is proportional to crop maturity. Anthesis-silking interval and ears per plant had less influence on grain yield for maize grown under well watered sites. However, under managed drought stress and low nitrogen

stress, grain yield was negatively correlated with ASI whereas the correlation between grain yield and ears per plant was positive and significant. This is an indication that under stress ASI was found to be associated with increased partitioning of photo-assimilates to developing ears and thus the increase in grain yield and ears per plant. Anthesis-silking interval and ears per plant are thus very important secondary traits and both reflect the ability of the hybrid to produce grain under stress.

CHAPTER 4

COMBINING ABILITY AND HETEROTIC GROUPING OF SIXTY FIVE QUALITY PROTEIN MAIZE INBRED LINES

ABSTRACT

Information on combining ability and heterotic grouping is important to breeders. Sixty five quality protein maize inbred lines were used in this study. The aim was to evaluate the performance of the hybrids in different conditions, establish GCA effects of the lines, SCA effects of the F₁ hybrids and assign the inbred lines into their respective heterotic groups.

The inbred lines were crossed to two inbred line testers (CML 144 and CML159) in heterotic group B and A respectively using the line x tester mating design and 130 F₁ hybrids were produced. Two QPM hybrids were included as checks to form six sets of trials with 132 entries each. The hybrids formed were evaluated under one managed drought condition in Kiboko and five well-watered conditions in Embu, Kakamega, Kiboko, Kibos (in Kenya) and Namulonge (in Uganda). Inbred line 45 had high, significant and positive GCA effect for grain yield under managed drought stress and across well-watered conditions. Based on SCA effects for grain yield, the two inbred line testers grouped 29 lines into heterotic group B, 25 inbred lines into heterotic group A and 11 into heterotic group AB. Entries 55, 60, 87 and 113 were the top performers in terms of grain yield both under managed drought and across well-watered conditions. These entries should be tested further with the aim of exploiting them commercially.

4.1 Introduction

Heterosis is the superiority of an F_1 over some measure of performance of the parents (Falconer and Mackay, 1996). Heterosis has been extensively exploited to produce hybrids with superior performance (Duvick, 1999; Troyer, 2004). A heterotic group is defined as a collection of germplasm that, when crossed with germplasm from an external group, tends to exhibit a higher degree of heterosis than when crossed with a member of its own group (Lee, 1995). Adequate characterization of germplasm, assignment of genotypes into heterotic groups, and extensive testing facilitate the utilization of heterosis by breeders (Reif *et al.*, 2005). Assigning of maize genotypes into heterotic groups has been the key to the economic success of maize primarily because it allows the exploitation of heterosis (Troyer, 2006) particularly for grain yield. Although the heterosis concept is not completely understood, it seems that all modes of gene action could be involved in its expression (Carena and Hallauer, 2001).

There are several methodologies commonly used in heterotic grouping of inbred lines. Pedigree analysis method is one of the methods used by breeders. However, most inbred lines do not have clear record of pedigree. In the quantitative genetic analysis method, the heterotic performance and variance of F_1 hybrids are usually used for heterotic grouping. Specific combining ability of different hybrids is the principle of this method. It is based on the assumption that SCA of two lines from different heterotic groups is greater than those from the same group. Molecular markers have also been used in heterotic grouping. Genetic markers directly based on the polymorphism of DNA structure can be analyzed not only by using different parts of the plant but also at

different growth stages. This method is not affected by the environmental factors and thus it is a powerful method for assessment of genetic diversity. Extensive testing of new genotypes using different types of testers and mating designs has permitted the estimation of general (GCA) and specific combining abilities (SCA) (Hallauer and Miranda, 1988). General combining ability enables breeders to exploit the existing variability in breeding materials, to identify individual genotypes conferring desirable attributes and to distinguish relatedness among genotypes (Melani and Carena, 2005). The SCA helps to determine heterotic patterns among populations or inbred lines, identify promising single crosses and assign inbred lines into heterotic groups (Parentoni *et al.*, 2001).

The use of testers in a maize recurrent selection program has been well documented (Hallauer and Miranda 1988; Russell *et al.*, 1992; Menz *et al.*, 1999). An ideal tester is one that highly discriminates among the lines and is a good representative of all testers (Yan and Hunt, 2002). The use of an inbred line as a tester was suggested by Russell and Eberhart (1975) and inbred lines testers are widely used by maize breeders. Inbred line testers have been used in hybrid breeding to classify maize into heterotic groups. Vasal *et al.* (1992) used this approach in evaluating the performance of the test crosses of 92 tropical and 88 subtropical maize lines using two dent and two flint line testers. The lines exhibiting contrasting specific combining ability effects with two of the four testers were placed into separate heterotic groups.

The CIMMYT maize breeding program in Kenya has a number of QPM inbred lines that are at various stages of inbreeding. Information on combining ability and heterotic

grouping of these QPM inbred lines has not been obtained. The objectives of this study were to; (i) estimate the general combining ability (GCA) of the inbred lines and specific combining ability (SCA) of the hybrids and evaluate the performance of the test crosses under well watered and managed drought.(ii) classify the QPM inbred lines into known heterotic groups using specific combining ability effects for grain yield.

4.2 Materials and methods

4.2.1 Germplasm

Sixty five early maturing quality protein maize (QPM) inbred lines at the S₅ level of inbreeding were used in this study (Table 4.1). These inbred lines were developed from conversion programs of normal endosperm CIMMYT maize inbred lines (CMLs) and early maturing open-pollinated varieties (OPVs) to QPM. Thirty inbred lines were developed from conversion of 12 normal endosperm CMLs and one maize inbred line, and 35 inbred lines were developed from conversion of four normal endosperm early maturing OPVs. The inbred lines were selected for this study based on topcross performance, protein quality, good kernel modification and good agronomic characteristics. The 65 inbred lines were crossed to two QPM inbred line testers (CML144 and CML159). CML144 is classified as heterotic group B while CML159 is classified as heterotic group A.

Table 4. 1 Quality protein maize inbred lines used in the study

Parents	Pedigree	Tryptophan %
1	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-48-B-1-B	0.082
2	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-48-B-2-B	0.082
3	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-48-B-3-B	0.082
4	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-48-B-5-B	0.082
5	ECA-MOROSR(BC1)F2-4-ECAVEE4/PL15QPMC7SRC1F2//POOL15QPMSR-B-115-B-1-B	0.073
6	ECA-MOROSR(BC1)F2-4-ECAVEE4/PL15QPMC7SRC1F2//POOL15QPMSR-B-115-B-3-B	0.073
7	CML312/CML144//CML159//POOL15QPMSR-B-59-B-1-B	0.072
8	CML312/CML144//CML159//POOL15QPMSR-B-59-B-2-B	0.072
9	CML312/CML144//CML159//POOL15QPMSR-B-59-B-4-B	0.072
10	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-27-B-1-B	0.071
11	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-27-B-4-B	0.071
12	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-27-B-5-B	0.071
13	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-27-B-6-B	0.071
14	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-27-B-7-B	0.071
15	CML312/CML144//CML159//POOL15QPMSR-B-27-B-4-B	0.064
16	CML312/CML144//CML159//POOL15QPMSR-B-27-B-6-B	0.064
17	CML312/CML144//CML159//POOL15QPMSR-B-27-B-7-B	0.064
18	CML312/CML144//CML159//POOL15QPMSR-B-27-B-8-B	0.064
19	CML312/CML144//CML159//POOL15QPMSR-B-27-B-9-B	0.064
20	CML373/CML144//CML159//POOL15QPMSR-B-34-B-1-B	0.063
21	CML373/CML144//CML159//POOL15QPMSR-B-34-B-2-B	0.063
22	CML444/CML144//CML159//POOL15QPMSR-B-32-B-5-B	0.063
23	CML216/CML144//CML159//POOL15QPMSR-B-32-B-1-B	0.063
24	CML216/CML144//CML159//POOL15QPMSR-B-32-B-2-B	0.063
25	CML216/CML144//CML159//POOL15QPMSR-B-32-B-3-B	0.063
26	CML216/CML144//CML159//POOL15QPMSR-B-32-B-8-B	0.063
27	ECA-EE-DLN-PL1-1/PL15QPMC7SRC1F2//POOL15QPMSR-B-16-B-B-B	0.091
28	ECA-MOROSR(BC1)F2-9-ECAVEE9/PL15QPMC7SRC1F2//POOL15QPMSR-B-81-B-B-B	0.085
29	ECA-MOROSR(BC1)F2-9-ECAVEE9/PL15QPMC7SRC1F2//POOL15QPMSR-B-98-B-B-B	0.085
30	ECA-MOROSR(BC0)F2-9/PL15QPMC7SRC1F2//POOL15QPMSR-B-42-B-B-B	0.084
31	P329/CML144//CML159//POOL15QPMSR-B-56-B-B-B	0.082
32	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-48-B-B-B	0.082
33	ECA-MOROSR(BC1)F2-6-ECAVEE6/PL15QPMC7SRC1F2//POOL15QPMSR-B-61-B-B-B	0.080
34	ECA-MOROSR(BC1)F2-4-ECAVEE4/PL15QPMC7SRC1F2//POOL15QPMSR-B-15-B-B-B	0.080
35	CML445/CML144//CML159//POOL15QPMSR-B-30-B-B-B	0.080
36	ECA-MOROSR(BC1)F2-6-ECAVEE6/PL15QPMC7SRC1F2//POOL15QPMSR-B-88-B-B-B	0.079
37	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-74-B-B-B	0.079
38	CML312/CML144//CML159//POOL15QPMSR-B-16-B-B-B	0.078
39	CML445/CML144//CML159//POOL15QPMSR-B-5-B-B-B	0.078

Table 4.1 continued

Parents	Pedigree	Tryptophan %
40	LLSYNTH1/PL15QPMC7SRC1F2//POOL15QPMSR-B-58-B-B-B	0.078
41	ECA-MOROSR(BC1)F2-7-ECAVEE7/PL15QPMC7SRC1F2//POOL15QPMSR-B-80-B-B-B	0.077
42	CML221/CML144//CML159//POOL15QPMSR-B-32-B-B-B	0.077
43	LLSYNTH1/PL15QPMC7SRC1F2//POOL15QPMSR-B-17-B-B-B	0.077
44	ECA-MOROSR(BC1)F2-4-ECAVEE4/PL15QPMC7SRC1F2//POOL15QPMSR-B-2-B-B-B	0.077
45	ECA-MOROSR(BC1)F2-6-ECAVEE6/PL15QPMC7SRC1F2//POOL15QPMSR-B-97-B-B-B	0.076
46	LLSYNTH1/PL15QPMC7SRC1F2//POOL15QPMSR-B-1-B-B-B	0.076
47	ECA-MOROSR(BC1)F2-5-ECAVEE5/PL15QPMC7SRC1F2//POOL15QPMSR-B-58-B-B-B	0.076
48	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-82-B-B-B	0.076
49	CML219/CML144//CML159//POOL15QPMSR-B-47-B-B-B	0.076
50	LLSYNTH1/PL15QPMC7SRC1F2//POOL15QPMSR-B-82-B-B-B	0.075
51	ECA-MOROSR(BC1)F2-4-ECAVEE4/PL15QPMC7SRC1F2//POOL15QPMSR-B-90-B-B-B	0.075
52	CML212/CML144//CML159//POOL15QPMSR-B-42-B-B-B	0.075
53	CML205/CML144//CML159//POOL15QPMSR-B-68-B-B-B	0.075
54	CML222/CML144//CML159//POOL15QPMSR-B-39-B-B-B	0.075
55	CML212/CML144//CML159//POOL15QPMSR-B-41-B-B-B	0.075
56	ECA-EE-DLN-PL1-1/PL15QPMC7SRC1F2//POOL15QPMSR-B-27-B-B-B	0.075
57	ECA-MOROSR(BC1)F2-7-ECAVEE7/PL15QPMC7SRC1F2//POOL15QPMSR-B-35-B-B-B	0.074
58	SYNTHSR/PL15QPMC7SRC1F2//POOL15QPMSR-B-52-B-B-B	0.074
59	CML440/CML144//CML159//POOL15QPMSR-B-29-B-B-B	0.073
60	CML445/CML144//CML159//POOL15QPMSR-B-2-B-B-B	0.073
61	CML445/CML144//CML159//POOL15QPMSR-B-11-B-B-B	0.073
62	CML312/CML144//CML159//POOL15QPMSR-B-59-B-B-B	0.072
63	ECA-MOROSR(BC1)F2-5-ECAVEE5/PL15QPMC7SRC1F2//POOL15QPMSR-B-12-B-B-B	0.072
64	CML384/CML144//CML159//POOL15QPMSR-B-52-B-B-B	0.072
65	ECA-EE-DLN-PL1-1/PL15QPMC7SRC1F2//POOL15QPMSR-B-18-B-B-B	0.071

Source: Dan Makumbi, personal communication

A highly significant correlation of $r=0.85$ between lysine and tryptophan content in quality protein maize has been obtained (Hernandez and Bates, 1969). On the basis of this result, it was recommended that the more rapid simpler tryptophan method be adopted in protein laboratories and that the co-variate lysine be estimated indirectly from the regression equation $Y=0.3601+4.0745X$, where Y and X represent the lysine and tryptophan content, respectively. Consequently, this method, with minor modifications, has been adopted by CIMMYT. For the lines used in this study, only the

tryptophan content for the 65 lines was analyzed in the laboratory and the percentage content is presented in Table 4.1 (D. Makumbi, personal communication).

4.2.2 Planting and cultural practices

The nursery for making the crosses was planted in December 2008 at KARI Kiboko Research Center. The plots were 4 m long, 0.75 m between rows and 0.20 m between hills. Regent[®] 5 g per hill (active ingredient: Fipronil) was applied before planting to control soil, germination and seedling pests. At planting diammonium phosphate (DAP, 18:46:0) was applied at a rate of 27 Kg N ha⁻¹ and 60 Kg P ha⁻¹. Two seeds were planted per hill and later thinned to one plant per hill two weeks after emergence. An insecticide (Bulldock[®] active ingredient: Beta Cyfluthrin) was applied at 3 weeks after planting to control stem borers at Kiboko. Four weeks after emergence 60 kg ha⁻¹ of Calcium Ammonium Nitrate (CAN) was applied. The nurseries were kept free from weeds through hand weeding to avoid unnecessary competition for nutrients. The crosses were made in a line by tester mating system, with each tester planted together with the 65 inbred lines in a separate nursery, giving two nurseries for making the crosses. Each inbred line was planted on one row followed by a row of the tester inbred line.

4.2.3 Pollination and trial formation

Prior to initiation of flowering, the inbred lines were checked daily for signs of ear stem emergence and pollen shed. Before the silks emerged, all ear stems were covered with a shoot bag to avoid unwanted pollination. Tassels to be used as pollen sources were covered with a tassel bag to prevent foreign pollen from landing on the anthers a day

before the pollen was to be used. On the day of pollination, pollen from plants in the same row was bulked and used to pollinate female parents whose silks had emerged and were ready for pollination. This was carried out very carefully to avoid contamination. Each inbred line was used both as female and male parent. Each pollinated ear was covered with a tassel bag until harvest. At harvest, selection was done for the best ears with viable seeds and showing no signs of ear rots. Ears from reciprocal crosses were bulked to form one set of hybrids. With 65 inbred and 2 testers, 130 hybrids were formed.

Seed from 130 hybrids and two experimental single crosses that were used as checks formed a trial with 132 entries. All experiments were planted using the alpha (0, 1) lattice design (Patterson and Williams, 1976) with two replications and one row plot for each entry. Each incomplete block had 6 plots, giving 22 blocks in each replication.

4.2.4 Field Evaluation and trial management

The trial was evaluated at five locations in Kenya and one location in Uganda (Table 4.2). The choice of the experimental site was based on their unique ecological locations that represent some of the most common smallholder farming systems in East Africa.

At all locations, land was prepared by ploughing and harrowing followed by application of Di-Ammonium Phosphate (18:46:0) at the rate of 27 Kg N ha⁻¹ and 60 Kg P ha⁻¹. Calcium Ammonium Nitrate (CAN) was top dressed at the rate of 60 Kg ha⁻¹ four weeks after emergence. All experiments were kept free from weeds through hand weeding at each location.

The experimental unit was 4 or 5 meter row plot, with spacing of 75 cm between rows, and 20 or 30 cm between hills depending on the location. Two seeds were planted per hill and later thinned to one plant per hill two weeks after emergence to achieve a desired plant density for each location. The hybrids were evaluated under two growing conditions: well-watered and managed drought stress. Under well watered environments, the trials were grown under rain fed conditions in Kibos, Kakamega and Embu, and under irrigation in Kiboko. The moisture was sufficient throughout the growing season. The managed drought stress experiment was carried out at Kiboko during the dry season (June-October) which is rain free thus, allowing for the control of drought stress by withdrawing irrigation water during flowering. Irrigation was applied at the beginning of the season to establish a good plant stand. Afterwards drought stress was achieved by withdrawing irrigation water during two weeks before flowering until the end of the flowering period and throughout the grain filling stage resulting to atleast 25% reduction in grain yield of the optimum conditions. (Bänziger *et al.*, 2000).

Table 4. 2 Locations used to evaluate the F₁ hybrids

Site	Country	Longitude	Latitude	Elevation m asl †	Annual Rainfall (mm)	Soil type	Management
Kiboko	Kenya	36.37 ⁰ E	3.18 ⁰ S	975	530	Sandy clay	M DRT, WW
Embu	Kenya	37.41 ⁰ E	0.45 ⁰ S	1480	1200-1500	Clay loam	WW
Kakamega	Kenya	34.45 ⁰ E	0.16 ⁰ N	1585	1995	Sandy loam	WW
Kibos	Kenya	34.48 ⁰ E	0.04 ⁰ S	1184	1093	Black cotton soil	WW
Namulonge	Uganda	34.04 ⁰ E	0.32 ⁰ N	1150	1500	Sandy clay	R DRT

†m asl: meters above sea level; mm: millimeters; M DRT: Managed drought; R DRT: Random drought; WW: Well-watered.

4.2.5 Data collection for agronomic traits

Under both well-watered and drought conditions, data were recorded for grain yield and other agronomic traits. Grain yield in tons ha⁻¹ was calculated using grain weight at harvest adjusted to 12.5% moisture content using the formula:

$$\frac{(\text{Field weight}/1000) * [(100-\text{moisture content})/87.5 * (10,000/\text{plot area})] * \text{shelling}}{\text{percentage}}$$

Data were recorded for the following traits:

1. Days to silking: day from planting to 50% extruded silks.
2. Anthesis date: number of days after planting when 50% of the plants had shed pollen.
3. Plant height: measured as height from the base of a plant to the first tassel branch of the same plant.
4. Ear height: height between the base of the plant to the insertion of the top ear of the same plant.
5. Root lodging: percentage of plants leaning at an angle >30° from the vertical.
6. Stalk lodging: percentage of plants with broken stalks at or below the main ear at maturity.
7. Husk cover: percentage of plants with ears that were not completely covered by the husks.
8. Ear rots: percentage of ears that were rotten.
9. Ears per plant: number of ears with at least one fully developed grain divided by the number of harvested plants.

10. Ear aspect on a scale (1-5), 1= nice and uniform cobs with the preferred texture in the area; 5= ugly cobs with the undesirable texture in the area.

During the grain filling period, disease severity was rated for northern leaf blight (*Exserohilum turcicum*) and gray leaf spot (*Cercospora zeaе maydis*) on a 1-5 scale (1= clean, no infection to 5= severely diseased).

Under managed drought stress, leaf senescence and leaf rolling were scored. Leaf senescence, scored on a scale of 1-10 was taken during grain filling by estimating the percentage of dead leaf area and dividing it by 10; where 1=10% dead leaf area, 10=100% dead leaf area. Leaf rolling score was taken on a scale of 1 (unrolled, turgid leaves, desirable) to 5 (severely rolled leaves, undesirable) following Bänziger *et al.*, (2000).

4.2.6 Statistical analysis

Analysis of variance for each location and across well-watered environments was carried out using PROC GLM procedure of SAS (SAS, 2003). Adjusted entry means were computed using the PROC MIXED procedure of SAS (SAS, 2003) considering entries as fixed, with replications and blocks within replicates as random factors. Entry means were separated using the least significant difference (LSD) method. The adjusted means were used to compute the phenotypic correlations between the traits.

Line by tester analysis was carried out after the check entries were omitted based on the method described by Kempthorne, (1957). For each environment and across environments, general combining ability (GCA) and specific combining ability (SCA)

effects for grain yield and other agronomic traits were computed based on the line x tester model. The linear model for line x tester (L x T) analysis is:

$$Y_{ijk} = \mu + l_i + t_j + (lx\ t)_{ij} + e_{ijk}$$

where:

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

μ is the general mean;

l_i is the effects of the i^{th} line;

t_j is the effect of the j^{th} tester;

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

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

In L x T analysis, variance due to lines and testers is equivalent to variation due to general combining ability (GCA) effects while variance due to L x T interaction is equivalent to variation due to specific combining ability (SCA) effects. For all traits at each environment, and across environments, GCA (g_i or g_j) and SCA (s_{ij}) effects were estimated as follows:

$$g_i = (y_{i.} - y_{..})$$

$$g_j = (y_{.j} - y_{..})$$

$$s_{ij} = (y_{ij} - y_{..} - g_i - g_j)$$

where y_{ij} is the mean of the hybrid between the i^{th} line and the j^{th} tester, $y_{i.}$ is the mean of all hybrids involving the i^{th} line, $y_{.j}$ is the mean of all hybrids involving the j^{th} tester, and $y_{..}$ is the mean of all hybrids (Sharma, 1998). Standard errors for GCA and SCA effects were used to compute t-values and a two tailed t-test was used to test the significance of GCA and SCA effects. Line x tester analysis, computation of

GCA and SCA effects were carried out using SAS codes written for PROC GLM of SAS. The SCA effects were used to classify the inbred lines into the two known heterotic groups (A and B) used at CIMMYT for tropical maize. An inbred line which possessed negative SCA with any one of the heterotic testers was grouped with the tester with which it revealed negative SCA effects.

Significant

4.3 Results and discussion

4.3.1 Analysis of variance for grain yield and agronomic traits at individual sites

The results of analyses of variance for grain yield and other agronomic traits at individual sites are presented in Tables 4.3 to 4.8. Mean squares for grain yield were significantly different ($P < 0.001$) at all well-watered conditions among genotypes and F_1 hybrids (Tables 4.3-4.7). There was significant ($P < 0.05$) variation among genotypes and F_1 hybrids for grain yield, ears per plant, and ear aspect under managed drought stress (Table 4.8) suggesting differences in response to drought stress among the test genotypes.

Mean squares for anthesis and silking dates, plant height, and ear height were highly significant ($P < 0.001$) among the test genotypes and F_1 hybrids at all well-watered sites (Tables 4.4-4.7). Under managed drought stress, mean squares for silking and anthesis dates were significant ($P < 0.001$) among the test genotypes and F_1 hybrids indicating that there was variation in flowering for these genotypes.

Mean squares for ASI were highly significant ($P < 0.001$) among the test genotypes and F_1 hybrids at Kibos, Kakamega, Kiboko, and Embu under well-watered conditions and Kiboko under managed drought (Tables 4.3-4.8). This suggested differences in the ASI among the genotypes and F_1 hybrids.

Significant differences observed among the lines for all the traits evaluated indicate the presence of a high level of genetic variability in the inbred lines. Morpho-agronomic trait variations among CIMMYT's QPM genotypes have been previously reported by several investigators (Vasal *et al.*, 1993a; b; Akande and Lamidi, 2006). Furthermore, Prasanna *et al.* (2001) noted that genetic variability for most traits in maize is very high and amenable to enhancements. The existence of a wide range between minimum and maximum values of each trait further confirms the presence of substantial variation among the lines studied. The presence of such variation is an opportunity for maize breeders to improve traits of interest through selection, hybridization and recombination of desirable genotypes.

SOURCE	df	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP		HC %	GLS		ET 1-5	EA 1-5	PA 1-5
								#	%		1-5	1-5			
REP	1	31.15***	31.37***	37.88***	0.31	6550.09***	2370.00***	0.12**	47.94	0.03	1.23*	0.08	1.75***		
GENOTYPES	131	1.46***	7.44***	8.38***	3.91**	439.93***	217.90***	0.03***	51.84***	0.04	0.30**	0.13*	0.24***		
F1 HYBRIDS	129	1.48***	7.18***	8.23***	3.97**	442.28***	219.99***	0.03***	52.54***	0.04	0.30**	0.13***	0.24***		
LINE	64	1.80***	12.03***	11.92***	3.42*	506.88***	251.78***	0.04***	69.82***	0.04	0.34**	0.15***	0.27***		
TESTER	1	15.58***	1.54	92.40***	117.79***	6400.39***	3671.27***	0.82***	208.80**	0.00	5.41***	0.70**	0.70*		
LINE*TESTER	64	0.94*	2.42	3.22	2.75	284.59*	134.27*	0.02	32.82*	0.05	0.19	0.10	0.20*		
ERROR	131	0.67	2.36	2.90	2.36	208.46	99.79	0.02	23.25	0.05	0.19	0.09	0.13		

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; HC: Husk cover; GLS: Grey leaf spot; ET=: *E. turcicum*; EA: Ear aspect; PA: Plant aspect.

Table 4. 4 Analysis of variance for grain yield and agronomic traits under well-watered conditions at Kibos

SOURCE	df	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP		ER	GLS		ET 1-5	EA 1-5	PA 1-5
								#	%		1-5	1-5			
REP	1	1.49	1.83	5.18	0.85	136.74	9.47	0.01	78.44	10.05***	0.31*	1.09**	3.08***		
GENOTYPES	131	2.21***	9.63***	11.09***	4.77***	373.46***	210.63***	0.01**	115.17***	0.36***	0.12***	0.48***	0.24***		
F1 HYBRIDS	129	2.20***	9.64***	10.91***	4.77***	360.20***	206.86***	0.01**	116.82***	0.36***	0.12***	0.48***	0.24***		
LINE	64	2.36***	17.86***	17.07***	5.40***	477.58***	268.90***	0.01*	91.92***	0.56***	0.15***	0.46***	0.27***		
TESTER	1	76.04***	0.19	153.85***	143.27***	2586.15***	1478.46***	0.00	2759.92***	1.70***	1.39***	18.58***	4.06***		
LINE*TESTER	64	0.89*	1.56	2.53	1.98**	208.03	124.95*	0.01**	100.43***	0.14**	0.07	0.22*	0.15		
ERROR	131	0.67	1.53	2.12	1.21	180.83	95.16	0.01	42.22	0.09	0.06	0.16	0.13		

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; ER: Ear rots; GLS: Grey leaf spot; ET: *E. turcicum*; EA: Ear aspect; PA: Plant aspect.

SOURCE	df	MEAN SQUARES												
		GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	HC %	ER %	GLS 1-5	ET 1-5	EA 1-5	PA 1-5
REP	1	97.37***	0.19	0.74	0.19	1746.37**	151.52	0.03*	121.91*	15.91	0.16*	0.29*	13.19***	3.19***
GENOTYPES	131	2.30***	11.31***	10.78***	2.45***	391.09***	242.20***	0.02***	32.92*	14.38*	0.11***	0.10**	0.18**	0.20**
F1 HYBRIDS	129	2.23***	11.09***	2.23***	2.45***	390.52***	243.24***	0.02***	33.25*	14.51*	0.11***	0.10*	0.18**	0.20**
LINE	64	2.32***	17.55***	17.80***	1.79**	446.49***	251.03**	0.02***	42.31**	13.53*	0.12***	0.15***	0.14	0.20**
TESTER	1	17.38***	109.85***	0.1	103.45***	8265.98***	4321.54***	0.37***	226.92**	272.96***	2.12***	0.35*	6.78***	3.94***
LINE*TESTER	64	1.91*	3.08**	3.87	1.53*	211.49	171.73	0.01*	21.15	11.45	0.06	0.05	0.12	0.13
ERROR	131	1.17	1.86	1.86	1.01	193.16	136.44	0.01	23.78	9.85	0.05	0.07	0.11	0.12

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; HC: Husk cover; ER: Ear rot; GLS: Grey leaf spot; ET: *E. Turcicum*; EA: Ear aspect; PA: Plant aspect.

Table 4. 6 Analysis of variance for grain yield and agronomic traits under well-watered conditions at Kiboko

SOURCE	df	MEAN SQUARES											
		GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	RL %	SL %	HC %	ER %	EA 1-5
REP	1	6.54***	2.76	14.56***	4.64*	806.75***	192.27*	0.08***	103.00**	82.97*	11.88	119.21***	0.50*
GENOTYPES	131	1.80***	7.42***	6.63***	1.87***	222.43***	319.46***	0.01*	8.70	83.07***	132.48***	6.21	0.29**
F1 HYBRIDS	129	1.78***	7.39***	6.67***	1.89***	221.78***	319.70***	0.01*	8.81	84.20***	134.02***	6.24	5.17***
LINE	64	1.88***	12.44***	10.87***	2.50***	350.87***	422.74***	0.01*	7.71	85.69***	127.09***	7.65	5.84***
TESTER	1	7.53**	54.47***	16.75***	10.80***	656.03**	8995.22***	0.06***	5.18	509.04***	2032.80***	5.70	20.72**
LINE*TESTER	64	1.60***	1.60*	2.32**	1.13	85.91*	81.10	0.00	9.97	76.07***	111.28***	4.84	4.25**
ERROR	131	0.69	1.09	1.27	0.88	57.84	68.65	0.00	9.23	24.75	38.79	6.90	0.11

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: Ear rots; EA: Ear aspect.

SOURCE	df	MEAN SQUARES													
		GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	RL %	SL %	HC %	ER %	GLS 1-5	ET 1-5	EA 1-5	PA 1-5	
REP	1	4.07*	17.00**	25.47***	0.85	0.02	1.5	12.65	201.25	14.99	0.05*	0.34***	0.46*	0.59**	
GENOTYPES	131	3.25***	12.59***	13.89***	3.26***	0.01	35.18*	8.05	524.56***	35.57*	0.02*	0.02*	0.29***	0.17***	
F1 HYBRIDS	129	3.29***	12.30***	13.56***	3.29***	0.01	34.82*	8.12	516.39***	35.76*	0.02*	0.02*	0.30***	0.17***	
LINE	64	4.05***	21.07***	24.80***	3.13	0.02	39.38*	7.03	534.31***	45.06	0.02	0.02	0.38	0.20***	
TESTER	1	64.08***	102.19***	3.23	69.06	0.24	16.91	18.52	16296.19***	88.98	0.06	0.02	4.32	3.35***	
LINE*TESTER	64	1.59	2.13	2.46	2.42	0.01	30.55	9.05	251.92*	25.62	0.02	0.03	0.15	0.08	
ERROR	131	1.23	1.80	1.90	1.37	0.01	27.96	9.34	164.45	25.3	0.02	0.02	0.10	0.08	

* , ** , *** , Significant at 0.05, 0.01 and 0.001 probability levels, respectively

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; ET: *E. turcicum*; EA: Ear aspect; PA: Plant aspect.

Table 4. 8 Analysis of variance for grain yield and other agronomic traits under managed drought stress at Kiboko

SOURCE	df	MEAN SQUARES													
		GY† t ha ⁻¹	EPP #	ER %	HC %	RL %	SEN 1-10	SL %	AD days	df	ASI days	SD days	df	MOD 1-5	
REP	1	2.24*	0.36*	31.37*	72.45*	163.72	7.23*	3.98	1	53.47***	1	4.86	12.33*	1	0.28
GENOTYPES	131	0.96*	0.08*	8.46	21.15	141.16*	2.99*	11.87	129	11.47***	80	19.35***	25.04***	131	0.59*
F1 HYBRIDS	129	0.98*	0.08*	8.59	21.46	141.67*	0.03	12.01	127	11.20***	79	18.33***	23.17***	129	0.59*
LINE	64	0.91	0.08*	8.40	27.52*	140.90*	0.02	12.45	64	18.67***	53	20.13***	27.91***	64	0.53
TESTER	1	1.39	0.14	0.67	8.53	1981.68***	0.02	17.27	1	126.56***	1	22.47*	0.62	1	8.78***
LINE*TESTER	64	1.04*	0.09*	8.89	15.60	113.70	0.04*	11.50	62	1.83*	25	14.29***	14.36***	64	0.53
ERROR	131	0.74	0.05	8.46	20.13	101.76	2.17	13.14	127	1.21	74	4.02	3.44	127	0.40

* , ** , *** , Significant at 0.05, 0.01 and 0.001 probability levels, respectively

†GY: Grain yield; EPP: Ears per plant; EA: Ear aspect; ER: Ear rots; HC: Husk cover; RL: Root lodging; SEN: Senescence; SL: Stem lodging; AD: Anthesis date; ASI: Anthesis-silking interval; SD: Silking date; MOD: Modification.

4.3.2 Performance of hybrids under well-watered conditions

Mean grain yield and agronomic traits for the top 20 hybrids at the well-watered sites are presented in Tables 4.9 to 4.13. The mean yield for the hybrids was highest at Embu (9.05 t ha⁻¹) and lowest at Kibos (4.26 t ha⁻¹) (Tables 4.13 and 4.10 respectively). Under well-watered conditions, yield of hybrids between the inbred lines and tester 1 (CML144) were higher compared to those with tester 2 (CML159). For example at Kibos, top 20 hybrids were crosses with tester 1 (Table 4.10). The mean days to anthesis for the hybrids ranged from 59-77 days while days to silking ranged from 59-76 days. At Kiboko, the hybrids matured earlier than any other site (Table 4.12). This might have been due to the high temperatures experienced at this site during the season. The mean anthesis-silking interval for the top performing hybrids at all sites ranged from 0.20 to -1.36 days. The proper synchronization of the male and female flowering contributed to superior grain filling of these hybrids. At Kibos, there was a high percentage of root lodging compared to all other well-watered sites (Table 4.10). Poor husk cover percentages were also high among some entries at this site. Entry 57 was an exception and only 1.9% of the ears had open tips and was second in performance in terms of grain yield at this site. At Kakamega which is a hot spot for turicum leaf blight disease, most hybrids showed some level of tolerance with scores ranging from 1.9 to 3.1 (Table 4.11).

The existence of a wide range between minimum and maximum values of each trait further confirms the presence of substantial variation among the lines studied. The presence of such variation is an opportunity for maize breeders to improve traits of interest through selection, hybridization and recombination of desirable genotypes.

Table 4. 9 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Namulonge

NO.	ENTRY	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	HC %	GLS		ET		EA		PA	
											1-5	1-5	1-5	1-5	1-5	1-5	1-5	1-5
1	57	29x1	7.05	60.3	60.6	0.0	195.0	79.7	1.46	0.0	1.3	2.1	2.1	2.7	2.7	2.5	2.5	2.5
2	3	2x1	7.03	63.5	62.2	-1.5	208.7	104.8	1.29	8.9	1.5	2.5	2.5	2.7	2.7	2.5	2.8	2.8
3	127	64x1	6.74	66.4	66.6	0.5	214.1	109.4	1.38	0.0	1.5	2.1	2.1	2.5	2.5	2.8	3.0	3.0
4	90	45x2	6.70	63.2	61.3	-1.5	197.8	104.0	1.11	0.0	1.5	2.0	2.0	2.6	2.6	2.5	2.5	2.5
5	11	6x1	6.55	62.8	62.4	-0.5	185.3	86.6	1.11	0.0	1.5	1.8	1.8	2.7	2.7	2.7	2.7	2.7
6	39	20x1	6.32	67.2	64.4	-3.0	181.8	82.9	0.95	0.0	1.5	2.2	2.2	2.7	2.7	2.7	2.7	2.7
7	94	47x2	6.08	66.0	66.3	0.5	179.7	86.0	1.27	0.0	1.5	1.9	1.9	2.7	2.7	2.8	2.8	2.8
8	125	63x1	6.05	64.8	62.6	-2.5	186.7	85.9	1.04	0.0	1.5	2.1	2.1	2.7	2.7	3.0	3.0	3.0
9	73	37x1	6.05	61.8	59.4	-2.5	188.2	81.5	1.39	6.7	1.3	2.0	2.0	2.7	2.7	3.0	3.0	3.0
10	33	17x1	6.00	63.6	63.8	0.5	212.4	104.8	1.25	0.0	1.0	2.0	2.0	2.5	2.5	3.0	3.0	3.0
11	103	52x1	6.00	65.2	63.1	-2.0	172.7	86.7	1.25	13.4	1.5	2.3	2.3	3.0	3.0	2.5	2.5	2.5
12	1	1x1	5.94	63.9	62.4	-1.5	205.6	77.8	1.23	0.0	1.5	2.0	2.0	3.0	3.0	3.0	3.0	3.0
13	31	16x1	5.94	64.5	66.3	2.0	197.0	100.5	1.38	0.0	1.5	2.2	2.2	3.5	3.5	3.0	3.0	3.0
14	56	28x1	5.92	63.3	64.6	1.0	174.7	80.5	0.98	5.9	1.3	2.3	2.3	2.5	2.5	2.7	2.7	2.7
15	84	42x2	5.91	65.9	66.1	0.0	189.1	75.4	1.15	0.0	1.3	2.5	2.5	3.0	3.0	3.3	3.3	3.3
16	113	57x1	5.89	61.7	59.2	-2.0	183.7	78.7	1.18	0.0	1.5	2.0	2.0	2.8	2.8	2.7	2.7	2.7
17	63	32x1	5.80	63.7	63.3	-0.5	201.6	94.7	1.10	0.0	1.3	2.5	2.5	2.9	2.9	2.7	2.7	2.7
18	75	38x1	5.79	66.0	67.1	1.0	207.6	94.4	1.06	0.0	1.5	1.5	1.5	2.5	2.5	2.8	2.8	2.8
19	60	30x2	5.76	63.1	63.7	0.5	190.2	85.3	1.02	0.0	1.5	2.2	2.2	3.0	3.0	3.0	3.0	3.0
20	12	6x2	5.76	65.1	65.9	1.0	182.0	84.1	1.05	0.0	1.8	2.6	2.6	2.5	2.5	2.5	2.5	2.5
21	131	Check 1	5.05	67.5	66.9	-0.5	203.9	91.0	0.99	3.4	1.5	1.8	1.8	2.8	2.8	2.7	2.7	2.7
22	132	Check 2	4.84	68.3	67.7	-0.5	177.6	79.4	1.00	0.0	1.3	2.5	2.5	2.8	2.8	3.3	3.3	3.3
		Mean of trial	4.90	64.30	64.30	0.00	182.60	83.70	1.07	2.40	1.40	2.30	2.30	2.90	2.90	3.10	3.10	3.10
		Mean of top 20 hybrids	6.17	64.10	63.57	-0.53	192.70	89.17	1.18	1.74	1.43	2.15	2.15	2.76	2.76	2.79	2.79	2.79
		Mean of checks	4.94	67.91	67.27	-0.50	190.75	85.19	1.00	1.67	1.38	2.14	2.14	2.77	2.77	3.01	3.01	3.01
		LSD (0.05)	1.27	2.60	3.10	3.00	22.90	17.20	0.22	9.60	0.40	0.80	0.80	0.60	0.60	0.70	0.70	0.70
		CV	13.08	2.10	2.40	-5775.0	6.30	10.40	10.18	200.5	14.90	17.10	17.10	9.70	9.70	11.20	11.20	11.20

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; HC: Husk cover; GLS: Grey leaf spot; ET: *E. Turcicum*; EA: Ear aspect; PA: Plant aspect.

Table 4. 10 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Kibos

NO.	ENTRY	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	RL %	SL %	HC %	ER %	GLS		ET		EA		PA 1-5
														1-5	1-5	1-5	1-5			
1	89	45x1	6.62	62.3	61.8	0.0	204.8	104.7	1.09	28.7	13.1	26.6	0.8	2.6	2.2	2.2	1.7	2.2	2.2	2.2
2	57	29x1	6.41	60.2	59.8	-0.5	206.1	94.2	1.00	32.0	5.7	1.9	0.0	2.2	2.1	2.1	2.1	2.1	2.1	2.0
3	85	43x1	6.41	60.6	60.8	0.5	197.8	94.9	1.04	40.7	2.7	57.8	7.9	2.1	2.1	2.1	2.7	2.7	2.3	2.3
4	39	20x1	6.22	67.7	65.5	-2.0	184.5	88.6	1.02	26.1	16.8	25.9	0.0	2.4	2.5	2.5	2.2	2.2	2.2	2.2
5	87	44x1	6.21	63.5	62.0	-1.0	198.1	100.3	1.03	31.5	8.5	59.3	3.2	3.4	2.5	2.5	2.3	2.3	2.3	2.3
6	123	62x1	6.04	65.8	64.5	-0.5	200.5	102.7	0.99	29.6	8.0	10.5	2.8	2.6	2.4	2.4	1.7	2.2	2.2	2.2
7	93	47x1	5.98	63.6	63.0	0.0	190.8	89.8	1.06	50.8	6.8	6.1	0.6	2.7	2.2	2.2	1.9	2.3	2.3	2.0
8	37	19x1	5.97	64.5	65.0	0.5	189.3	88.5	1.10	45.1	8.3	3.1	0.9	2.7	2.5	2.3	2.3	2.2	2.3	2.0
9	79	40x1	5.89	61.7	62.6	0.0	198.2	89.4	1.00	0.6	2.5	4.0	1.7	2.4	2.3	2.3	2.4	2.4	2.2	2.2
10	29	15x1	5.88	65.5	65.3	0.0	204.0	101.2	1.09	38.3	7.8	38.7	2.0	2.3	2.3	2.3	2.4	2.2	2.2	2.2
11	127	64x1	5.65	65.3	66.3	1.0	208.5	106.8	1.07	36.4	3.4	4.4	4.8	2.5	2.1	2.1	2.2	2.2	1.7	1.7
12	115	58x1	5.62	64.5	64.6	0.0	198.7	89.0	1.11	19.1	8.7	38.6	2.7	2.7	2.3	2.3	2.7	2.7	2.5	2.5
13	77	39x1	5.59	62.9	62.1	-0.5	198.1	95.6	1.01	35.4	3.7	79.1	0.5	2.3	2.1	2.1	3.0	3.0	2.5	2.5
14	21	11x1	5.58	62.0	62.1	0.0	187.9	93.1	1.11	37.4	15.3	66.9	0.1	2.0	2.3	2.3	2.6	2.6	2.5	2.5
15	1	1x1	5.58	64.2	63.7	-1.0	199.4	90.0	1.04	14.9	10.8	8.6	0.3	2.8	2.4	2.4	1.9	2.2	2.2	2.3
16	31	16x1	5.57	65.7	65.8	0.0	186.2	86.6	0.98	14.4	6.1	15.2	0.1	2.9	2.4	2.4	2.0	2.0	2.3	2.3
17	13	7x1	5.56	64.8	65.0	0.0	201.2	99.3	1.09	23.7	38.6	20.1	2.2	2.5	2.2	2.2	2.5	2.5	2.0	2.0
18	41	21x1	5.45	63.8	64.7	0.5	183.8	84.8	1.01	24.7	3.3	54.7	1.7	2.3	2.4	2.4	3.2	3.2	2.2	2.2
19	113	57x1	5.41	59.6	60.6	1.0	193.2	86.5	1.07	51.6	2.9	16.6	0.0	2.8	2.5	2.5	2.5	2.5	2.3	2.3
20	91	46x1	5.38	60.9	62.7	1.0	190.5	80.0	1.05	56.0	8.2	7.7	0.0	1.8	2.2	2.2	2.4	2.4	2.2	2.2
45	131	Check 1	4.75	66.8	67.3	0.0	192.5	95.4	0.93	48.9	16.6	79.3	2.9	2.3	2.3	2.5	3.1	3.1	2.3	2.3
86	132	Check 2	3.82	68.2	71.0	3.0	183.6	92.7	0.90	16.1	2.8	35.4	0.0	2.2	2.6	2.6	3.2	3.2	2.8	2.8
		Mean of trial	4.26	64.00	65.10	1.10	189.80	89.10	1.04	35.20	12.00	44.50	6.00	2.50	2.50	2.50	3.00	3.00	2.60	2.60
		Mean of top 20 hybrids	5.85	63.45	63.40	-0.05	196.08	93.30	1.05	31.85	9.05	27.29	1.62	2.51	2.31	2.31	2.33	2.33	2.23	2.23
		Mean of checks	4.28	67.47	69.20	1.51	188.06	94.03	0.91	32.50	9.72	57.34	1.45	2.24	2.52	2.52	3.13	3.13	2.50	2.50
		LSD (0.05)	1.59	1.60	2.300	2.10	19.20	13.50	0.15	35.60	18.40	29.40	12.50	0.40	0.40	0.40	0.60	0.60	0.70	0.70
		CV	18.76	1.30	1.80	95.10	5.10	7.60	7.32	50.90	77.60	33.30	104.50	9.10	8.10	8.10	10.90	10.90	14.30	14.30

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: Ear rot; GLS: Grey leaf spot; ET: *E. Turcicum*; EA: Ear aspect; PA: Plant aspect.

Table 4. 11 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Kakamega

NO.	ENTRIES	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	RL %	SL %	HC %	ER %	GLS		EA		PA
														1-5	1-5	1-5	1-5	
1	77	39x1	9.38	75.9	73.8	-1.8	200.0	106.8	1.11	28.0	10.8	2.7	0.0	2.0	1.9	2.8	2.6	
2	55	28x1	9.16	76.9	78.1	1.4	200.4	103.2	1.00	12.3	15.4	7.2	0.0	1.9	2.3	2.8	2.9	
3	51	26x1	8.74	79.5	78.8	-0.9	180.3	89.2	1.00	4.3	31.9	0.0	0.0	2.3	2.3	2.7	3.0	
4	121	61x1	8.50	81.4	78.9	-2.8	193.2	108.5	1.23	18.1	25.5	0.0	0.0	1.9	2.4	2.7	2.4	
5	117	59x1	8.42	76.7	74.6	-2.1	197.8	94.4	1.23	18.2	1.7	2.5	3.1	2.1	2.3	2.8	2.5	
6	56	28x2	8.40	76.2	76.4	0.1	195.6	92.1	1.08	18.1	0.60	5.0	5.0	2.1	2.2	3.0	2.5	
7	73	37x1	8.31	74.9	73.8	-1.4	204.0	101.3	1.54	27.5	24.8	8.6	0.2	2.5	2.1	2.6	2.6	
8	34	17x2	8.21	77.4	77.9	0.5	167.9	87.6	0.98	32.9	16.8	5.6	0.0	2.0	2.4	3.4	3.5	
9	70	35x2	8.10	76.3	76.2	0.0	183.0	97.9	1.03	8.9	14.8	2.7	2.2	2.3	2.2	3.1	2.7	
10	129	65x1	8.03	73.7	73.3	-0.2	193.6	98.8	1.03	1.5	30.2	0.0	0.0	2.5	1.9	2.7	2.8	
11	40	20x2	8.02	75.4	73.5	-1.4	197.5	79.0	0.93	16.9	8.5	16.7	8.3	2.0	2.3	3.0	2.9	
12	87	44x1	7.96	78.1	74.1	-4.0	196.0	110.4	1.23	5.0	8.4	0.0	0.0	2.3	2.6	2.7	2.5	
13	59	30x1	7.90	75.8	73.2	-2.3	189.4	93.7	1.10	30.3	13.6	0.0	0.4	2.0	2.4	2.8	2.8	
14	23	12x1	7.83	75.3	74.0	-1.5	198.2	101.3	1.16	14.9	0.1	0.0	2.6	2.3	2.4	3.0	2.5	
15	58	29x2	7.81	73.9	74.3	0.2	180.0	82.6	1.08	30.2	7.1	2.5	0.2	2.5	2.6	3.0	2.8	
16	127	64x1	7.79	82.1	81.3	-0.7	207.0	106.7	1.08	35.2	11.6	0.0	2.5	2.0	2.2	3.0	2.4	
17	27	14x1	7.79	76.4	75.6	-1.2	209.9	114.6	1.05	18.9	10.3	7.5	0.2	2.0	2.4	3.0	2.4	
18	123	62x1	7.68	79.3	78.2	-1.6	189.6	106.6	1.15	5.4	27.4	0.0	0.0	2.0	3.0	2.7	2.7	
19	113	57x1	7.68	73.1	73.4	-0.1	183.4	93.5	1.16	0.0	5.0	2.5	2.2	2.5	2.7	2.8	2.7	
20	45	23x1	7.66	81.1	79.0	-2.4	182.2	90.3	1.03	6.1	44.0	2.7	4.8	2.0	2.8	3.0	3.2	
21	131	Check 1	8.67	76.9	77.1	-0.2	180.8	98.1	0.95	28.5	14.0	4.8	0.2	2.0	2.3	2.8	3.0	
70	132	Check 2	6.66	82.5	81.0	-1.8	204.6	100.2	1.11	27.9	26.9	0.0	0.6	2.1	2.2	2.9	2.9	
		Mean of trial	6.67	77.0	76.7	-0.30	187.00	93.60	1.06	23.00	17.30	2.80	1.70	2.10	2.50	3.10	3.00	
		Mean of top 20 hybrids	8.17	76.98	75.93	-1.11	192.44	97.94	1.11	16.63	15.43	3.31	1.59	2.16	2.36	2.88	2.73	
		Mean of checks	7.67	79.70	79.01	-1.00	192.69	99.14	1.03	28.20	20.46	2.40	0.40	2.02	2.25	2.83	2.95	
		LSD (0.05)	1.84	2.00	2.40	1.80	24.90	17.80	0.19	29.00	24.70	9.70	6.00	0.40	0.50	0.60	0.60	
		CV	13.85	1.30	1.50	-270.20	6.70	9.60	8.91	63.50	71.70	175.5	182.5	9.70	9.30	10.0	9.70	

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: Ear rot; GLS: Grey leaf spot; ET: *E. Turcicum*; EA: Ear aspect; PA: Plant aspect.

Table 4. 12 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Kiboko

NO.	ENTRY	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI days	PH cm	EH cm	EPP #	RL %	SL %	HC %	ER %	EA 1-5
1	49	25x1	11.25	60.5	61.7	1.0	231.0	134.7	1.08	0.0	1.8	0.0	0.0	2.0
2	60	30x2	10.55	58.2	58.8	0.5	228.8	113.5	1.03	0.0	0.0	9.7	0.2	2.5
3	59	30x1	10.53	58.4	57.2	-1.0	231.6	125.4	1.05	2.7	0.0	0.0	0.0	2.2
4	47	24x1	10.49	61.3	61.8	0.5	226.8	131.7	0.98	0.0	0.6	0.0	0.5	2.2
5	63	32x1	10.42	59.0	58.2	-1.0	245.2	126.5	1.10	0.0	0.8	0.0	0.2	2.8
6	35	18x1	10.36	60.8	61.4	0.5	245.7	139.7	1.20	0.0	1.2	0.0	0.0	2.0
7	26	13x2	10.32	57.1	57.6	0.5	234.1	117.3	0.98	0.0	0.4	2.6	0.0	2.5
8	79	40x1	10.30	57.2	57.2	0.0	224.1	117.6	1.05	0.0	0.3	2.5	0.3	2.5
9	77	39x1	10.10	57.2	56.8	-0.5	223.6	111.6	1.01	0.0	0.3	4.9	0.3	2.0
10	55	28x1	10.08	60.3	59.2	-1.0	248.0	132.0	1.11	7.5	0.0	5.1	0.2	2.3
11	119	60x1	10.06	59.5	60.2	0.5	230.0	115.2	1.30	6.7	12.2	0.2	1.7	2.5
12	89	45x1	10.04	57.6	57.3	0.0	236.7	139.5	1.07	0.0	14.8	0.0	0.1	2.3
13	51	26x1	10.02	60.6	61.1	0.5	226.2	130.4	1.02	0.0	0.0	9.8	0.0	2.5
14	1	1x1	10.00	58.2	57.8	-0.5	236.9	127.2	1.04	0.0	2.5	0.0	0.0	2.0
15	87	44x1	9.93	57.2	57.3	0.0	236.5	134.3	1.05	0.0	0.0	2.9	0.0	2.5
16	3	2x1	9.87	57.2	57.9	0.5	238.3	120.2	1.02	0.0	1.7	2.2	0.1	2.5
17	12	6x2	9.82	57.3	59.2	2.0	236.7	122.2	1.02	0.0	0.0	0.0	0.6	2.3
18	72	36x2	9.71	57.2	57.5	0.5	224.2	110.7	1.06	5.6	0.0	16.9	0.2	2.7
19	54	27x2	9.66	57.5	58.1	0.5	231.9	108.8	1.13	0.0	0.0	4.6	1.6	2.9
20	45	23x1	9.66	61.6	62.3	0.5	234.6	137.9	1.08	0.0	7.0	2.3	2.7	2.5
131	131	Check 1	10.36	60.0	60.0	0.0	235.6	128.0	0.97	0.0	0.2	0.0	0.0	3.0
132	132	Check 2	8.47	61.2	61.2	0.0	237.0	130.6	1.01	0.0	0.0	0.1	2.8	3.0
Mean of trial			8.70	58.40	59.10	0.70	228.4	117.50	1.01	0.80	2.20	4.00	0.90	2.70
Mean of top 20 hybrids			10.16	58.69	58.93	0.20	233.54	124.82	1.07	1.13	2.18	3.19	0.44	2.37
Mean of Checks			9.41	60.60	60.58	0.00	236.28	129.30	0.99	0.00	0.10	0.05	1.40	3.01
LSD (0.05)			1.51	1.80	2.10	1.90	11.00	15.10	0.13	6.00	9.20	12.20	4.90	0.60
CV			8.71	1.60	1.80	129.40	2.40	6.50	6.55	374.7	207.3	152.5	275.6	11.60

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: Ear rot; EA: Ear aspect.

Table 4. 13 Grain yield and agronomic traits of the top 20 entries under well-watered conditions at Embu

NO.	ENTRY	CROSS	GY† t ha-1	AD days	SD days	ASI days	EPP #	RL %	SL %	HC %	ER %	GLS		EA	PA
												1-5	1-5		
1	59	30x1	12.10	70.5	68.5	-2.0	1.12	0.0	0.0	0.1	2.0	1.0	1.5	2.5	2.8
2	63	32x1	11.53	72.5	69.5	-3.0	1.23	0.0	0.1	9.8	3.7	1.0	1.5	2.7	2.1
3	103	52x1	11.52	73.0	71.5	-1.5	0.81	2.4	7.0	26.5	11.0	1.0	1.5	2.9	2.7
4	57	29x1	11.24	67.0	65.0	-2.1	1.10	0.0	0.0	5.2	4.2	1.0	1.5	2.5	2.5
5	45	23x1	11.16	75.5	75.0	-0.5	0.98	2.4	1.4	10.0	2.4	1.5	1.5	2.5	2.6
6	77	39x1	11.13	72.0	69.0	-3.0	0.95	0.0	0.1	87.4	2.4	1.0	1.5	2.9	2.5
7	113	57x1	10.98	66.5	65.0	-1.4	1.08	2.4	0.4	7.4	0.0	1.0	1.5	2.0	2.4
8	95	48x1	10.87	70.5	72.0	1.5	1.08	0.0	0.3	7.7	0.0	1.0	1.5	2.0	2.5
9	21	11x1	10.84	70.5	68.0	-2.5	0.95	0.0	0.0	12.0	2.4	1.0	1.5	2.8	2.9
10	76	38x2	10.73	72.0	70.5	-1.4	0.93	4.8	0.7	21.6	0.0	1.0	2.0	2.7	2.2
11	75	38x1	10.70	74.5	75.0	0.5	0.98	0.0	0.0	11.8	2.5	1.8	1.5	3.0	2.5
12	73	37x1	10.68	71.0	66.0	-4.9	1.17	0.0	0.5	21.4	8.3	1.0	1.5	2.8	2.2
13	91	46x1	10.59	67.5	65.5	-2.0	1.03	0.0	0.1	9.9	4.8	1.0	1.5	2.6	2.5
14	115	58x1	10.57	71.0	69.0	-2.0	1.07	2.4	0.0	7.0	2.0	1.0	1.5	2.5	2.7
15	98	49x1	10.53	67.5	68.5	1.0	1.00	0.0	0.4	5.2	7.3	1.0	1.5	3.5	2.0
16	88	44x2	10.45	68.5	66.0	-2.6	0.98	0.0	1.6	11.9	7.5	1.0	1.5	2.6	2.9
17	60	30x2	10.42	68.5	69.0	0.4	1.00	0.0	0.4	2.4	0.0	1.0	1.5	2.7	2.5
18	85	43x1	10.42	68.5	67.5	-1.1	1.10	0.0	0.0	31.7	6.8	1.0	1.7	2.8	2.5
19	114	57x2	10.41	66.0	66.0	0.0	0.98	0.0	0.4	32.2	2.5	1.0	1.5	2.5	1.9
20	35	18x1	10.39	73.0	72.5	-0.5	1.05	0.0	0.1	2.8	0.0	1.0	1.5	2.5	2.2
131	131	Check 1	9.56	73.5	71.5	-1.9	1.00	0.0	2.2	48.9	0.0	1.0	1.7	3.0	2.9
132	132	Check 2	8.69	76.5	76.0	-0.5	0.86	9.5	2.3	7.5	2.8	1.2	1.7	2.8	2.5
Mean of trials			9.05	71.40	70.20	-1.20	0.97	2.20	1.10	18.50	4.50	1.00	1.50	2.80	2.50
Mean of top 20 hybrids			10.86	70.30	68.95	-1.36	1.03	0.72	0.68	16.20	3.48	1.06	1.54	2.65	2.46
Mean of checks			9.12	75.00	73.75	-1.20	0.93	4.75	2.25	28.18	1.400	1.12	1.75	2.90	2.74
LSD (0.05)			2.16	2.70	2.70	2.30	0.22	10.50	5.50	25.20	10.00	0.20	0.20	0.60	0.50
CV			12.02	1.90	2.00	-97.50	11.47	236.20	246.6	68.80	111.90	12.10	7.90	10.10	10.20

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; ET: E. Turcicum, EA: Ear aspect; PA: Plant aspect.

4.3.3 Performance of hybrids under managed drought stress

Mean grain yield and agronomic traits of the top 20 best performing hybrids are presented in Table 4.14. The mean yield for the trial under drought was 1.03 t ha⁻¹. Hybrids between tester 2 (CML159) formed majority of the better yielding hybrids under managed drought stress compared to hybrids with tester 1 (CML144). Thirteen of the top 20 hybrids were hybrids with tester 2 as a parent (Table 4.14). Inbred line 4 and 13 made high yielding crosses with both testers implying that the two lines had positive SCA effects with both testers. Three hybrids performed significantly better than the highest yielding check. The mean anthesis-silking interval of the hybrids was significantly shorter than that of the experimental checks (2.8 vs. 12.5 days). This suggested that there was proper synchronization of the male and female flowering of the hybrids compared to the checks contributing to superior grain yields.

In one of the few examples of selection based on drought-adaptive traits, the lowland tropical maize population Tuxpeno Sequia underwent eight cycles of recurrent selection across three controlled levels of drought at a rainless site in Mexico. Selections were for progenies with high yield, reduced anthesis-silking interval (ASI), increased relative stem-leaf extension rate, cooler canopy temperature and increased stay-green, all observed under drought, and for average yield, maturity and plant height under well-watered conditions (Edmeades *et al.*, 1987; Fischer *et al.*, 1989).

The secondary traits were thought to indicate improved ability to maintain a positive water balance under drought, and were consistent with the best available knowledge in crop

physiology. Data collected during selection revealed faster progress with the use of these secondary traits in addition to grain yield *per se*, and that the correlation between these and yield under drought were generally high and significant (Fischer *et al.*, 1989). Ears per plant were less than one for all entries. Number of ears per plant is a trait related to barrenness and the results in this study suggest that drought induced barrenness in these hybrids. A higher number of ears per plant under managed drought stress has been used as an indicator of drought tolerance (Bolaños and Edmeades, 1996).

Bolaños and Edmeades (1993b, 1996) reported a strong dependence of grain yield on ASI. Bolaños and Edmeades (1996) reported an average genetic correlation of -0.48 between grain yield and ASI and noted that grain yield decreased to less than 20% of its well-watered levels as ASI increased from 0 to 5 days, and then declined asymptotically to almost zero yields as ASI increased.

Leaf senescence scores were on average lower for the top three hybrids with the higher yields compared to the checks. This confirms earlier reports that senescence can increase the efficiency of selection of grain yield in drought environments (Betran *et al.*, 2003a).

Table 4. 14 Grain yield and secondary traits of the top 20 entries under managed drought stress at Kiboko

NO.	ENTRY	CROSS	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	RL %	SL %	HC %	ER %	SEN 1-10	NDVI 0-1	MOD 1-5	EA 1-5
1	18	9X2	3.00	71.5	72.0	0.5	0.7	3.6	0.0	0.0	0.0	5.1	0.8	3.8	3.0
2	34	17X2	2.97	71.5	75.5	4.0	0.8	11.8	0.0	3.0	0.0	5.3	0.9	3.3	2.8
3	90	45X2	2.82	69.0	68.5	-0.5	0.7	14.5	0.0	0.0	0.0	6.2	0.9	2.8	3.0
4	102	51X2	2.73	65.0	69.0	4.0	0.5	0.0	0.0	7.9	3.4	6.7	0.9	2.3	3.3
5	55	28X1	2.62	70.5	73.0	2.5	0.4	11.5	0.0	0.0	0.0	6.2	0.9	2.5	3.0
6	103	52X2	2.44	70.0	71.0	1.0	0.7	0.0	0.0	0.0	0.0	5.1	0.8	3.5	3.3
7	72	36X2	2.30	67.0	69.5	2.5	0.8	5.3	2.7	0.0	0.0	5.7	0.9	3.5	3.0
8	4	2X2	2.29	66.5	69.0	2.5	0.6	7.9	0.0	5.3	3.4	5.2	0.9	3.8	3.3
9	10	5X2	2.28	69.0	72.0	3.0	0.6	2.8	0.0	8.4	0.0	6.7	0.8	3.3	3.3
10	60	30X2	2.28	70.0	73.0	3.0	0.5	3.0	5.9	2.7	0.0	6.3	0.8	3.5	3.3
11	14	7X2	2.23	70.5	73.5	3.0	0.6	11.8	0.0	6.3	0.0	5.2	0.8	3.0	3.3
12	7	4X1	2.16	67.5	71.5	4.0	0.7	5.9	0.0	5.3	0.0	5.2	0.9	2.5	3.0
13	93	47X1	2.16	68.5	75.0	6.5	0.6	3.4	0.0	0.0	0.0	6.7	0.9	2.5	2.8
14	32	16X2	2.14	71.0	75.5	4.5	0.9	12.5	3.0	0.0	0.0	5.9	0.9	3.5	3.0
15	107	54X1	2.00	70.5	-	-	0.5	0.0	0.0	0.0	0.0	5.7	0.8	2.3	4.0
16	113	57X1	1.98	65.5	69.0	3.5	0.7	17.2	0.0	0.0	0.0	6.4	0.9	2.5	3.3
17	8	4X2	1.98	65.5	69.5	4.0	0.4	16.7	0.0	0.0	0.0	7.0	0.9	3.3	3.0
18	87	44X1	1.95	68.5	71.5	3.0	0.6	2.8	0.0	0.0	0.0	6.8	0.9	2.3	3.3
19	25	13X1	1.92	69.5	70.5	1.0	0.7	14.4	0.0	0.0	0.0	4.5	0.9	3.0	2.8
20	26	13X2	1.88	68.5	68.3	0.8	0.5	3.2	3.2	0.0	0.0	6.9	0.9	3.8	3.5
21	131	Check 1	1.08	70.5	83.0	12.5	0.4	3.2	0.0	0.0	0.0	8.2	0.9	3.0	3.3
22	132	Check 2	0.60	74.5	-	-	0.3	0.0	0.0	0.0	0.0	6.6	0.9	3.5	3.8
	Mean of trial		1.03	69.21	73.13	4.46	0.37	8.71	1.07	0.78	0.34	7.46	0.85	3.08	3.62
	Mean of top 20 hybrids		2.30	68.78	71.41	2.78	0.62	7.39	0.73	1.93	0.34	5.91	0.85	3.03	3.14
	Mean of checks		0.84	72.50	83.00	12.50	0.30	1.58	0.00	0.00	0.00	7.35	0.85	3.25	3.50
	LSD		1.70	2.16	3.70	4.00	0.46	19.96	7.17	8.87	5.75	2.91	0.10	1.25	1.15

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; RL: Root lodging; SL: Stem lodging; HC: Husk cover;

ER: Ear rot; SEN: Senescence; NDVI: Normalized difference vegetative index; MOD: Modification; EA: Ear aspect.

-: no values were recorded since the hybrids did not attain 50% silking.

4.3.4 Performance of hybrids across well-watered conditions

The average yield of the best 20 hybrids and the checks was 7.7 t ha⁻¹ and 7.42 t ha⁻¹ respectively (Table 4.15). Entries 55, 60, 103 and 113 had good yield both under optimal conditions and drought stress. This indicated that it should be possible to combine stress tolerance and yield potential in these QPM hybrids. Out of the 20 best performing hybrids for yield under optimal conditions, 18 entries were crosses with tester 1 (CML144). Perhaps most of the parents involved in this crosses belong to the same heterotic group.

The mean days to anthesis and silking across optimal sites were 67 days, while the average anthesis-silking interval was 0.1 days (Table 4.15). In comparison to the anthesis-silking interval under drought stress which was 4.5 days, this meant that that with drought stress, ASI increased (Table 4.14).

The mean number of ears per plant was higher than one for all best performing hybrids across optimal conditions and this resulted into the high yields. Lower scores for ear aspect were recorded across optimal sites (Table 4.15) than under drought stress (Table 4.14). This confirms earlier findings that some QPM genotypes under severe drought stress can significantly increase the frequency of soft and poorly modified grains, relative to the same genotypes under optimal growing conditions (Ngaboyisonga *et al.*, 2006).

Table 4. 15 Grain yield and secondary traits of the top 20 entries across well-watered sites.

NO.	ENTRY	CROSS	GY [†] t ha ⁻¹	AD days	SD days	ASI days	EPP #	PH cm	EH cm	HC %	ER %	GLS		ET		EA		PA	
												1-5	1-5	1-5	1-5	1-5	1-5	1-5	1-5
1	77	39X1	8.26	66.3	65.1	-1.2	1.0	199.4	100.3	36.2	0.6	1.7	2.0	2.8	2.6				
2	57	29X1	8.08	63.3	63.0	-0.3	1.1	214.4	98.7	1.5	1.0	1.6	2.0	2.5	2.5				
3	59	30X1	7.98	66.1	65.2	-0.9	1.1	193.9	92.9	12.4	1.2	1.7	2.2	2.7	2.9				
4	79	40X1	7.98	65.6	65.1	-0.5	1.1	203.8	101.8	2.6	2.3	1.8	2.0	2.7	2.6				
5	85	43X1	7.96	64.1	64.4	0.3	1.1	212.4	105.6	20.7	3.6	1.6	2.1	2.7	2.6				
6	87	44X1	7.75	66.7	64.1	-2.6	1.1	207.9	110.6	15.1	3.0	2.0	2.3	2.7	2.7				
7	39	20X1	7.70	69.8	67.4	-2.4	1.0	199.0	97.6	5.5	1.3	1.7	2.1	2.7	2.6				
8	113	57X1	7.70	62.8	62.6	-0.2	1.1	190.4	89.4	5.8	1.2	1.9	2.2	2.5	2.7				
9	3	2X1	7.65	65.8	65.1	-0.7	1.1	215.4	108.1	14.7	3.6	2.1	2.3	2.9	2.5				
10	60	30X2	7.63	65.9	66.5	0.6	1.0	202.4	99.2	15.6	9.8	1.9	2.2	3.0	2.8				
11	103	52X1	7.63	68.2	67.5	-0.7	1.0	199.0	103.4	27.6	5.9	1.9	2.2	2.9	2.8				
12	51	26X1	7.57	69.2	69.0	-0.2	1.0	191.4	96.4	6.1	1.4	1.8	2.3	2.7	3.0				
13	63	32X1	7.57	67.2	66.2	-1.0	1.1	215.3	106.4	14.5	0.9	1.8	2.4	3.0	2.7				
14	55	28X1	7.56	68.0	67.3	-0.7	1.0	208.7	105.2	8.5	1.3	1.8	2.1	2.6	2.4				
15	1	1X1	7.54	67.2	66.0	-1.2	1.1	213.9	101.2	3.1	1.4	1.9	2.1	2.4	2.6				
16	127	64X1	7.54	70.0	70.3	0.3	1.1	211.4	111.8	3.6	3.6	1.8	1.9	2.7	2.5				
17	89	45X1	7.47	66.3	65.5	-0.8	1.2	203.7	109.3	5.8	0.0	1.8	2.2	2.4	2.9				
18	114	57X2	7.47	62.4	63.4	1.0	1.0	185.8	82.4	17.4	5.3	1.8	2.5	2.9	2.6				
19	115	58X1	7.46	67.3	66.6	-0.7	1.2	210.6	91.0	9.4	1.7	1.8	2.1	2.8	2.8				
20	91	46X1	7.44	63.8	63.8	0.0	1.1	187.6	89.3	3.7	2.3	1.6	1.9	2.7	2.7				
131	131	Check 1	8.07	67.6	67.0	-0.6	1.0	212.8	107.9	21.9	0.8	1.8	2.0	2.8	2.6				
132	132	Check 2	6.76	70.4	70.4	0.0	1.0	204.5	100.0	12.1	2.9	1.8	2.2	2.9	2.9				
Mean of the trial			6.72	67.02	67.08	0.06	1.03	197.02	95.98	14.42	3.28	1.77	2.21	2.93	2.81				
Mean of the top 20 hybrids			7.70	7.7	66.3	65.71	-0.6	1.08	203.32	100.03	11.49	2.57	1.80	2.16	2.72				
Mean of checks			7.42	69	68.7	-0.30	1.00	208.65	103.95	17.00	1.85	1.80	2.10	2.85	2.75				
LSD			0.83	1.15	1.32	1.03	0.09	12.43	9.82	9.28	4.59	0.22	0.28	0.30	0.34				
CV			13.99	1.96	2.25	1948.93	9.66	6.42	10.42	73.3	142.41	12.67	13.01	11.47	12.19				

†GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; PH: Plant height; EH: Ear height; HC: Husk cover; ER: Ear rot; GLS: Grey leaf spot; ET: *E. Turcicum*; EA: Ear aspect; PA: Plant aspect.

4.3.5 Analysis of variance for grain yield and agronomic traits across well-watered conditions and across all sites

Highly significant differences ($P < 0.001$) due to the environment were observed for all the traits across optimal sites (Table 4.16) and across all sites (Table 4.17). Mean squares due to genotypes and F_1 hybrids were highly significant ($P < 0.001$) for all traits across well-watered and across all sites indicating variable performance among the entries for all traits. The F_1 hybrid x environment and genotype x environment interactions were highly significant ($P < 0.01$) for all traits across well-watered sites (Table 4.16) and across all sites (Table 4.17). This indicated that the hybrids responded differently at the varying environments.

4.3.6 Line x tester analysis for grain yield and agronomic traits at individual sites

There was highly significant ($P < 0.01$) variation among the lines and testers (GCA) for grain yield at all well-watered sites (Tables 4.3-4.7) suggesting that additive gene effects were important for control of grain yield under well-watered conditions. At Namulonge highly significant ($P < 0.001$) variation among the lines and testers for grain yield, silking dates and ears per plant was revealed (Table 4.3). Significant differences among lines and testers suggest the presence of significant GCA effects for these traits among both lines and testers. Line x tester interaction (SCA) was significant ($P < 0.05$) for GY, PH, EH, HC, and PA at Namulonge (Table 4.3). At Kibos, both lines and testers were significant ($P < 0.05$) for all traits except anthesis date and ears per plant where the variation among testers was not significant (Table 4.4). F_1 hybrids revealed significant ($P < 0.05$) mean squares for all traits except silking dates for the testers and ear aspect for the lines at Kakamega (Table 4.5).

Table 4. 16 Analysis of variance for grain yield and other agronomic traits across well-watered conditions

SOURCE	df	MEAN SQUARES											
		GY† t ha ⁻¹	AD days	SD days	ASI days	EA 1-5	EPP #	HC %	df	ER %	SL %	PA 1-5	RL %
ENV	4	1231.95***	13903.15***	11737.55***	209.50***	6.47***	0.41***	85952.14***	3	1541.33***	16045.81***	27.34***	73963.93***
REP*ENV	5	28.13***	10.63***	16.77***	1.37	3.06***	0.05***	1691.22***	4	57.13*	2786.79***	2.15***	23822.34***
GENOTYPES	131	4.79***	37.46***	35.23***	7.74***	0.60***	0.03***	793.93***	131	56.38***	224.48***	0.24***	471.13***
F1 HYBRIDS	129	4.73***	37.12***	34.91***	7.83***	0.61***	0.03***	770.98***	129	56.86***	226.24***	0.24***	477.01***
LINE	64	4.99***	68.93***	64.82***	6.90***	0.49***	0.03***	821.60***	64	46.79***	247.91***	0.32***	499.38
TESTER	1	152.21***	165.61***	50.02***	397.66***	35.23***	0.97***	30347.86***	1	1635.27***	4022.75***	2.26***	12980.52***
LINE*TESTER	64	2.16***	3.30***	4.76***	2.67***	0.18*	0.01*	258.22***	64	42.27***	145.24*	0.13	259.27
GENOTYPES*ENV	524	1.56***	2.73***	3.89***	2.13***	0.19***	0.01***	279.57***	393	38.31***	148.44***	0.20***	327.81*
F1HYBRIDS*ENV	516	1.56***	2.62***	3.80***	2.14***	0.19***	0.01***	280.24***	387	38.82***	149.78***	0.20***	330.29*
LINE*ENV	256	1.85***	3.00***	4.41***	2.33***	0.22***	0.01***	295.78***	192	37.12***	132.17***	0.21***	321.25
TESTER*ENV	4	7.10***	25.65***	54.08***	11.68***	1.75***	0.13***	5872.67***	3	497.43***	3581.13***	3.26***	5485.44***
LINE*TESTER*ENV	256	1.19	1.88	2.41	1.79***	0.14	0.01	177.32***	192	33.36***	113.78	0.14	258.78
ERROR	649	1.06	1.79	2.39	1.35	0.13	0.01	114.94	519	21.82	112.49	0.13	0.14

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY= Grain yield; AD= anthesis date; SD=silking date; ASI= anthesis-silking interval; EA: Ear aspect; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; SL: Stem lodging; PA: Plant aspect; RL: Root lodging.

Table 4. 17 ANOVA for grain yield and other agronomic traits across all sites

SOURCE	MEAN SQUARES			MS			MEAN SQUARES			MEAN SQUARES				
	df	GY†	EPP	HC	df	AD	df	SD	ASI	df	EH	PH	ET	GLS
ENV	5	2370.50***	19.35***	75149.27***	5	11144.84***	5	10284.19***	629.98***	3	57496.21***	116327.59***	52.77***	110.27***
REP(ENV)	6	23.18***	0.10***	1705.23***	6	17.06***	6	15.46***	2.24	4	723.41***	2394.63***	0.53***	2.36***
GENOTYPES	131	4.15***	0.04***	652.51***	131	46.24***	131	42.97***	11.50***	131	549.52***	819.20***	0.24***	0.19***
F1 HYBRIDS	129	4.10***	0.04***	658.74***	129	42.63***	129	42.44***	11.64***	129	548.13***	812.68***	0.24***	0.20***
LINE	64	4.51***	0.04***	715.28***	64	84.33***	64	79.38***	12.95***	64	724.89***	1144.26***	0.30***	0.29***
TESTER	1	116.24***	0.56***	25670.59***	1	268.60***	1	27.37**	362.37***	1	16851.07***	15300.12***	4.51***	2.22***
LINE*TESTER	64	1.95***	0.02	211.40***	64	3.60***	64	6.08***	3.93***	64	116.64	254.74**	0.11*	0.07
GENOTYPES*ENV	655	1.57***	0.03***	250.16***	653	2.69***	604	5.07***	3.64***	393	146.89***	202.57**	0.10**	0.11***
F1 HYBRIDS*ENV	645	1.57***	0.03***	250.93***	643	2.60***	595	4.80***	3.51***	387	147.22***	200.70**	0.10**	0.11***
LINE*ENV	320	1.76***	0.02**	263.39***	320	3.01***	309	5.68***	4.31***	192	156.52***	212.52*	0.12**	0.15***
TESTER*ENV	5	13.15***	0.22***	5635.30***	5	25.88***	5	44.44***	9.34***	3	538.48**	869.48**	0.89***	0.56***
LINE*TESTER*ENV	320	1.20*	0.02***	154.34***	318	1.81***	281	3.25***	2.64***	192	131.81*	178.43	0.08	0.07
ERROR	779	1.01	0.018	99.24	775	1.76	724	2.516	1.63	519	102.49	167.28	0.09	0.06

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; EPP: Ears per plant; HC: Husk cover; AD: Anthesis date; SD: Silking date; ASI: Anthesis silking interval; EH: Ear height; PH: Plant height; ET: E. Turcicum; GLS: Grey leaf spot.

At the well-watered site in Kiboko, partition of the hybrids into genetic components revealed significant ($P < 0.05$) mean squares for both lines and testers for all traits except stem lodging and ear rots (Table 4.6). At Embu, mean squares for both lines and testers were significant ($P < 0.01$) for grain yield, anthesis date and husk cover. Mean squares for the lines were also significant for silking dates and root lodging (Table 4.7).

Under managed drought, lines were significant for all traits except grain yield, ear rots, senescence, stem lodging and modification (Table 4.8). For the testers mean squares were significant for root lodging, anthesis date, anthesis-silking interval and modification. Significant mean squares for lines and testers for the traits mean additive gene action was present in these traits. At Kibos, lines x tester mean squares were not significant for anthesis dates, silking dates, turcicum disease, plant height and plant aspect (Table 4.4). Lines x tester mean squares were only significant ($P < 0.05$) for grain yield, anthesis date, anthesis-silking interval and ears per plant at Kakamega (Table 4.5). At the well-watered site in Kiboko, line x tester mean squares were significant for all traits except anthesis-silking interval, ear height, root lodging, ears per plant and ear rots (Table 4.6). Only husk cover had significant line x tester mean squares at the well-watered site in Embu (Table 4.7).

Under managed drought stress, no significant differences were observed among lines and testers for grain yield while line x tester interaction (SCA) was significant ($P < 0.05$) for grain yield, ears per plant, senescence, anthesis date, anthesis-silking interval and modification (Table 4.8). Significant line x tester mean squares indicated that non additive gene effects

were important for the traits. Significant differences for entries, lines, testers, and line x tester mean squares imply that there was scope for selecting for these traits among the entries.

4.3.7 Combining ability effects for agronomic traits at individual sites under well-watered conditions

General combining ability effects for grain yield and other agronomic traits at well-watered sites are presented in Tables 4.16 to 4.20 while the SCA effects for grain yield are presented in Table 4.24. At Namulonge inbred lines 9, 12, 22, 24, 56 and 61 had highly significant ($P < 0.01$) GCA effects for GY (1.03, 1.26, 1.55, and 1.44t ha⁻¹ respectively) (Table 4.16). Inbred line 22 also had positive and significant GCA effects for grain yield at Kibos (Table 4.19). At the other three sites under well-watered conditions, this line showed positive but non-significant GCA effects. Inbred line 24 showed high and positive GCA effects for grain yield at all sites except Kibos with this line recording the highest GCA effect (2.17 t ha⁻¹) at Embu (Table 4.22).

Line 53 had positive and significant GCA effects for grain yield at Embu, Kakamega and Namulonge. At Kibos and Kiboko, the GCA effects for grain yield for line 53 were positive absent. Positive GCA effects suggest good alleles for grain yield in these inbred lines. These lines can be desirable parents for hybrids and for use in a pedigree breeding program for quality protein maize.

Table 2.19. *Continued* comparing status of water under well-watered conditions at Namulonge

LINE	GY ¹ t ha ⁻¹	AD days	SD days	ASI days	EH cm	PH cm	EPP #	ET 1-5	GLS 1-5	HC %
1	0.66*	-0.5	-0.48	0.02	3.76	22.29***	0.09	-0.33	-0.05	-2.42
2	-0.58	-1.50*	-0.23	1.27	-3.76	-6.21	-0.07	0.68***	-0.05	2.38
3	0.19	-1.75*	-0.73	1.02	0.13	7.29	0.00	0.05	-0.05	0.91
4	-0.69*	1.00	1.77*	0.77	-5.37	-6.46	-0.14**	0.05	0.20	-2.42
5	-0.19	-1.50*	-1.48	0.02	4.88	6.54	0.05	-0.08	-0.05	-2.42
6	0.43	-1.25	-0.73	0.52	9.88*	2.29	-0.02	-0.20	0.07	9.21***
7	-0.55	1.50*	2.77***	1.27	6.38	-2.96	0.00	-0.08	0.07	1.16
8	0.36	0.75	1.52*	0.77	3.63	7.04	0.12*	-0.20	0.07	-2.42
9	1.03***	-1.25	0.02	1.27	9.38*	17.04**	0.06	-0.20	-0.18	0.53
10	-0.73*	1.25	1.77*	0.52	0.38	5.04	-0.17**	0.30	0.07	2.28
11	-0.41	0.25	1.77*	1.52*	1.13	-6.21	-0.04	0.05	-0.05	0.91
12	0.83**	-1.50*	-1.23	0.27	11.13**	16.04**	0.08	0.55**	0.07	6.71**
13	0.27	2.25***	1.27	-0.98	-0.37	8.54	-0.16**	-0.45*	-0.05	5.23*
14	-0.68*	2.00**	2.02*	0.02	-8.62*	-2.96	-0.02	-0.08	-0.30**	-2.42
15	-0.58	3.50***	3.77***	0.27	13.38***	-1.46	-0.04	0.18	-0.05	-2.42
16	-0.68*	2.75***	2.77***	0.02	3.88	-9.71	-0.08	-0.08	0.07	-2.42
17	-0.49	2.50***	1.77*	-0.73	-0.12	-17.46**	-0.05	0.18	0.07	-2.42
18	-1.03**	2.00**	1.52*	-0.48	-5.12	-3.46	-0.06	0.05	-0.05	-0.34
19	-0.68*	1.25	1.77*	0.52	-9.12*	-21.21***	-0.05	-0.08	0.07	-2.42
20	0.11	-0.75	-0.23	0.52	11.88**	8.54	0.07	-0.08	-0.05	-2.42
21	0.72*	0.75	0.27	-0.48	-2.12	2.79	0.00	-0.20	-0.05	0.53
22	1.26***	-3.50***	-3.23***	0.27	-1.37	9.79	0.22***	-0.33	-0.05	-2.42
23	-0.01	-0.25	0.77	1.02	9.38*	11.04	0.09	-0.08	-0.18	-2.42
24	0.88**	-1.25	-0.98	0.27	-3.87	3.79	0.11*	-0.20	0.07	-2.42
25	-0.58	2.25***	1.77*	-0.48	7.63	16.54**	0.05	-0.33	-0.05	-0.94
26	0.10	-0.25	0.27	0.52	3.38	18.54**	-0.05	0.43*	-0.05	-2.42
27	-0.39	-2.25***	-0.73	1.52*	-10.12*	-13.71*	0.00	0.43*	-0.05	-2.42
28	-1.71***	0.00	0.52	0.52	-12.37**	-19.71***	-0.19***	0.30	0.07	6.98**
29	-0.31	1.00	1.02	0.02	-1.12	-9.21	0.05	-0.33	0.07	2.01
30	0.03	-1.00	-1.23	-0.23	1.88	8.29	-0.05	-0.08	-0.05	3.46
31	0.75*	-2.00**	-3.73***	-1.73*	0.88	2.54	0.25***	-0.33	-0.05	8.26***
32	0.30	1.00	2.77***	1.77*	-0.37	2.04	-0.10	-0.20	0.07	-2.42
33	-0.02	-1.00	-0.73	0.27	-7.12	-10.96	-0.07	0.18	0.07	4.96*
34	0.66*	0.25	-1.73*	-1.98*	3.63	1.54	0.05	-0.33	0.07	1.98

LINE	GY	AD	SD	ASI	EH	PH	EPP	EY	GLS	AVC
	t ha ⁻¹	days	days	days	cm	cm	#	1-5	1-5	%
35	0.30	-1.25	-1.48	-0.23	0.13	-0.21	-0.04	-0.20	0.07	-2.42
36	-0.53	0.50	-0.48	-0.98	-2.12	-3.71	-0.11	0.05	0.07	-2.42
37	0.21	2.25***	1.77*	-0.48	-1.12	6.04	0.13*	-0.20	-0.18	-2.42
38	0.74*	-3.00	-2.48**	0.52	7.13	16.29**	-0.05	-0.20	0.07	6.41**
39	0.37	-1.00	-2.98***	-1.98**	16.88***	20.79***	0.03	0.30	-0.18	-2.42
40	0.73*	-0.75	-1.48	-0.73	12.88**	5.54	0.10	-0.08	0.07	-2.42
41	-0.38	-3.75***	-2.23**	1.52*	-18.37***	-24.71***	-0.05	-0.58**	-0.05	-2.42
42	0.26	2.25***	1.77*	-0.48	-2.37	-7.96	0.15**	-0.20	0.07	-2.42
43	-0.54	-0.75	-0.23	0.52	-10.37*	-15.21**	-0.07	0.30	0.07	-0.74
44	0.24	-0.50	0.77	1.27	-3.12	4.04	0.02	-0.45*	0.07	-2.42
45	0.24	0.00	-0.98	-0.98	-10.62*	-13.46*	-0.04	0.68***	-0.05	-2.42
46	-0.11	-1.25	-0.98	0.27	-8.87*	-13.46*	-0.10	0.55**	-0.05	2.28
47	-0.06	-2.25***	-1.98*	0.27	2.13	-0.21	-0.03	0.18	-0.05	-0.94
48	0.71*	0.25	-0.23	-0.48	-1.37	-14.71*	0.06	0.43*	0.07	22.01***
49	-1.16***	0.75	1.27	0.52	-9.62*	-9.71	-0.08	-0.45*	-0.05	-2.42
50	-1.12***	1.75**	2.27**	0.52	-5.87	-18.21**	0.01	-0.20	0.07	-2.42
51	-1.15***	-3.00***	-2.73***	0.27	-9.12*	-15.46**	-0.18***	0.05	-0.05	-2.42
52	-0.64*	1.00	1.52*	0.52	-7.12	6.79	-0.03	-0.08	0.07	5.73*
53	0.68*	-3.50***	-4.23***	-0.73	-10.12*	-7.21	-0.01	0.18	0.07	-2.42
54	0.33	0.50	-0.73	-1.23	-3.37	8.29	0.05	0.05	-0.18	-2.42
55	0.63*	-0.50	0.02	0.52	4.63	6.29	0.05	0.43*	0.07	-0.84
56	1.55***	-0.75	-0.48	0.27	2.63	5.29	-0.01	-0.08	0.20	-2.42
57	-0.06	1.75**	0.27	-1.48	-3.62	3.54	-0.04	0.05	0.07	-2.42
58	-0.59	2.75***	1.52*	-1.23	10.63*	6.29	0.25***	-0.08	0.07	-0.84
59	-0.77*	1.75**	0.77	-0.98	5.13	0.29	0.03	0.18	-0.18	-2.42
60	-0.08	-0.75	-1.73*	-0.98	-12.12**	-16.71**	-0.04	-0.20	0.07	-2.42
61	1.44***	0.75	1.27	0.52	20.13***	20.04	0.11*	-0.45*	0.07	-2.42
62	0.38	-2.00**	-1.73*	0.27	1.63	5.79	-0.05	0.18	0.20	-2.42
63	-0.27	3.00***	1.27	-1.73*	10.13**	0.79	-0.07	-0.08	-0.05	-2.42
64	0.17	1.00	-0.23	-1.23	7.38	5.79	0.04	0.30	-0.18	0.53
65	0.25	0.25	-1.23	-1.48	-10.37**	-6.71	0.03	0.43*	0.07	-0.49
Tester 1	0.24***	0.08	-0.60***	-0.67***	3.76***	4.96***	0.06***	-0.14***	0.00	-0.90**
Tester 2	-0.24***	-0.08	0.60***	0.67***	-3.76***	-4.96***	-0.06***	0.14***	0.00	0.90**

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EH: Ear height; PH: Plant height; EPP; Ears per plant; ET: *E. Turcicum*; GLS: Grey leaf spot; HC: Husk cover.

Table 4. 19 General combining ability (GCA) effects for grain yield and agronomic traits of 65 QPM inbred lines under well-watered conditions at Kibos

LINE	GY [†] t ha ⁻¹	AD days	SD days	ASI days	EH cm	PH cm	EPP #	ER %	ET 1-5	GLS 1-5	HC %
1	0.73	0.52	-1.06	0.52	2.21	7.69	-0.01	-4.61	-0.01	0.03	-19.44**
2	0.31	-0.98*	-1.06	-0.98*	12.21***	5.19	0.00	-0.68	0.11	-0.34**	6.29
3	1.01**	-0.73	-1.31*	-0.73	4.71	2.69	0.02	-1.08	-0.26*	-0.22	23.16**
4	-0.35	-0.73	-0.81	-0.73	2.21	2.69	-0.03	-6.08	0.11	0.03	-9.21
5	-0.32	0.02	-0.31	0.02	-6.54	-7.31	0.03	-1.36	-0.14	0.03	5.29
6	-0.09	0.52	-0.81	0.52	0.96	0.19	0.02	0.39	-0.01	-0.47***	21.41**
7	1.10**	1.27**	0.44	1.27**	4.71	6.44	0.02	0.49	-0.39***	-0.22	0.39
8	0.01	2.52***	1.94***	2.52***	-4.04	-2.31	0.02	-6.08	-0.01	0.03	-16.49*
9	0.24	1.27**	0.94	1.27**	0.96	0.19	-0.05	-1.56	0.11	-0.22	-5.96
10	0.38	1.02*	0.19	1.02*	-0.29	2.69	-0.02	-1.68	0.11	-0.34**	-4.29
11	0.99*	0.52	0.44	0.52	7.21*	3.94	0.00	-6.08	-0.26*	0.16	-11.19
12	-0.22	-1.48***	-0.81	-1.48***	12.21***	16.44***	-0.02	-0.21	0.24*	0.66***	6.71
13	0.47	2.77***	0.94	2.77***	-11.54***	-17.31***	-0.03	3.74	-0.01	-0.22	8.54
14	0.71	0.27	-0.31	0.27	-5.29	-2.31	-0.05	-1.56	-0.01	-0.34**	12.94
15	-0.68	3.02***	2.19***	3.02***	2.21	2.69	0.05	-4.31	0.11	-0.22	14.91*
16	-0.71	3.77***	4.94***	3.77***	-1.54	1.44	-0.04	1.37	0.11	-0.09	-6.16
17	-0.35	3.27***	3.94***	3.27***	4.71	5.19	0.07	-2.33	0.11	0.16	-21.76**
18	-0.94*	4.27***	6.44***	4.27***	7.21*	2.69	0.01	0.69	-0.01	-0.34**	-27.06***
19	-0.58	4.02***	5.44***	4.02***	-2.79	-6.06	0.02	-3.28	0.11	-0.22	-16.19*
20	0.02	0.77	0.44	0.77	3.46	1.44	-0.01	7.87*	0.11	-0.34**	-3.84
21	-0.03	0.02	-0.56	0.02	5.96	7.69	-0.02	-0.46	0.11	-0.22	9.99
22	1.54***	-3.73***	-4.56***	-3.73***	0.96	10.19*	-0.04	-1.68	-0.26*	-0.34**	-11.29
23	0.03	-0.23	-0.56	-0.23	3.46	6.44	0.03	-3.58	0.24*	0.28*	15.26*
24	-0.52	-0.23	-0.56	-0.23	-0.29	-2.31	0.04	12.54***	0.11	0.16	16.09*
25	0.43	3.02***	1.94***	3.02***	12.21***	23.94***	0.02	2.94	-0.14	-0.34**	-4.01
26	-0.64	0.02	-0.81	0.02	3.46	8.94	0.01	-4.41	0.11	0.16	16.64*
27	-0.12	-2.48***	-2.31***	-2.48***	-10.29**	-22.31***	0.01	-4.76	0.11	-0.34**	-9.19
28	-1.42***	-0.98*	0.19	-0.98*	-22.79***	-29.81***	-0.06	3.04	0.36***	0.78***	-9.79
29	-0.27	1.27**	2.19***	1.27**	10.96**	10.19*	0.07	9.37**	-0.26*	0.41***	36.99***
30	-0.07	-1.23**	-1.06	-1.23**	-4.04	-7.31	-0.02	3.14	-0.14	-0.09	26.64***
31	0.28	-1.23**	-1.56**	-1.23**	0.96	5.19	-0.05	-1.78	-0.39***	0.16	-9.06
32	-0.77	2.02***	4.44***	2.02***	-7.79*	7.69	-0.02	-4.51	-0.01	0.66***	11.26
33	-0.18	-1.48***	-0.81	-1.48***	-0.29	1.44	0.03	7.47*	-0.14	-0.09	39.01***
34	-0.48	-2.48***	-1.31*	-2.48***	-7.79*	-3.56	-0.04	-1.61	0.11	0.03	14.91*

Table 4. 20 General combining ability (GCA) effects for grain yield and agronomic traits of 65 QPM inbred lines under well-watered conditions at Kakamega

LINE	GY [†] t ha ⁻¹	AD days	SD days	ASI days	EH cm	PH cm	EPP #	ER %	GLS 1-5	ET 1-5	HC %
1	0.22	-0.51	0.31	0.82	-2.17	3.17	-0.06	-1.69	0.14	-0.18	-0.29
2	0.34	-1.51**	-0.94	0.57	6.58	5.67	0.00	0.91	0.02	0.02	-1.54
3	0.03	0.24	-0.19	-0.43	-5.92	-8.08	-0.03	-1.69	-0.11	-0.11	5.14*
4	0.25	-1.51**	-1.19*	0.32	6.58	9.42	0.02	-0.64	0.02	0.12	3.11
5	-1.23**	0.49	0.81	0.32	-4.67	-5.58	0.04	-1.69	-0.23	0.09	3.59
6	0.58	-1.01*	-1.44*	-0.43	21.58***	18.17**	-0.01	-0.29	-0.23	-0.01	2.36
7	-0.66	1.24*	1.31*	0.07	-4.67	-4.33	-0.09	4.51**	0.02	0.27*	0.96
8	0.53	0.99*	1.31*	0.32	2.83	3.17	0.06	0.56	0.27	-0.16	-2.79
9	0.03	1.74***	1.81**	0.07	-5.92	-10.58	-0.06	-0.37	-0.11	-0.06	-0.01
10	0.26	1.24*	1.81**	0.57	-5.92	-0.33	0.03	-0.44	0.02	0.02	1.11
11	0.01	-0.01	0.56	0.57	-13.42**	-15.58*	-0.09	0.81	0.14	-0.06	-0.29
12	-0.82	-0.01	-0.19	-0.18	-8.42	-1.83	-0.05	-0.29	0.14	0.19	-0.19
13	0.66	1.24*	-0.94	-2.18***	-3.42	8.17	-0.10*	2.48	-0.11	-0.01	5.54*
14	0.31	0.49	0.31	-0.18	-9.67	-5.58	-0.05	0.91	0.02	0.19	-1.46
15	-0.31	3.99***	4.56***	0.57	11.58*	14.42*	-0.05	-0.12	0.02	-0.23*	-2.79
16	-0.29	2.49***	2.56***	0.07	0.33	-1.83	-0.07	6.91***	0.02	0.12	2.81
17	0.18	1.99***	2.06***	0.07	1.58	-5.58	0.00	-0.57	-0.11	0.07	2.21
18	0.64	2.74**	2.81***	0.07	4.08	-3.08	-0.04	-0.37	-0.23*	-0.23*	-0.29
19	0.55	1.99***	2.56***	0.57	0.33	-4.33	-0.05	-0.37	0.02	-0.01	-2.79
20	-0.08	0.99*	1.31*	0.32	-8.42	-11.83	0.03	-1.69	0.02	0.14	-2.79
21	2.13***	-0.76	0.31	1.07*	6.58	11.92	-0.02	0.68	-0.11	-0.23*	3.29
22	0.56	-4.01***	-3.69***	0.32	-2.17	8.17	-0.02	-1.69	0.14	0.12	-1.54
23	-0.08	-1.01*	-2.19***	-1.18*	19.08***	18.17**	0.00	-1.69	0.27**	0.02	-0.16
24	1.14*	-1.51**	-1.94**	-0.43	2.83	3.17	-0.01	0.81	-0.11	-0.06	0.96
25	-1.19**	2.74***	3.06***	0.32	4.08	19.42**	-0.06	-0.37	-0.11	-0.33**	-1.46
26	-0.10	-1.51**	-1.69**	-0.18	14.08**	23.17***	0.07	-1.69	0.14	0.29*	-1.46
27	-0.68	-1.01*	-1.19*	-0.18	-3.42	-8.08	0.07	3.68*	-0.36	0.42***	4.11
28	-1.74***	-2.26***	-1.69**	0.57	-12.17**	-16.83	-0.04	2.41	-0.11	-0.01	2.61
29	0.39	0.74	0.81	0.07	6.58	-4.33	-0.01	-0.44	0.39***	-0.31**	-1.46
30	-0.36	-1.51**	-0.94	0.57	9.08*	6.92	0.13**	-0.49	0.14	-0.13	-2.79
31	1.19**	-2.26***	-2.69***	-0.43	-3.42	3.17	0.28***	0.76	0.27**	-0.31*	6.91**
32	-0.23	2.99***	2.81***	-0.18	-3.42	3.17	-0.09*	5.33***	0.27**	-0.16	-1.59
33	0.55	-0.51	-0.94	-0.43	7.83	4.42	0.12*	-0.77	-0.23*	-0.26*	2.29
34	-0.89	-0.51	-0.69	-0.18	-13.42**	-16.83**	-0.01	-0.37	0.02	0.19	-2.79

LINE	CVS r ha ⁻¹	AD [†] days	SD [†] days	ASI days	EH cm	EH cm	EPP #	EK %	GLS 1-5	GLS 1-5	EY %	ER %
35	0.98*	-0.76	-0.69	0.07	5.33	0.67	-0.02	-1.69	0.02	0.07	-2.79	-2.79
36	-1.38**	-3.01***	-2.69***	0.32	-3.42	1.92	0.01	-1.69	-0.11	-0.06	-2.79	-2.79
37	-0.43	2.49***	2.56***	0.07	-8.42	-10.58	0.04	1.08	0.27**	0.07	-0.16	-0.16
38	0.71	-4.76***	-3.69***	1.07*	1.58	9.42	-0.04	-1.69	-0.11	0.02	5.66*	5.66*
39	1.10*	-0.26	-2.19***	-1.93***	4.08	4.42	0.03	-0.44	0.14	-0.08	3.46	3.46
40	0.33	-0.51	-2.19***	-1.68***	10.33*	5.67	0.06	-1.69	0.14	-0.23*	-2.79	-2.79
41	-0.32	-3.51***	-3.19***	0.32	-0.92	-3.08	0.05	3.23*	-0.23*	-0.06	-1.31	-1.31
42	0.48	-2.26***	-3.19***	-0.93*	4.08	-3.08	0.00	-0.37	0.27**	-0.41***	-2.79	-2.79
43	0.31	-1.01*	-0.19	0.82	-2.17	-21.83***	-0.01	1.81	0.02	0.14	-0.41	-0.41
44	0.77	-2.26***	-1.44*	0.82	6.58	-4.33	0.04	-0.49	0.02	-0.26*	-0.16	-0.16
45	-1.08*	1.24**	1.06	-0.18	-9.67*	-10.58	-0.04	-1.69	-0.11	0.19	-1.31	-1.31
46	-1.41**	-2.01***	-2.19***	-0.18	-8.42	-4.33	-0.09	0.68	-0.11	0.27*	3.16	3.16
47	-0.67	-1.76***	-1.19*	0.57	-2.17	-3.08	-0.02	-0.44	0.02	-0.01	-0.29	-0.29
48	-0.10	2.24***	1.56**	-0.68	0.33	8.17	-0.04	4.21**	-0.11	0.22	15.41***	15.41***
49	-0.51	-0.01	-0.69	-0.68	9.08*	10.67	-0.12*	-1.69	0.02	-0.06	-2.79	-2.79
50	-1.01*	1.74***	1.31*	-0.43	-13.42**	-24.33***	0.00	-0.29	-0.11	-0.18	-2.79	-2.79
51	-0.50	-2.01***	-1.94**	0.07	-10.92*	-6.83	0.02	-0.44	0.14	0.37**	-2.79	-2.79
52	-0.58	0.49	0.56	0.07	4.08	14.42*	0.04	-1.69	0.27**	0.12	-2.79	-2.79
53	1.04*	-4.76***	-4.19***	0.57	-3.42	-5.58	0.06	0.48	0.14	0.19	-1.54	-1.54
54	-0.6	1.24	1.56**	0.32	-3.42	11.92	0.03	-1.69	-0.11	-0.01	-2.79	-2.79
55	1.05*	-0.51	-1.19*	-0.68	-7.17	-6.83	0.06	-0.44	-0.11	-0.11	2.21	2.21
56	0.83	-0.51	-0.69	-0.18	2.83	4.42	0.04	-0.37	0.39***	-0.11	-0.11	-0.11
57	0.63	1.49**	1.81**	0.32	-3.42	10.67	-0.02	-1.69	-0.11	0.02	-2.79	-2.79
58	0.63	2.74***	1.56**	-1.18*	9.08*	10.67	0.08	-0.44	-0.11	0.02	-1.46	-1.46
59	-0.38	2.49***	2.06***	-0.43	12.83**	1.92	0.01	-1.69	-0.11	0.57***	-2.79	-2.79
60	-0.42	-1.51**	-2.19***	-0.68	0.33	0.67	-0.02	-0.29	0.02	-0.08	-2.79	-2.79
61	0.76	2.74***	3.31***	0.57	6.58	-0.58	-0.04	-0.44	0.02	0.07	-2.79	-2.79
62	0.16	-2.51***	-1.44*	1.07*	0.33	3.17	0.01	-0.49	0.14	-0.31**	-2.79	-2.79
63	-0.92*	5.24***	5.31***	0.07	-3.42	-9.33	-0.01	-1.69	-0.48***	-0.11	-1.46	-1.46
64	-0.98*	2.49***	3.06***	0.57	4.08	6.92	0.03	-0.44	-0.11	0.12	-2.79	-2.79
65	-0.37	0.49	0.81	0.32	-15.92***	-30.58***	0.00	-0.49	-0.23*	0.24*	1.46	1.46
Tester 1	0.26***	0.65***	0.02	-0.63***	4.08***	5.64***	0.04***	-1.02***	0.09***	-0.04*	-0.93**	-0.93**
Tester 2	-0.26***	-0.65***	-0.02	0.63***	-4.08***	-5.64***	-0.04***	1.02***	-0.09***	0.04*	0.93**	0.93**

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; AD; Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; ER: Ear rots; GLS: Grey leaf spot; ET: *E. turcicum*; HC: Husk cover.

Estimates of GCA effects for anthesis dates differed significantly between the lines. Parents 22, 27, 38, 41, 51 and 53 were among those lines which manifested significantly ($P < 0.05$) negative GCA values at the five well-watered sites. Significant negative GCA effects suggest that the lines have good alleles for earliness. Utilization of these lines in a breeding program is expected to produce hybrids that are early maturing.

Estimates of GCA effects for ears per plant were only significant for a few lines. Inbred line 31 showed consistently positive and significant ($P < 0.001$) GCA effects at Namulonge; 0.25 (Table 4.18), and Kakamega; 0.28 (Table 4.20). Positive significant GCA effects suggested increased number of ears per plant thus this line has the potential to contribute increased number of ears per plant to its progenies.

Estimates for GCA effects for turcicum leaf blight differed significantly among the lines at Namulonge (Table 4.18), Kibos, (Table 4.19) and Kakamega (Table 4.20). Line 44 showed negative and significant GCA effects for this disease at the three sites. Lines 29, 31 and 42 showed significant and negative GCA effects for turcicum at Kakamega and Kibos. At Namulonge, the GCA effects for turcicum for these lines were negative but not significant (Table 4.18). Negative GCA effects for turcicum leaf blight disease probably were due to low disease pressure.

Table 4. *Effect of grain yield and meteoric stress on GCA effects for grain yield and meteoric stress of 25 GCA maize lines under well-watered conditions at Kiboko*

LINE	GY [†] t ha ⁻¹	AD days	SD days	ASI days	EH cm	PH cm	EPP #	ER %	HC %
1	0.56	-0.87	-1.60*	-0.73	4.42	9.89***	-0.01	-0.88	-0.53
2	0.00	-0.37	-0.60	-0.23	6.67	-3.24	-0.04	-0.88	-0.15
3	-0.48	-0.62	0.40	1.02*	-0.21	0.26	-0.04	1.69	4.97
4	0.02	-0.37	-0.35	0.02	7.67*	8.89**	0.02	-0.88	-4.10
5	0.66	-1.12*	-1.60*	-0.48	4.72	8.14**	-0.05	-0.88	-2.90
6	0.93*	0.88	0.90	0.02	20.04***	16.01***	-0.04	-0.88	-2.90
7	-0.01	1.63**	1.65**	0.02	9.54*	3.64	0.05	-0.88	-4.10
8	-0.31	1.63**	2.15***	0.52	0.79	6.01*	-0.03	-0.88	0.65
9	-0.15	1.63**	2.15***	0.52	2.79	-0.24	-0.04	0.37	-2.78
10	1.07**	1.38**	1.90***	0.52	10.67**	7.76**	0.10**	-0.88	-1.73
11	-0.72	2.88***	1.65**	-1.23**	12.92***	1.39	-0.01	0.32	-4.10
12	0.58	-1.37**	-1.35**	0.02	-0.71	10.39***	-0.01	-0.88	-2.90
13	0.07	0.63	-0.10	-0.73	-4.58	6.26*	0.04	0.24	-2.85
14	-0.69	0.13	1.90***	1.77***	-12.96***	-1.11	-0.01	0.44	4.22
15	0.13	3.13***	3.15***	0.02	21.54***	15.26***	-0.03	0.52	-1.73
16	0.62	2.63***	2.90***	0.27	10.79**	1.89	0.04	0.44	-2.90
17	0.76*	2.88***	2.90***	0.02	11.92**	4.26	-0.05	0.37	-4.10
18	0.70	1.63***	1.65**	0.02	9.17*	-2.74	0.05	-0.88	-2.90
19	0.11	2.13***	2.40***	0.27	6.42	0.14	-0.01	-0.88	0.85
20	0.09	-0.37	0.15	0.52	-3.33	4.64	0.09**	1.32	-1.73
21	0.69	1.13*	-0.10	-1.23**	-2.71	7.14**	0.04	-0.88	1.17
22	0.49	-3.37***	-3.10***	0.27	-3.21	0.89	0.01	-0.88	-4.10
23	0.16	-0.87	-0.85	0.02	7.79*	20.14***	-0.03	-0.88	17.52***
24	1.79***	-0.12	-1.10*	-0.98*	2.17	0.64	0.02	-0.88	0.72
25	-0.32	2.88***	1.90***	-0.98*	4.29	11.14***	-0.01	-0.88	-1.65
26	0.48	0.13	-1.10*	-1.23**	5.67	17.26***	0.04	-0.88	20.95***
27	-0.49	-1.62	-2.35***	-0.73	-15.08***	-17.99***	0.03	-0.88	-2.85
28	-1.69***	-0.62	-0.35	0.27	-11.83**	-9.11***	-0.06	0.37	-0.40
29	0.21	0.63	0.40	-0.23	12.54***	7.01**	-0.03	1.44	0.65
30	0.60	-0.62	-0.60	0.02	-2.71	-6.86*	0.03	0.37	4.40
31	-0.83*	-0.37	-0.85	-0.48	-4.08	-4.24	0.00	1.74	15.45***
32	0.86*	1.13*	2.40***	1.27**	-5.21	8.76**	0.00	0.32	-4.10
33	0.60	-0.87	-0.60	0.27	-11.58**	-12.61***	-0.01	0.32	4.22
34	-0.78	-3.12***	-2.35***	0.77	-14.21***	-17.61***	-0.03	-0.88	9.22**

LINE	CVY† t/ha	AD days	SD days	ASI days	EI cm	PH cm	EH cm	PH cm	ER %	HC %	Yield t/ha
35	0.52	-1.12*	-0.85	0.27	-6.08	-10.49***	0.04	-0.88	-2.90	-0.88	-2.90
36	-1.51***	-1.37**	-0.35	1.02*	-4.46	-3.74	0.00	-0.88	-4.10	-0.88	-4.10
37	-1.10	1.88***	1.40**	-0.48	-0.71	-6.86*	-0.13***	-0.88	-4.10	-0.88	-4.10
38	0.37	-2.87***	-2.10***	0.77	-2.58	8.14**	-0.06*	-0.88	-2.90	-0.88	-2.90
39	-0.38	0.38	0.40	0.02	9.92*	9.26***	-0.03	0.37	5.75	0.37	5.75
40	1.02**	-0.12	-0.85	-0.73	17.67***	8.76**	0.04	-0.88	-4.10	-0.88	-4.10
41	-0.22	-2.62***	-2.60***	0.02	-9.58*	-13.11***	-0.01	-0.88	-4.10	-0.88	-4.10
42	-0.37	-2.12***	-2.35***	-0.23	-9.21*	-19.86***	-0.01	-0.88	-1.65	-0.88	-1.65
43	-0.21	-0.12	-0.10	0.02	-1.21	-10.86***	0.02	0.32	-0.40	0.32	-0.40
44	0.04	-1.87***	-2.10***	-0.23	-4.83	-4.74	0.03	-0.88	-4.10	-0.88	-4.10
45	0.50	-0.37	-0.35	0.02	10.29**	4.64	0.00	-0.88	-4.10	-0.88	-4.10
46	-1.05**	-2.12***	-0.85	1.27**	-18.83***	-11.36***	0.00	-0.88	3.42	-0.88	3.42
47	-0.56	-1.12*	0.40	1.52**	-1.21	-5.74*	0.00	-0.88	-1.65	-0.88	-1.65
48	-0.27	0.13	-0.10	-0.23	-2.21	-8.24**	-0.03	-0.88	17.50***	-0.88	17.50***
49	-0.82*	-0.12	0.15	0.27	-0.21	0.39	-0.04	3.29**	1.05	3.29**	1.05
50	-1.20**	0.88	1.15*	0.27	-0.96	-9.61***	-0.04	-0.88	-4.10	-0.88	-4.10
51	0.24	-2.62***	-3.85***	-1.23**	-11.46**	-6.36*	0.00	2.82*	-4.10	2.82*	-4.10
52	0.58	-0.12	0.40	0.52	5.17	8.14**	0.00	-0.88	1.92	-0.88	1.92
53	0.23	-4.37***	-3.35***	1.02*	-20.83***	-18.74***	0.01	1.57	-2.85	1.57	-2.85
54	0.34	-0.12	0.40	0.52	-10.83**	7.01**	0.04	0.24	7.12*	0.24	7.12*
55	0.60	-1.87***	-2.10***	-0.23	0.29	-1.49	0.00	-0.88	4.75	-0.88	4.75
56	0.37	-0.12	0.40	0.52	3.29***	3.51	0.01	-0.88	-2.90	-0.88	-2.90
57	0.49	1.38**	0.65	-0.73	-3.58	3.89	0.16***	0.19	-4.10	0.19	-4.10
58	0.33	1.88***	0.40	-1.48**	15.04***	15.26***	0.01	-0.88	-4.10	-0.88	-4.10
59	-0.41	2.63***	1.90***	-0.73	11.29**	1.64	0.01	3.07*	-4.10	3.07*	-4.10
60	-0.52	-2.37***	-0.35	2.02***	-17.96***	-8.11**	-0.06*	1.62	-2.90	1.62	-2.90
61	-0.97*	2.13***	2.65***	0.52	9.04*	-0.74	-0.03	-0.88	-4.10	-0.88	-4.10
62	-0.43	-2.12***	-1.35***	0.77	-5.21	-11.36***	-0.03	-0.88	-0.53	-0.88	-0.53
63	-0.29	2.88***	1.40***	-1.48**	-0.71	-10.36***	0.00	0.59	2.15	0.59	2.15
64	0.25	1.13*	-0.10	-1.23**	3.29	-1.61	0.10**	6.12***	-4.10	6.12***	-4.10
65	-1.26***	1.63***	0.40	-1.23**	-32.71***	-9.24***	0.04	3.19**	-1.15	3.19**	-1.15
Tester 1	0.17***	0.46***	0.25***	-0.20**	5.88***	1.59***	0.02***	-0.15	-2.80***	-0.15	-2.80***
Tester 2	-0.17***	-0.46***	-0.25***	0.20**	-5.88***	-1.59***	-0.02***	0.15	2.80***	0.15	2.80***

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EI: Ear height; PH: Plant height; EPP: Ears per plant; ER: Ear rots; HC: Husk cover.

Table 4. 22 General combining ability (GCA) effects for grain yield and agronomic traits of 65 QPM inbred lines under well-watered conditions at Embu.

LINE	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	ER %	ET 1-5	GLS 1-5	HC %
1	0.16	0.41	-0.92	-1.33*	-0.02	3.39	-0.04	-0.03	10.26
2	-0.64	-0.09	-0.92	-0.83	0.04	0.89	-0.04	0.10	8.91
3	1.07*	-1.59*	-0.92	0.67	-0.03	2.27	-0.04	-0.03	2.46
4	0.78	-1.34*	-2.17**	-0.83	-0.02	-3.34	-0.04	-0.03	15.01*
5	-0.32	-1.09	-0.92	0.17	-0.01	-4.54	-0.04	-0.03	9.74
6	-2.26***	-0.59	0.58	1.17*	-0.10	-3.34	0.08	-0.03	2.94
7	-0.29	2.91***	2.58	-0.33	0.04	5.77*	-0.04	-0.03	-1.29
8	-0.90	2.66***	3.83***	1.17*	-0.01	2.94	-0.04	-0.03	-1.66
9	-0.22	2.16**	2.58***	0.42	-0.06	-1.64	0.08	-0.03	-4.04
10	0.29	1.41*	2.08**	0.67	0.03	-1.14	-0.04	-0.03	0.79
11	-0.29	1.66*	2.83***	1.17*	0.02	-4.54	-0.04	-0.03	-0.39
12	0.72	-0.84	-1.42*	-0.58	0.03	8.74***	-0.04	-0.03	8.46
13	-0.79	2.41***	2.33***	-0.08	-0.04	4.92*	-0.04	-0.03	-3.61
14	-1.28	0.91	1.33	0.42	-0.06	-1.74	-0.04	-0.03	-6.26
15	-0.83	3.91***	4.83***	0.92	-0.10	-3.29	-0.04	-0.03	1.21
16	1.24*	3.16***	4.58***	1.42*	0.00	-3.34	-0.04	0.22***	-4.41
17	-0.36	2.91***	2.83***	-0.08	-0.06	-3.34	-0.04	0.22***	-9.96
18	0.09	3.91***	5.08***	1.17*	-0.03	4.42	0.08	-0.03	-3.91
19	-0.52	2.41***	3.08***	0.67	-0.03	-1.81	0.08	-0.03	-12.34
20	0.67	0.91	0.33	-0.58	0.10	-1.14	-0.04	-0.03	-13.54*
21	-2.00***	2.41***	1.33	-1.08	-0.03	2.02	-0.04	-0.03	-12.06
22	0.97	-5.09***	-5.17***	-0.08	0.05	-2.46	0.08	-0.03	-0.44
23	-0.63	0.91	1.33	0.42	-0.04	2.49	-0.04	-0.03	17.29**
24	2.17***	-1.84**	-1.42*	0.42	0.09	-3.54	-0.04	-0.03	-17.11**
25	-1.64**	4.41***	3.33***	-1.08	0.00	-0.84	-0.04	-0.03	7.86
26	0.70	0.91	0.08	-0.83	0.05	0.42	0.08	-0.03	6.69
27	-0.34	-2.59***	-3.67***	-1.08	0.03	-0.86	0.08	-0.03	17.51**
28	-1.36*	-2.09**	-2.67***	-0.58	-0.12*	0.22	-0.04	-0.03	19.31**
29	0.69	0.91	1.33	0.42	-0.03	1.72	-0.04	-0.03	1.91
30	-0.87	-0.09	0.08	0.17	-0.10	2.62	-0.04	-0.03	2.89
31	0.00	-0.34	-2.42**	-2.08***	0.15**	3.42	-0.04	-0.03	12.46*
32	1.69***	1.91**	2.58***	0.67	-0.02	-3.29	0.21***	0.35***	-1.66
33	0.91	-0.09	-0.92	-0.83	0.00	-3.34	-0.04	-0.03	51.21***
34	-0.22	-1.84**	-1.42*	0.42	0.02	0.29	-0.04	-0.03	5.46

	days	days	days	days	days	#	%	1-5	1-5	%
35	0.27	0.16	0.58	0.42	0.03	0.03	-1.34	-0.04	-0.03	-7.24
36	0.12	-1.59*	-1.42*	0.17	0.03	0.03	-3.41	0.08	-0.03	-8.81
37	-1.34*	1.66*	1.58*	-0.08	-0.03	-0.03	-3.29	-0.04	-0.03	-2.06
38	0.21	-4.34***	-2.92***	1.42*	0.05	0.05	1.24	0.08	-0.03	15.91*
39	0.91	-1.84**	-4.17***	-2.33***	0.03	0.03	3.97	-0.04	-0.03	-7.36
40	0.33	-2.09**	-3.67***	-1.58**	0.19***	0.19***	-2.26	0.08	-0.03	-15.91*
41	0.03	-4.34***	-4.17***	0.17	-0.01	-0.01	0.52	-0.04	-0.03	-0.21
42	0.07	-2.59***	-3.42***	-0.83	0.02	0.02	-3.29	0.08	-0.03	-13.16*
43	1.36*	-1.34**	0.33	1.67**	0.07	0.07	-3.34	0.08	-0.03	-9.19
44	0.98	-2.34**	-1.67*	0.67	0.03	0.03	2.62	-0.04	-0.03	-15.86*
45	0.10	-0.34	-1.17	-0.83	0.02	0.02	-4.54	-0.04	0.10	-5.21
46	0.60	-2.84***	-3.17***	-0.33	-0.02	-0.02	0.59	0.08	0.10	7.24
47	0.41	-1.09	-0.42	0.67	0.03	0.03	2.84	0.08	-0.03	6.46
48	1.57**	0.66	0.58	-0.08	-0.10	-0.10	0.94	-0.04	-0.03	21.64***
49	0.34	-0.59	-0.42	0.17	0.00	0.00	-0.91	0.08	-0.03	-11.19
50	-3.67***	1.16	2.58***	1.42*	-0.15**	-0.15**	10.32***	0.08	-0.03	-3.31
51	0.25	-4.34***	-3.17***	1.17*	-0.03	-0.03	-3.14	-0.04	-0.03	-2.81
52	-0.46	0.91	0.08	-0.83	-0.03	-0.03	1.82	-0.04	0.22***	-6.41
53	1.68**	-5.09***	-4.67***	0.42	0.05	0.05	-3.29	-0.04	-0.03	1.26
54	0.93	-1.84**	-1.67*	0.17	0.06	0.06	0.22	-0.04	-0.03	-3.91
55	-0.83	0.41	0.83	0.42	-0.12*	-0.12*	9.27***	-0.04	-0.03	-1.66
56	-0.09	-2.34***	-2.92***	-0.58	-0.12*	-0.12*	-3.14	-0.04	0.22***	-6.41
57	-1.56**	1.91**	2.83***	0.92	-0.02	-0.02	1.62	0.08	-0.03	-11.16
58	0.50	2.91***	1.58*	-1.33	0.03	0.03	1.29	0.21***	-0.03	-18.31**
59	-0.09	0.91	1.08	0.17	0.03	0.03	-2.16	-0.04	-0.03	5.66
60	0.07	-2.09**	-1.17	0.92	0.03	0.03	2.74	0.08	-0.03	-5.66
61	0.69	3.41***	3.58***	0.17	0.10	0.10	-1.11	-0.04	-0.03	-11.06
62	0.05	-1.09	-1.67*	-0.58	-0.03	-0.03	-2.04	0.08	-0.03	-17.11**
63	0.34	1.66*	1.08	-0.58	0.05	0.05	-2.34	-0.04	-0.03	5.66
64	-0.04	1.66*	1.08	-0.58	0.02	0.02	0.07	-0.04	-0.03	4.31
65	-0.13	1.16	0.33	-0.83	0.04	0.04	0.49	-0.04	-0.03	6.09
Tester 1	0.50***	0.63***	0.11	-0.52***	0.03***	0.03***	-0.59	-0.01	0.02*	-7.92***
Tester 2	-0.50***	-0.63***	-0.11	0.52***	-0.03***	-0.03***	0.59	0.01	-0.02*	7.92***

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; AD; Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EH: Ear height; PH: Plant height; EPP: Ears per plant; ER: Ear rots; HC: Husk cover.

4.3.8 Combining ability effects for grain yield and agronomic traits under managed drought stress

General combining ability effects for grain yield ranged between 1.14 t ha^{-1} and -0.52 t ha^{-1} under managed drought (Table 4.23). Inbred lines 4 and 45 had highly significant ($P < 0.001$) GCA effects for grain yield (1.04 and 1.14 t ha^{-1} , respectively) under managed drought stress. These two parents also had negative GCA effects for AD and ASI, suggesting that they were early maturing. These inbred lines can be desirable parents for hybrid formation and for inclusion in a breeding program, since there is a possibility that they may contribute favorable alleles for early maturity and drought tolerance. Thirty out of 65 lines had positive GCA effects for grain yield under managed drought (Table 4.23).

The GCA effects for ASI under managed drought stress ranged from -4.46 to 7.29 days (Table 4.23). Parent 45 has the lowest GCA value for ASI (-4.46^{***} days). This same line also showed the highest GCA effect for grain yield ($1.44^{***} \text{ t ha}^{-1}$) and good GCA for EPP (0.19^*) under managed drought stress. Tolerant varieties tend to have lower ASI values under drought. The 5 best yielding hybrids under managed drought stress emanated from crosses involving parents 9, 17, 45, 51 and 28 with tester 2 for the first four parents and tester 1 for parent 28, which had high and positive GCA values for grain yield (Tables 4.14 and 4.23). Only six out of 65 parents had positive GCA values for ear rots implying that most of these lines were resistant for ear rots under drought stress.

Significant differences were observed among the lines for ears per plant, an important secondary trait used to select for drought tolerant germplasm. The highest positive GCA effect for EPP was for P13 (0.24**), which also showed good GCA effects for GY and ASI under managed drought (Table 4.23). Positive significant GCA effects suggested increased ears per plant and these lines show the potential to contribute to increased number of ears per plant to their progenies.

Specific combining ability effects for yield under managed drought was highest and significant for the cross between line 28 x CML144 (1.18***, 1.96 t ha⁻¹) (Table 4.24).

LINE	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	ER %	HC %	MOD 1-5	SEN 1-10
1	-0.15	0.33	-0.16	-0.96	-0.08	-0.35	-0.80	-0.20	-0.03
2	0.59**	-1.92***	-0.16	-1.96*	0.16	-0.35	1.83	0.30	0.05
3	0.20	-1.67**	-	-1.71	0.11	-0.35	18.33***	0.17	-0.002
4	1.04***	-2.67***	-	-0.21	0.21*	-0.35	1.83	0.17	0.02
5	0.22	0.58	-3.66**	-1.21	0.11	-0.35	3.38	0.30	-0.15**
6	0.10	0.58	2.09*	0.04	-0.05	-0.35	-0.80	0.05	-0.03
7	0.49	1.83***	2.09*	-0.46	0.06	-0.35	3.90	0.30	-0.10*
8	-0.11	1.08*	2.59**	0.54	-0.12	-0.35	-0.80	0.17	-0.002
9	0.74**	2.08***	2.59**	-3.71***	0.10	-0.35	-0.80	-0.20	-0.10*
10	0.34	-0.42	0.09	-0.21	0.08	-0.35	-0.80	0.42	0.00
11	-0.47	0.58	3.09***	-	-0.07	-0.35	-0.80	0.30	-0.03
12	-0.49	0.58	-3.41***	-	-0.19*	1.33	-0.80	0.80**	-0.15**
13	0.87**	-0.17	-	-3.96***	0.24**	-0.35	-0.80	-0.41	0.15**
14	0.01	1.83***	-	-0.21	-0.08	-0.35	-0.80	0.30	-0.002
15	-0.35	2.33***	-	-0.71	-0.01	-0.35	-0.80	0.30	0.07
16	0.19	1.83***	10.09***	0.29	0.14	-0.35	-0.80	-0.45	0.07
17	0.77**	2.58***	7.09***	-0.21	0.14	-0.35	0.68	-0.70**	0.07
18	-0.14	2.58***	7.09***	-1.71	-0.02	-0.35	-0.80	-0.70**	-0.08
19	-0.19	2.83***	-	1.79	-0.03	-0.35	-0.80	-0.58*	0.05
20	-0.68*	0.58	2.09*	-	-0.24**	-0.35	-0.80	0.30	0.12*
21	-0.78**	-0.17	0.09	-	-0.21*	-0.35	-0.80	-0.20	0.02
22	-0.41	3.33***	-5.66***	-	-0.13	-0.35	-0.80	0.80*	0.12*
23	-0.47	2.33***	-2.91**	7.29***	-0.10	-0.35	-0.80	-0.20	-0.002
24	-0.32	3.33***	0.09	2.79***	-0.12	-0.35	-0.80	0.42	-0.08
25	-0.57*	1.83***	1.09	4.79***	0.14	-0.35	-0.80	0.92***	-0.08
26	-0.71*	4.33***	0.09	-	-0.23**	-0.35	-0.80	0.30	0.12*
27	-0.52	0.33	1.09	1.29	-0.16	-0.35	-0.80	-0.20	0.05
28	0.48	-0.17	-1.16	-1.71	-0.05	-0.35	-0.80	-0.08	0.05
29	-0.26	-3.67***	-	-2.46*	0.20*	-0.35	-0.80	0.17	0.07
30	0.73**	1.33	-1.16	-1.71	0.09	-0.35	0.53	0.17	-0.03
31	0.27	3.33***	-2.16*	-2.71**	0.18*	-0.35	-0.80	-0.58*	0.02
32	-0.73**	0.08	10.09***	1.29	-0.16	-0.35	0.68	-0.20	0.02
33	-0.43	-1.92***	-0.91	2.54**	-0.08	-0.35	-0.80	0.05	-0.03
34	-0.06	-1.42***	-2.41**	-0.21	-0.02	-0.35	5.05*	-0.20	-0.10*

LINE	GY t ha ⁻¹	AD days	SD days	ASI days	EPP #	ER %	HC %	MOD 1-5	SEN 1-10
35	-0.86**	-0.17	0.09	-	-0.23*	-0.35	-0.80	-0.08	0.05
36	0.36	-0.92	-	-0.71	0.18*	-0.35	-0.80	-0.33	0.07
37	0.21	-0.92	2.09*	-1.71	0.16	-0.35	-0.80	0.17	-0.002
38	-0.31	0.58	-3.66***	10.29***	-0.19*	-0.35	-0.80	0.17	0.05
39	-0.15	-1.92***	-1.41	0.79	-0.05	-0.35	0.68	-0.83**	0.07
40	-0.35	-1.67**	-4.16***	1.29	-0.17	-0.35	-0.80	-0.20	-0.05
41	-0.60*	-2.67***	0.09	-	-0.19*	-0.35	-0.80	-0.45	-0.002
42	0.10	1.33*	0.59	0.79	0.16	-0.35	-0.80	-0.45	-0.05
43	0.26	-3.92***	5.09***	-0.21	0.13	-0.35	-0.80	-0.20	-0.05
44	0.18	-1.17*	-3.91***	-1.21	-0.01	1.05	-0.80	0.17	0.07
45	1.14***	-0.17	-0.91	-4.46***	0.19*	-0.35	-0.80	-0.20	-0.03
46	-0.40	-3.67***	5.09***	3.29***	0.02	-0.35	-0.80	-0.08	-0.05
47	0.71*	-1.92***	-3.91***	2.04**	0.21*	1.33	-0.80	-0.20	-0.03
48	-0.02	-0.92	0.09	5.79***	-0.04	-0.35	-0.80	0.30	-0.18
49	0.03	-1.92***	-0.24	-3.21**	0.05	1.43	-0.80	0.55*	-0.03
50	-0.20	-2.67***	-	6.29***	-0.18*	-0.35	-0.80	-0.45	-0.002
51	0.51	-2.42***	-0.66	-0.21	-0.03	-0.35	3.15	0.05	-0.08
52	0.63*	0.08	-	-0.46	0.12	-0.35	-0.80	0.17	0.12**
53	-0.02	0.08	-4.24***	-1.21	0.07	-0.35	0.60	-0.20	-0.03
54	0.04	2.08***	1.76	-	-0.10	7.55	-0.80	0.30	0.05
55	0.63*	-3.42***	-1.41	2.29*	0.21*	-0.35	-0.80	0.42	-0.03
56	-0.51	2.58***	1.09	-	-0.20*	-0.35	-0.80	-0.20	-0.03
57	0.50	-3.92***	1.09	-0.87	0.23*	-0.35	-0.80	-0.08	-0.002
58	-0.34	-1.42**	0.09	3.13**	0.05	-0.35	0.78	-0.58*	0.10*
59	-0.18	-1.42**	2.09*	-1.21	-0.01	7.98	-0.80	0.17	0.02
60	0.08	1.58**	-0.91	-1.21	-0.05	-0.35	-0.80	-0.33	-0.08
61	0.21	3.08***	-	-3.21***	-0.04	-0.35	-0.80	0.30	0.12*
62	-0.07	1.83***	-4.91***	-2.21*	0.07	-0.35	-0.80	0.05	-0.002
63	-0.08	-2.67***	1.84*	2.29*	0.10	-0.35	-0.80	-0.08	-0.10*
64	-0.13	3.83***	2.09*	-	-0.09	-0.35	-0.80	0.17	0.10*
65	-0.56*	-3.42***	-0.91	-1.21	-0.20*	-0.35	-0.80	0.17	-0.08
Tester 1	-0.07*	0.68***	-0.41***	-0.72***	-0.02*	-0.05	-0.18	-0.18***	-0.01
Tester 2	0.07*	-0.66***	0.36***	0.62***	0.02*	0.05	0.18	0.18***	0.01

* **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; AD; Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; ER: Ear rots; HC: Husk cover; MOD: Modification; SEN; Leaf Senescence

Table 4. 24 Specific combining ability effects for grain yield under managed drought stress, across well-watered sites and across all sites

Line	Managed drought stress		Across well-watered		Across Sites	
	Tester 1	Tester 2	Tester 1	Tester 2	Tester 1	Tester 2
1	-0.10	0.10	0.02	-0.02	0.001	-0.001
2	-0.59*	0.59*	0.38	-0.38	0.22	-0.22
3	0.71*	-0.71*	0.34	-0.34	0.40	-0.40
4	0.17	-0.17	-0.12	0.12	-0.08	0.08
5	-0.95***	0.95***	-0.24	0.24	-0.35	0.35
6	0.13	-0.13	-0.22	0.22	-0.16	0.16
7	-0.64	0.64*	0.42	-0.42	0.25	-0.25
8	0.05	-0.05	-0.16	0.16	-0.13	0.13
9	-1.15***	1.15***	-0.16	0.16	-0.33	0.33
10	0.57*	-0.57*	-0.20	0.20	-0.07	0.07
11	-0.08	0.08	-0.21	0.21	-0.19	0.19
12	-0.04	0.04	0.13	-0.13	0.10	-0.10
13	0.09	-0.09	-0.36	0.36	-0.28	0.28
14	-0.42	0.42	0.02	-0.02	-0.05	0.05
15	-0.12	0.12	-0.21	0.21	-0.20	0.20
16	-0.84	0.84**	0.36	-0.36	0.16	-0.16
17	-1.10	1.10	-0.09	0.09	-0.26	0.26
18	-0.41	0.41	-0.05	0.05	-0.11	0.11
19	-0.36	0.36	-0.12	0.12	-0.16	0.16
20	0.08	-0.08	0.51*	-0.51*	0.44*	-0.44
21	0.00	0.00	-0.05	0.05	-0.04	0.04
22	0.01	-0.01	-0.33	0.33	-0.27	0.27
23	-0.06	0.06	0.29	-0.29	0.23	-0.23
24	0.09	-0.09	0.41	-0.41	0.36	-0.36
25	-0.05	0.05	0.46	-0.46	0.37	-0.37
26	-0.02	0.02	0.74**	-0.74**	0.61**	-0.61**
27	-0.08	0.08	-0.32	0.32	-0.28	0.28
28	1.18***	-1.18***	0.21	-0.21	0.37	-0.37
29	0.20	-0.20	0.06	-0.06	0.08	-0.08
30	-0.44	0.44	-0.17	0.17	-0.21	0.21
31	0.62*	-0.62*	0.23	-0.23	0.30	-0.3
32	0.10	-0.10	0.41	-0.41	0.36	-0.36
33	-0.01	0.01	0.34	-0.34	0.28	-0.28
34	-0.30	0.30	0.20	-0.20	0.11	-0.11
35	0.06	-0.06	-0.75**	0.75**	-0.61	0.61**
36	-0.83**	0.83**	-0.05	0.05	-0.18	0.18
37	0.41	-0.41	0.09	-0.09	0.14	-0.14
38	0.66*	-0.66*	-0.37	0.37	-0.20	0.20
39	0.44	-0.44	0.83***	-0.83***	0.77***	-0.77***
40	0.01	-0.01	0.29	-0.29	0.25	-0.25
41	0.02	-0.02	-0.42	0.42	-0.35	0.35
42	-0.40	0.40	-0.50*	0.50*	-0.49*	0.49*
43	-0.09	0.09	0.23	-0.23	0.18	-0.18
44	0.81**	-0.81**	0.01	-0.01	0.14	-0.14
45	-0.57*	0.57*	-0.27	0.27	-0.32	0.32

Table 4.24 continued

Line	Managed drought stress		Across well-watered		Across sites	
	Tester 1	Tester 2	Tester 1	Tester 2	Tester 1	Tester 2
46	-0.41	0.41	0.47	-0.47	0.33	-0.33
47	0.49	-0.49	-0.51*	0.51*	-0.35	0.35
48	-0.38	0.38	-0.27	0.27	-0.29	0.29
49	0.72**	-0.72**	-0.51*	0.51*	-0.31	0.31
50	0.47	-0.47	-0.54*	0.54*	-0.37	0.37
51	-1.11***	1.11***	0.02	-0.02	-0.16	0.16
52	0.85**	-0.85**	0.19	-0.19	0.30	-0.30
53	-0.16	0.16	-0.14	0.14	-0.15	0.15
54	1.00**	-1.00**	-0.43	0.43	-0.19	0.19
55	0.00	0.00	0.06	-0.06	0.05	-0.05
56	0.10	-0.10	-0.33	0.33	-0.26	0.26
57	0.52	-0.52	-0.23	0.23	-0.10	0.10
58	-0.21	0.21	0.10	-0.10	0.04	-0.04
59	0.41	-0.41	-0.13	0.13	-0.04	0.04
60	0.72*	-0.72	0.11	-0.11	0.21	-0.21
61	-0.07	0.07	-0.05	0.05	-0.05	0.05
62	0.53	-0.53	0.56*	-0.56*	0.55*	-0.55*
63	-0.12	0.12	-0.14	0.14	-0.14	0.14
64	0.01	-0.01	0.01	-0.01	0.01	-0.01
65	-0.03	0.03	0.13	-0.13	0.10	-0.10

4.3.9 Line x tester analysis across optimum and across all sites

Across well-watered sites, partitioning of the entry mean squares into line, tester, and line x tester (SCA) revealed highly significant ($P < 0.01$) variation for line and tester sources of variation for all traits except root lodging (Table 4.16). Line x tester interaction revealed highly significant ($P < 0.001$) variation for GY, AD, SD, ASI, HC, and ER, and significant ($P < 0.05$) variation for EA, EPP, and SL. Significant mean squares for lines and testers (GCA) is an indication that additive genetic variance was important for these traits. Line x environment (GCA x E) and tester x environment interaction across well-watered conditions were highly significant for all traits except root lodging (Table 4.16). Significant GCA x E suggests that GCA effects were not consistent across environments. The line x tester x

environment (SCA x E) interaction was highly significant ($P < 0.001$) for ASI, HC, and ER across well-watered sites (Table 4.16). Across all sites, the line x tester mean squares were significant ($P < 0.05$) for all traits except ears per plant, ear height and GLS (Table 4.17). Thus for these traits, non additive gene effects were important. Significant GCA and SCA mean squares implied that variation exists for yield potential among both lines and testers. Across all sites, both line x environment and tester x environment interactions were highly significant ($P < 0.01$) for all traits except PH (Table 4.17). This is an indication that the GCA effects associated with parents were not consistent across environments. Significant mean squares are an indication that the hybrids performed differently across environments for those particular traits.

4.3.10 Combining ability effects across well-watered sites

The GCA effects for grain yield across well-watered sites ranged from 1.09 t ha^{-1} to -0.59 t ha^{-1} (Table 4.25). Lines 29, 30 and 57 had high and significant ($P < 0.01$) GCA effects of 0.96 t ha^{-1} , 1.09 t ha^{-1} and 0.87 t ha^{-1} respectively. This suggests the potential of these lines for improvement for grain yield of quality protein maize. The estimates of GCA effects for ASI across well-watered environments varied among the lines (Table 4.25). Lines 44, 45 and 61 manifested highly significant ($P < 0.001$) negative GCA effects for ASI across well-watered sites. Lines 45 and 61 also had highly significant ($P < 0.001$) negative GCA effects for ASI under drought stress (Table 4.23). A shorter ASI indicates increased partitioning of assimilates to the developing ears under stress (Edmeades *et al.*, 1993) and thus is associated with a higher proportion of fertile ears. Thus, these lines could be useful as parents in a hybrid breeding program. Such hybrids would have to be tested under managed drought stress to

confirm their tolerance to drought. Estimates of GCA effects for anthesis date varied between the lines (Table 4.25). Twenty lines had significant negative GCA effects for anthesis date while another twenty had significant negative GCA effects for silking date across well-watered sites thus indicating that they carry alleles for early maturity. Lines with negative and significant GCA effects for ear rots, husk cover, root lodging and stem lodging suggest that these lines may be important sources of good allele to improve these traits.

Highest SCA effects for grain yield across well-watered sites was for the cross between line 39 x CML144 (0.83***, 8.26 t ha⁻¹) (Table 4.24). This was entry 77 which was the best performing entry in terms of grain yield across well-watered sites (Table 4.15).

4.3.11 Combining ability effects across all sites and heterotic grouping

The GCA estimates for yield across all sites ranged from 1.03 t ha⁻¹ to -1.33 t ha⁻¹ (Table 4.26). Parents 29, 30, 43, 44, 45 and 57 had the best GCA effects across all sites (Table 4.26). Significant GCA effects were observed for days to anthesis. Large and negative GCA effects for anthesis dates were observed for parents 29, 43, 46 and 57 across all sites showing that they were early maturing. Significant negative GCA effects for anthesis-silking interval were recorded across all environments for lines 9, 20, 44, 46 and 61. Significant GCA effects for ears per plant were recorded among the lines with lines 29 (0.07* ears), 37 (0.13*** ears) and 45 (0.10*** ears) across all environments. Thus, the lines showed the potential to increase the number of ears per plant in their progenies under well-watered conditions and also under managed drought. Lines 35, 37 and 49 had significant ($P < 0.01$) negative GCA effects for turicum leaf blight disease. This is an indication that the lines could be potential sources of resistance to this disease and could be used in a QPM breeding program. Significant negative

GCA effects for root and stem lodging suggested lodging resistance for those particular lines. Positive and significant SCA effects for grain yield across all sites was highest for the cross between line 39 x CML144 (0.77***) (Table 4.24).

An inbred line that expresses negative SCA effects when crossed to the tester implies that the two belong to the same heterotic group while positive SCA effects indicate that the lines are in opposite heterotic groups (Vasal *et al.*, 1992). This method was used to classify the 65 inbred lines into heterotic groups based on the SCA effects for grain yield with inbred lines CML144 (heterotic group B) and CML159 (heterotic group A). Out of 65 lines, 29 lines were grouped into heterotic group B while 25 were grouped into heterotic group A (Table 4.27). Because of very small SCA effects, ten (11) inbred lines (1, 4, 10, 14, 21, 29, 55, 58, 59, 61, and 64) could not be clearly classified into any heterotic group. These may be considered as heterotic group A/B and could be used to cross lines from either group. Of those classified into heterotic group A, nine (9) inbred lines had positive GCA for grain yield across locations. These lines could be used to form a heterotic QPM synthetic. Another heterotic QPM synthetic can be formed using the 10 inbred lines in heterotic group B that had positive GCA effects for grain yield across locations. These two synthetics can be used to extract new QPM inbred lines for further breeding work. The 29 inbred lines with positive GCA effects for grain yield across locations could be used to form a QPM open-pollinated variety that would be evaluated for performance together with already released QPM OPVs under both stress and non-stress conditions.

LINE	GY ¹ t ha ⁻¹	AD days	SD days	ASI days	EPP #	ER %	HC %	EA 1-5	PA 1-5	RL %	SL %
1	0.47	-0.19	-0.75	-0.56	0.001	-0.95	-2.48	-0.16	-0.15	4.74	4.84
2	0.22	-1.04**	-1.00*	0.04	0.004	1.84	3.76	0.22*	-0.06	0.49	-1.40
3	-0.11	-0.29	-0.3	-0.01	0.01	-0.92	9.50*	0.14	-0.06	-6.76	-0.50
4	-0.34	-1.54***	-1.50**	0.04	0.001	-0.64	5.76	0.09	-0.02	-2.28	-0.74
5	0.04	-0.09	-0.65	-0.56	-0.01	-2.95	-8.66**	-0.36***	0.23*	3.83	1.36
6	0.60*	-0.89*	-0.9	-0.01	-0.01	-2.22	-3.46	-0.26*	-0.24*	-6.78	0.76
7	-0.22	2.91***	2.00***	-0.91**	0.004	-1.53	4.07	-0.01	0.19	-2.39	6.39*
8	-0.16	1.56***	0.85	-0.71*	0.03	0.99	0.30	0.12	0.23*	-1.93	5.23
9	-0.37	0.96**	0.05	-0.91**	0.02	0.66	0.93	0.17	0.10	3.95	5.89
10	-0.11	-0.89*	-0.75	0.14	-0.01	0.06	3.18	0.02	-0.09	3.02	-2.51
11	0.36	-0.89*	-0.55	0.34	-0.02	0.29	7.33	0.02	-0.15	0.83	2.42
12	0.00	-0.59	-0.55	0.04	-0.03	-2.74	0.48	0.14	0.16	3.94	-4.00
13	-0.28	-0.64	-0.70	-0.06	0.01	-2.12	2.66	0.07	0.07	1.49	-3.84
14	-0.08	-0.29	-0.30	-0.01	-0.03	-1.03	6.61	-0.06	0.07	5.64	-3.80
15	-0.08	1.71***	1.75***	0.04	0.003	2.47	-0.57	0.17	0.10	3.04	9.10**
16	-0.06	1.71***	2.15***	0.44	0.03	-0.87	-4.54	0.07	-0.09	6.84	-1.78
17	0.19	1.11***	1.50**	0.39	-0.03	-0.80	-2.45	-0.03	0.01	4.38	1.52
18	0.25	1.26**	1.55***	0.29	-0.01	-1.04	-0.36	-0.08	-0.15	-1.15	-5.04
19	-0.08	1.06**	1.45**	0.39	-0.02	-2.37	-3.01	-0.03	0.01	11.9**	1.84
20	0.14	1.86***	0.7	-1.16	-0.06*	2.84	2.57	-0.08	-0.02	-4.78	-0.87
21	-0.33	0.76	1.05*	0.29	-0.04	-0.49	1.41	0.12	-0.09	-0.26	-6.81
22	-0.45	3.51***	3.70***	0.19	-0.03	-1.80	1.84	0.02	0.35**	-0.22	7.51**
23	0.04	2.96***	3.55***	0.59	-0.03	1.34	-2.61	0.02	0.10	-1.79	3.20
24	-0.05	2.71***	2.70***	-0.01	-0.02	-1.47	-7.20	-0.13	0.13	16.48***	1.79
25	-0.11	2.91***	3.50***	0.59	-0.02	0.96	-6.90	0.02	0.10	5.47	-0.75
26	-0.22	2.36***	3.05***	0.69*	-0.02	-1.59	-6.57	-0.06	0.29*	-0.28	1.16
27	0.16	0.31	0.40	0.09	0.06*	1.59	-4.86	-0.11	-0.12	-2.41	-2.19
28	0.30	0.71	0.25	-0.46	-0.01	0.34	0.59	-0.13	-0.34**	-3.49	-4.57
29	0.96**	-3.94	-3.95***	-0.01	0.04	-1.68	-3.95	-0.13	-0.27*	-0.41	-4.58
30	1.09***	-0.99*	-1.20*	-0.21	0.05	2.23	-0.35	-0.06	0.04	0.64	1.08
31	-0.66*	3.06***	2.40***	-0.66	0.001	0.21	-0.04	0.12	-0.02	-3.95	4.35
32	0.11	-0.14	-0.65	-0.51	0.02	-1.64	8.08*	0.17	-0.02	-7.23	2.93
33	-0.40	-1.99***	-2.05***	-0.06	0.03	-0.71	1.44	-0.13	0.07	-7.33	5.01

LINE	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	ER %	HC %	EA 1-5	PA 1-5	RL %	SL %
34	-1.58***	-1.19**	-0.80	0.39	-0.09	1.51	3.75	0.37***	0.16	0.36	-2.61
35	0.14	0.91*	1.15*	0.24	0.01	3.02*	8.02*	0.04	-0.02	-7.58	-0.99
36	-0.13	-0.89*	-0.75	0.14	0.004	1.41	6.92	-0.03	0.01	3.60	-1.48
37	0.28	-1.24**	-2.25***	-1.01**	0.13	1.03	6.81	-0.13	-0.18	3.22	-0.53
38	0.37	1.81***	3.00***	1.19***	-0.05	-0.54	0.30	0.04	0.01	5.54	-3.93
39	0.37	-0.79*	-0.80	-0.01	0.01	0.92	20.34***	0.12	-0.15	10.42*	-3.28
40	0.63*	-1.09**	-1.00*	0.09	0.002	-0.72	-8.94*	0.04	-0.24*	-8.31	-4.25
41	-0.64*	-1.74***	-1.45**	0.29	-0.02	-1.54	-4.39	0.09	0.10	-9.18*	2.04
42	-0.53	2.11***	1.80***	-0.31	0.03	-0.63	-2.91	0.19	0.01	-9.11*	7.12*
43	0.68*	-3.69***	-2.90***	0.79*	-0.02	-0.59	6.17	0.07	-0.21	1.30	-2.03
44	0.69*	-0.74	-2.35***	-1.61***	0.005	0.87	6.19	-0.08	-0.09	0.52	-5.54
45	0.69*	-0.59	-1.80***	-1.21***	0.09**	-2.04	-8.22*	-0.38***	0.07	11.19*	2.24
46	-0.09	-3.49***	-2.80***	0.69*	0.005	0.81	-6.64	-0.03	0.04	-4.17	-2.73
47	0.31	-1.09**	-1.65***	-0.56	0.03	-2.66	-9.18*	-0.36***	-0.06	10.26*	-2.63
48	0.03	-0.59	0.05	0.64	-0.02	-0.26	-3.48	-0.26*	0.01	-4.91	-5.44
49	0.42	-1.74***	-1.15*	0.59	0.01	0.36	-5.99	0.29**	-0.06	-0.85	5.95*
50	-0.87**	-2.34***	-1.15*	1.19***	-0.03	5.09***	7.25	0.24*	0.23*	1.41	-0.84
51	-0.20	-1.79***	-1.00*	0.79*	0.002	0.32	-1.57	-0.06	0.01	-9.67*	-0.58
52	0.39	0.71	0.25	-0.46	-0.03	3.67**	23.69***	0.27*	0.10	3.05	-3.47
53	-0.56	-0.09	0.00	0.09	-0.04	0.48	1.93	0.09	0.10	-8.90*	-2.18
54	-1.54***	1.31***	1.70***	0.39	-0.04	1.91	-1.47	0.17	0.16	-3.46	-1.84
55	-0.59	-2.94***	-2.40***	0.54	-0.07**	-0.02	-8.32*	0.27*	0.16	-5.88	-2.18
56	-0.35	0.71	0.65	-0.06	0.004	-0.21	-0.48	-0.06	0.13	6.29	5.41
57	0.87**	-4.39***	-4.05***	0.34	0.03	-0.07	-2.81	-0.23*	-0.15	-4.55	-2.7
58	0.31	0.06	0.00	-0.06	0.06*	-0.25	2.49	0.02	0.04	-4.91	-3.71
59	0.37	-0.79*	-0.65	0.14	-0.01	2.88	1.14	-0.08	-0.09	-3.18	-4.23
60	-0.01	0.51***	1.15*	-0.36	0.05	-0.81	-8.27*	-0.06	-0.18	-0.70	6.42*
61	0.21	2.81***	1.45**	-1.36***	0.07*	-1.20	-4.8	-0.16	0.01	2.00	8.34*
62	-0.26	2.01***	1.40**	-0.61	0.01	-0.11	-1.6	-0.16	0.04	-0.25	1.79
63	-0.53	-1.84***	-1.45**	0.39	-0.03	3.81*	-2.63	0.07	-0.09	-0.20	2.03
64	0.47	2.21***	2.55***	0.34	0.03	-1.16	-10.67**	0.02	-0.24*	5.34	-3.73
65	-0.15	-2.09***	-1.45**	0.64	-0.02	-1.59	-5.00	-0.06	0.01	-1.87	-3.42
Tester 1	0.03**	0.34***	-3.53	0.36	-0.55***	-0.16***	-1.25	-0.20	-4.83***	-0.05	1.97
Tester 2	-0.03**	-0.34***	3.53	-0.36	0.55***	0.16***	1.25	0.20	4.83***	0.05	-1.97

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; AD; Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; ER: Ear rots; HC: Husk cover; EA: Ear aspect; PA: Plant aspect; RL: Root lodging; SL: Stem lodging

Table 4. 26 General combining ability (GCA) effects for grain yield and agronomic traits of 65 QPM inbred lines across all sites

LINE	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	PH cm	EH cm	ER %	ET 1-5	GLS 1-5	HC %	RL %	SL %
1	0.36	-0.10	-0.3	-0.38	-0.01	10.76**	0.96	-0.83	-0.14	0.02	-2.20	3.20	3.65
2	0.28	-1.18***	-1.05*	-0.04	0.03	10.26**	3.55	1.74	0.23**	0.21*	3.44	0.52	-1.33
3	-0.06	-0.51	-0.63	-0.23	0.03	13.95***	9.93**	-0.80	0.03	0.09	10.97***	-5.92	-0.61
4	-0.11	-1.72***	-1.30**	0.25	0.03	-9.12*	-7.95*	-0.58	-0.02	0.02	5.10	-1.34	-0.81
5	0.07	0.03	-0.77	-0.68	0.01	-4.8	-1.95	-2.43	0.23**	0.02	-6.65*	1.86	1.15
6	0.51	-0.64	-0.22	0.25	-0.02	4.29	3.05	-1.85	-0.06	0.24*	-3.02	-6.38	0.66
7	-0.10	2.74***	2.32***	-0.59	0.01	-4.68	2.05	-1.29	-0.06	-0.16	4.04	0.66	4.90*
8	-0.16	1.49***	1.41**	-0.25	0.01	3.45	3.30	0.73	0.15	-0.13	0.12	-0.68	3.97
9	-0.18	1.15***	-0.13	-1.23**	0.03	-15.02***	-16.38***	0.46	0.25**	-0.04	0.64	3.09	4.49
10	-0.04	-0.81*	-0.3	0.33	0.00	0.35	4.65	-0.02	0.198	-0.07	2.52	1.74	-2.23
11	0.22	-0.64	-1.18*	-0.10	-0.03	0.54	-0.32	0.17	-0.09	-0.10	5.98	-0.27	1.72
12	-0.08	-0.39	-1.18*	-0.40	-0.06	3.63	2.77	-2.26	0.06	0.05	0.27	2.26	-3.42
13	-0.09	-0.56	-0.84	-0.46	0.05	0.45	-0.40	-1.76	-0.04	-0.07	2.08	1.18	-2.97
14	-0.07	0.07	-0.18	-0.09	-0.04	9.17*	13.12***	-0.89	-0.03	-0.16	5.37	4.73	-3.25
15	-0.13	1.82***	2.16***	0.16	0.00	0.70	3.99	1.91	-0.06	-0.04	-0.61	4.39	7.88***
16	-0.02	1.74***	2.10***	0.36	0.05	3.48	0.80	-0.76	-0.10	0.09	-3.92	7.92*	-1.35
17	0.28	1.36***	1.51**	0.27	0.00	1.60	1.80	-0.71	-0.02	-0.13	-1.93	6.08	1.00
18	0.19	1.49***	1.32**	0.04	-0.01	3.79	1.21	-0.90	0.10	-0.07	-0.44	-0.74	-4.25
19	-0.10	1.36***	1.51**	0.45	-0.03	-4.12	1.96	-1.97	-0.08	0.05	-2.64	10.74**	1.57
20	0.00	1.65***	0.07	-1.60***	-0.09**	1.42	-4.98	2.21	-0.13	-0.10	2.01	-3.55	-0.91
21	-0.40	0.61	0.42	-0.15	-0.07*	-2.99	-9.13***	-0.46	0.02	-0.16	1.04	-1.69	-5.37*
22	-0.45	3.49***	3.07***	-0.25	-0.05	7.73*	12.18***	-1.51	0.00	-0.07	1.40	-0.55	6.38**
23	-0.05	2.74***	4.05***	1.13**	-0.04	-2.05	3.37	1.01	0.03	0.05	-2.31	-2.04	2.64
24	-0.10	2.82***	3.01***	0.18	-0.03	-3.4	4.52	-1.24	0.08	0.09	-6.14	12.21**	1.22
25	-0.18	2.65***	3.73***	0.91*	0.01	-1.65	3.83	0.70	-0.03	-0.16	-5.88	3.97	-0.81
26	-0.30	2.69***	2.42***	0.25	-0.06	-7.87*	-1.29	-1.34	0.03	-0.04	-5.61	-1.99	1.03
27	0.05	0.32	0.46	0.13	0.02	0.70	0.90	1.20	0.03	-0.10	-4.18	-2.06	-1.70
28	0.33	0.57	0.14	-0.64	-0.01	7.38*	1.93	0.20	-0.09	-0.10	0.35	-3.13	-3.87
29	0.76**	-3.89***	-3.88***	-0.17	0.07*	7.26*	-1.45	-1.41	-0.01	-0.07	-3.43	1.25	-3.32
30	1.03***	-0.60	-0.63	-0.21	0.06	1.32	0.21	1.72	-0.05	0.02	-0.20	2.88	1.24
31	-0.50	3.11***	2.53***	-0.75	0.03	17.76***	7.05*	0.10	-0.21*	-0.13	-0.17	-2.92	3.84
32	-0.03	-0.10	-0.68	-0.41	-0.01	16.98***	6.65	-1.38	0.23**	0.05	6.85*	-4.23	2.13
33	-0.41	-1.97***	-1.18*	0.62	0.01	-15.52***	-9.73**	-0.63	0.26**	-0.20*	1.06	-6.12	4.21

LINE	GY† t ha ⁻¹	AD days	SD days	ASI days	EPP #	PH cm	EH cm	ER %	ET 1-5	GLS 1-5	HC %	RL %	SL %
34	-1.33***	-1.22***	-0.51	0.54	-0.08**	-18.87***	-14.79***	1.14	0.15	0.18	3.96	-1.20	-0.54
35	-0.03	0.65	0.52	-0.20	-0.03	0.92	7.24*	2.35	-0.23**	0.21*	6.55	-4.79	-0.73
36	-0.05	-0.89*	-0.47	0.25	0.03	0.26	1.05	1.06	-0.10	-0.01	5.63	1.64	-0.47
37	0.27	-1.18***	-1.88***	-0.88*	0.13***	1.67	-1.42	0.76	-0.27**	0.09	5.54	4.21	-0.64
38	0.25	1.61***	3.55***	1.95***	-0.07*	5.42	-4.20	-0.50	-0.04	0.34***	0.12	2.66	-3.36
39	0.28	-0.97***	-0.90	0.00	0.00	-4.43	-2.79	0.67	-0.07	-0.07	17.06***	10.40**	-2.84
40	0.47	-1.18***	-0.99*	0.13	-0.03	0.04	1.33	-0.64	-0.08	-0.01	-7.59*	-6.11	-3.62
41	-0.64*	-1.89***	-2.08***	-0.15	-0.05	-2.90	-3.51	-1.30	-0.05	-0.13	-3.80	-7.11	1.71
42	-0.43	1.99***	1.73***	-0.28	0.05	-4.99	-3.57	-0.57	-0.02	0.21*	-2.56	-7.19	5.48*
43	0.61*	-3.72***	-2.68***	0.87*	0.00	9.45**	2.40	-0.54	-0.12	-0.10	5.00	1.60	-1.84
44	0.60*	-0.81*	-2.36***	-1.64***	0.00	15.23***	12.96***	0.63	0.04	0.21*	5.02	-0.75	-4.33
45	0.77	-0.51	-1.84***	-1.50***	0.10***	6.60	12.33***	-1.70	-0.09	-0.01	-6.99*	9.74*	1.85
46	-0.14	-3.51***	-1.97***	1.37**	0.01	-12.37***	-9.48**	0.58	-0.20*	-0.16	-5.67	-3.94	-1.87
47	0.38	-1.22***	-0.93	0.12	0.06	-8.30*	-3.51	-2.19	-0.20*	0.15	-7.79*	7.37	-2.32
48	0.02	-0.64	0.42	1.04*	-0.02	-17.87***	-7.57*	-0.27	0.13	0.02	-3.04	-4.10	-3.78
49	0.35	-1.76***	-1.49**	0.18	0.02	0.67	1.46	0.50	-0.28***	-0.07	-5.12	-0.14	4.54
50	-0.76**	-2.39***	-0.68	1.59***	-0.05	-13.80***	-14.10***	4.00**	0.32***	0.02	5.91	-0.05	-0.89
51	-0.08	-1.89***	-1.36**	0.63	-0.01	-0.96	1.80	0.52	0.09	-0.10	-0.79	-9.50*	-0.68
52	0.43	0.61	0.57	-0.21	0.00	-1.46	2.24	2.87*	0.18*	0.05	19.60***	0.99	-2.99
53	-0.47	-0.06	0.11	0.02	-0.02	1.32	-0.26	0.67	-0.14	-0.13	1.71	-7.09	-1.68
54	-1.28***	1.44***	1.07*	-0.05	-0.05	-17.05***	-7.63*	1.46	-0.08	-0.10	-1.36	-4.53	-1.69
55	-0.38	-3.01***	-1.76***	1.08*	-0.03	-14.30***	-12.01***	-0.08	0.15	0.09	-7.07*	-3.63	-1.96
56	-0.37	1.03**	0.02	-0.50	-0.03	7.38*	-1.1	-0.24	0.06	0.46***	-0.53	4.13	4.11
57	0.81**	-4.31***	-3.94***	0.28	0.06*	-8.77*	-9.92**	-0.13	0.14	0.12	-2.48	-2.12	-2.38
58	0.20	-0.18	0.37	0.45	0.06	8.73*	-3.85	1.31	-0.03	-0.10	2.20	-5.12	-3.18
59	0.28	-0.89*	-0.81	-0.05	-0.01	-0.46	0.93	2.24	0.07	-0.07	0.81	-4.03	-3.60
60	0.01	1.53***	1.05*	-0.50	0.03	7.38*	-0.85	-0.72	0.00	-0.07	-7.03*	-0.66	4.92
61	0.21	2.86***	1.23**	-1.59***	0.05	9.67**	8.30**	-1.03	0.03	-0.07	-4.13	2.58	6.77**
62	-0.23	1.99***	1.37**	-0.82	0.02	1.01	8.18**	1.51	0.23**	-0.10	-1.47	0.62	1.21
63	-0.46	-1.97***	-1.49**	0.50	-0.01	-9.12*	-9.70**	2.98*	0.01	0.24*	-2.32	-1.21	2.03
64	0.37	2.49***	1.92***	-0.10	0.01	6.60	11.37***	-0.99	-0.17*	0.05	-9.03**	4.86	-1.70
65	-0.22	-2.31***	-1.86***	0.41	-0.05	-2.43	-1.51	-1.34	-0.05	0.02	-4.30	-2.72	-2.95
Tester 1	-0.07*	0.27**	-0.05	0.40**	0.02	1.62	-0.60***	3.84***	4.03***	-1.01	0.05*	-0.10	-0.13**
Tester 2	0.07*	-0.27**	0.05	-0.40**	-0.02	-1.62	0.59***	-3.84***	-4.03***	1.01	-0.05*	0.10	0.13**

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

† GY: Grain yield; AD; Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; PH: Plant height; EH: Ear height; ER: Ear rots; ET: *E. Turcicum*; HC: Husk cover; RL: Root lodging; SL: Stem lodging.

Table 4. 27 Heterotic grouping of 65 QPM inbred lines based on specific combining ability for grain yield with two inbred line testers

Line	Specific combining ability with		HET GRP	Line	Specific combining ability with		HET GRP
	CML144	CML 159			CML144	CML 159	
1	0.001	-0.001	AB	34	0.11	-0.11	A
2	0.22	-0.22	A	35	-0.61	0.61**	B
3	0.40	-0.40	A	36	-0.18	0.18	B
4	-0.08	0.08	AB	37	0.14	-0.14	A
5	-0.35	0.35	B	38	-0.20	0.20	B
6	-0.16	0.16	B	39	0.77***	-0.77***	A
7	0.25	-0.25	A	40	0.25	-0.25	A
8	-0.13	0.13	B	41	-0.35	0.35	B
9	-0.33	0.33	B	42	-0.49*	0.49*	B
10	-0.07	0.07	AB	43	0.18	-0.18	A
11	-0.19	0.19	B	44	0.14	-0.14	A
12	0.10	-0.10	A	45	-0.32	0.32	B
13	-0.28	0.28	B	46	0.33	-0.33	A
14	-0.05	0.05	AB	47	-0.35	0.35	B
15	-0.20	0.20	B	48	-0.29	0.29	B
16	0.16	-0.16	A	49	-0.31	0.31	B
17	-0.26	0.26	B	50	-0.37	0.37	B
18	-0.11	0.11	B	51	-0.16	0.16	B
19	-0.16	0.16	B	52	0.30	-0.30	A
20	0.44*	-0.44	A	53	-0.15	0.15	B
21	-0.04	0.04	AB	54	-0.19	0.19	B
22	-0.27	0.27	B	55	0.05	-0.05	AB
23	0.23	-0.23	A	56	-0.26	0.26	B
24	0.36	-0.36	A	57	-0.10	0.10	B
25	0.37	-0.37	A	58	0.04	-0.04	AB
26	0.61**	-0.61**	A	59	-0.04	0.04	AB
27	-0.28	0.28	B	60	0.21	-0.21	A
28	0.37	-0.37	A	61	-0.05	0.05	AB
29	0.08	-0.08	AB	62	0.55*	-0.55*	A
30	-0.21	0.21	B	63	-0.14	0.14	B
31	0.30	-0.30	A	64	0.01	-0.01	AB
32	0.36	-0.36	A	65	0.10	-0.10	A
33	0.28	-0.28	A				

*, **, ***, Significant at 0.05, 0.01 and 0.001 probability levels, respectively

4.4 Conclusions and recommendations

Hybrids with high yields under managed drought stress and across well-watered sites were identified. Entries 55, 60, 87, 103 and 113 were among the top 20 performers in terms of grain yield both under managed drought and across the five well-watered sites. This suggested presence of valuable genetic material that could be successfully used for further breeding work. Promising single crosses could be used as parents for the formation of three way hybrids after being evaluated in other locations.

Inbred lines with desirable GCA for yield were 4 and 45 with significant ($P < 0.001$) GCA effects for grain yield of 1.04 t ha^{-1} and 1.14 t ha^{-1} respectively under managed drought stress. Line 45 also showed significant ($P < 0.05$) GCA effect for grain yield of 0.69 t ha^{-1} across well-watered sites. This showed its ability to perform well under well-watered condition as well as managed drought. Across well-watered conditions, lines 29, 30 and 57 had significant ($P < 0.01$) GCA effects of 0.96 t ha^{-1} , 1.09 t ha^{-1} and 0.87 t ha^{-1} respectively. Best general combiners for grain yield across all sites were lines 29, 30, 43, 44, 45 and 57. These were parents to the top performers across well-watered environments as well as under managed drought. By use of two inbred line testers CML144 and CML159, 65 inbred lines were grouped into 3; 29 in heterotic group B, 25 in heterotic group A and 11 in heterotic group AB. The best general combiners for grain yield under drought were lines 45, 4, 13, 17, and 9 which were grouped into heterotic group B. These lines could be useful in developing synthetics which can be used in extraction of QPM lines. Lines with good GCA in each group may be used as parents in formation of hybrids. They may also be recombined and further improved using appropriate breeding schemes to enhance level of heterosis.

CHAPTER 5

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

Two studies were conducted to study the combining ability and classify quality protein maize (QPM) inbred lines developed at CIMMYT in Kenya. In the first study, 13 QPM inbred lines were crossed in diallel mating design to produce 78 single cross hybrids. The 78 F₁ hybrids and two checks were evaluated in six environments: three well-watered, one managed drought stress, one random drought, and one managed low nitrogen stress.

Across all environments, GCA and SCA mean squares for grain yield were significant, suggesting the importance of both additive and non-additive genetic effects in control of grain yield in this germplasm. Researchers have also indicated additive and non additive effects in the inheritance of different agronomic traits in maize (Zehui *et al.*, 2000; Bayisa *et al.*, 2008. Mean squares for GCA x environment were significant across all sites for grain yield and other traits. The significant GCA X Environment interaction mean squares indicates that there is significant variation in the combining ability of the lines under different environments. This result is consistent with findings of several researchers (Menkir *et al.*, 2003; Badu – Apraku *et al.*, 2005,2007) and underscores the need for testing inbred lines in contrasting environments to identify drought and low nitrogen tolerant maize hybrids with stable performance.

Baker (1978) suggested that the performance of a single-cross progeny can be adequately predicted on the basis of GCA, if SCA is not significant. Parents 1 and 2 had high and positive GCA effects for grain yield under well-watered and managed drought stress

suggesting that these lines carry good alleles for grain yield, and have potential to be used as parents in developing hybrids and pedigree breeding programs. Parents 3, 4, 5 and 11 had positive and significant GCA effects for grain yield under managed low nitrogen stress. These inbred lines showing positive GCA effects for grain yield under both stress and non-stress should be tested further in hybrid combination under both well-watered and managed drought at more locations to verify their performance. Entry 42 which was a cross between parents 2 and 13 was consistently among the top performance in terms of grain yield at all the three well-watered sites, managed drought, random drought and low nitrogen sites. Both parents of this hybrid exhibited good GCA for grain yield. This hybrid should be tested further for potential use as a parent in formation of three way crosses and double cross hybrids for the low and mid altitude ecologies of eastern Africa. Because of its good performance across environments, it also has potential to be used as a single cross hybrid.

Correlation analysis is used as one of the tools for determining the value of secondary traits in relation to grain yield (Hallauer and Miranda, 1988; Edmeades et al., 1997).

Positive correlation for grain yield and anthesis date under well watered environments was an indication that grain yield potential is proportional to crop maturity. Anthesis-silking interval and ears per plant had less influence on grain yield for maize grown under well watered sites. However, under managed drought stress and low nitrogen stress, grain yield was negatively correlated with ASI whereas the correlation between grain yield and ears per plant was positive and significant. This is an indication that under stress ASI was found to be associated with increased partitioning of photo-assimilates to developing ears

and thus the increase in grain yield and ears per plant. This is in agreement with the results of previous studies under drought stress (Edmeades et al., 1997; Bolaños and Edmeades, 1997; Betrán et al., 2003). Anthesis-silking interval and ears per plant are thus very important secondary traits and both reflect the ability of the hybrid to produce grain under stress.

In the second study, 65 early maturing QPM inbred lines were crossed to two inbred line testers (CML144 and CML159) in a line x tester mating design to form 130 hybrids. These 130 hybrids and two QPM single cross hybrid checks were evaluated in five well-watered environments and one managed drought stress site.

Partitioning of the entry mean squares into line, tester, and line x tester (SCA) revealed highly significant ($P < 0.01$) variation for line and tester sources of variation for grain yield, anthesis date, silking date, anthesis-silking interval and ears per plant across well-watered sites and thus both additive and non additive gene action were important for these traits. The line x tester mean squares were significant ($P < 0.05$) for all traits except ears per plant, ear height and GLS. Thus, for these traits, non additive gene effects were important. Significant GCA and SCA mean squares implied that variation exists for yield potential among both lines and testers. Across all sites, both line x environment and tester x environment interactions were highly significant ($P < 0.01$) for all traits except PH. This is an indication that the GCA effects associated with parents were not consistent across environments. The need for multi environment testing when estimating phenotypic values was reported earlier on by Christie and Shattuck (1992) and Zhang and Kang

(1997). Across-site data are considered more useful and practical for this study because breeding companies operating in tropical environments develop and release varieties based on performance across sites and not individual site performance, despite the existence of genotype \times environment interactions (Eberhart et al., 1995).

The GCA effects allow identification of superior parents that could be used to make and select better crosses for direct use or for further breeding (Simmonds, 1979). Inbred lines 29, 30, 43, 44 and 45 had significant and positive GCA effects for grain yield under managed drought as well as under well-watered sites. The two inbred line testers grouped 29 lines into heterotic group B, 25 lines into heterotic group A and 11 lines into heterotic group AB. Heterotic groups are formed by isolation and selection (natural or human) for adaptedness over time and are critical in maximizing the expression of heterosis in hybrids (Pawali, 2000). It is commonly assumed that the combination of lines of different heterotic groups results in hybrids with higher chances of genetic expression of the target effects of hybridization (Troyer, 1999; Austin *et al.*, 2000; Birchler et al., 2003; Tollenaar *et al.*, 2004; Ricci *et al.*, 2007).

In these studies, results suggest that it is possible to combine drought tolerance and good performance under optimum conditions in QPM germplasm. Based on GCA effects for grain yield, two QPM heterotic synthetics and an open-pollinated variety can be formed from this germplasm. The heterotic synthetics can be used to extract new QPM inbred lines for further breeding. Quality protein maize should be promoted in areas facing

malnutrition since hybrids with good performance comparable to normal endosperm maize can be obtained with sustained breeding efforts.

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APPENDICES

Appendix 1: Mean grain yield and agronomic traits for diallel hybrids at Kakamega under well-watered environment

ENTRY	CROSS	GY†	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	GLS	ET	EA	PA
1	1x2	10.84	71.5	71.7	0.0	227.1	124.8	41.5	0.0	1.00	30.7	6.1	1.7	2.3	1.8	1.3
2	1x3	8.28	73.0	73.1	0.3	238.8	137.7	25.3	2.7	1.09	21.6	2.2	1.5	2.2	2.2	2.3
3	1x3	9.11	69.0	69.2	-0.1	231.1	136.7	23.6	4.8	1.27	35.8	3.4	1.5	2.5	2.5	2.3
4	1x5	8.59	71.5	71.4	0.2	215.9	132.4	35.7	0.0	1.18	0.0	2.0	1.7	2.5	2.0	1.8
5	1x6	10.99	67.0	66.5	-0.8	207.7	119.9	2.6	5.2	1.46	20.3	0.1	1.5	1.8	1.8	1.0
6	1x7	8.53	69.9	70.0	0.5	218.7	127.6	32.0	2.7	1.00	5.3	0.0	1.7	3.0	2.5	1.8
7	1x8	9.24	65.5	70.6	5.1	232.1	131.9	17.6	8.8	1.15	9.4	2.5	1.5	2.2	2.3	2.0
8	1x9	11.47	71.5	69.5	-2.2	220.0	118.5	4.8	0.0	1.18	10.6	4.0	1.5	2.5	2.3	1.5
9	1x10	9.94	70.0	70.0	-0.1	207.3	121.5	1.1	0.0	1.17	0.0	0.0	1.8	2.8	2.2	1.5
10	1x11	7.66	69.0	70.1	1.1	218.7	120.4	12.3	3.0	1.03	2.5	3.2	1.5	3.3	2.5	1.5
11	1x12	9.17	70.5	70.6	-0.3	225.0	128.2	9.0	11.2	1.55	0.0	0.0	1.5	2.4	2.0	1.5
12	1x13	10.51	74.0	73.8	0.0	241.6	138.7	10.3	0.0	1.13	0.0	0.5	1.5	2.5	1.8	1.5
13	2x3	10.37	70.0	69.8	0.0	222.5	122.1	5.2	0.0	1.03	17.7	0.2	1.5	2.0	2.0	1.3
14	2x4	7.25	71.5	71.5	0.0	251.8	122.6	22.8	0.0	1.08	7.5	0.0	1.5	2.0	2.5	1.8
15	2x5	11.66	69.0	66.0	-3.0	209.1	108.9	49.6	0.0	1.33	8.2	0.0	1.7	1.9	2.0	1.5
16	2x6	7.17	68.0	66.7	-1.7	208.7	100.1	18.9	0.0	1.03	25.7	0.5	1.5	1.5	1.8	1.0
17	2x7	11.25	70.0	69.0	-1.2	240.0	129.7	40.1	0.0	1.03	10.6	2.3	1.5	2.5	2.3	1.8
18	2x8	10.19	73.0	72.8	-0.1	233.9	124.9	18.5	0.0	1.08	27.5	0.0	1.7	1.8	2.4	1.3
19	2x9	8.08	69.0	67.1	-2.0	216.3	93.9	2.1	0.0	1.13	6.0	0.0	1.5	2.0	2.4	1.0
20	2x10	10.66	70.0	69.8	0.1	230.0	119.5	0.7	0.0	1.06	2.7	0.0	1.5	2.5	1.5	1.5
21	2x11	13.39	70.0	69.9	0.0	237.7	117.7	7.3	0.0	1.00	5.2	2.7	1.5	2.3	1.5	1.3
22	2x12	9.50	70.0	70.0	0.3	233.7	134.1	8.3	15.4	1.03	41.3	3.1	1.5	2.0	2.0	1.5
23	2x13	7.51	75.0	73.7	-0.9	211.2	120.2	46.7	0.0	1.09	0.0	0.0	1.4	2.0	1.9	1.8
24	3x4	8.33	65.0	65.7	0.6	220.3	115.3	54.6	0.0	1.03	44.8	2.8	1.5	2.5	3.2	1.8
25	3x5	8.00	69.0	67.6	-1.8	228.8	121.2	38.1	0.0	1.13	3.2	2.5	1.5	2.3	2.7	1.5
26	3x6	8.69	66.5	66.5	0.1	192.0	99.5	4.7	0.0	1.03	4.8	4.6	1.5	2.0	2.2	3.3
27	3x7	5.22	69.0	68.0	-0.8	235.0	114.0	0.6	0.0	0.99	21.7	3.8	1.5	3.2	2.8	1.3
28	3x8	5.85	68.5	69.0	0.5	238.9	108.2	2.9	0.0	1.06	14.3	11.0	1.5	2.7	3.5	1.8
29	3x9	5.78	68.5	65.7	-3.0	211.7	99.8	25.8	0.0	1.06	2.8	3.0	1.5	3.0	2.7	1.3
30	3x10	8.40	66.5	66.0	-0.8	226.9	129.2	1.8	0.0	1.08	30.9	2.4	1.5	2.7	2.6	1.5
31	3x11	6.95	69.0	66.3	-2.3	211.7	104.7	-1.2	2.5	1.08	9.7	4.8	1.7	3.4	2.5	1.3
32	3x12	6.89	69.0	69.3	0.3	220.9	117.0	2.7	2.7	1.03	57.9	5.2	1.5	2.5	2.8	2.0
33	3x13	9.01	70.0	69.8	-0.2	240.2	131.1	15.9	0.0	1.11	44.0	3.1	1.7	2.3	2.5	2.5
34	4x5	7.19	66.0	65.6	-0.7	233.2	142.6	66.5	7.5	1.10	16.9	2.2	1.5	3.0	2.5	2.8
35	4x6	8.93	65.0	64.8	-0.1	197.8	96.4	48.7	0.0	1.24	32.5	0.0	1.5	2.0	2.7	1.3
36	4x7	7.78	68.0	67.9	-0.1	233.2	120.9	73.2	2.8	1.06	2.8	0.2	1.5	2.2	2.5	2.5
37	4x8	7.72	71.5	71.3	-0.1	238.4	133.0	6.8	0.0	1.06	0.0	5.1	1.5	2.5	2.5	1.3
38	4x9	7.92	67.5	66.3	-1.3	207.1	94.5	8.3	3.6	1.29	17.5	0.0	1.5	2.5	2.7	1.8
39	4x10	6.00	65.1	65.4	-0.1	216.7	115.8	47.9	3.2	1.10	11.8	0.0	1.5	2.5	2.7	1.5
40	4x11	9.57	67.5	67.4	-0.3	237.5	116.8	38.2	0.0	0.98	17.8	0.3	1.5	3.0	2.5	1.5
41	4x12	6.21	67.0	66.1	-1.0	241.9	136.2	22.1	0.0	1.12	40.4	3.8	1.7	2.5	2.7	2.3

Appendix 1 (continued): Mean grain yield and agronomic traits for diallel hybrids at Kakamega under well-watered environment continued.

CROSS	GY†	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	GLS	ET	EA	PA
4x13	11.06	69.0	68.9	-0.1	242.5	145.2	38.9	0.0	1.14	35.1	0.0	1.5	2.5	2.0	2.5
5x6	9.96	65.0	65.0	0.3	226.5	121.6	42.1	0.0	1.54	0.0	0.1	1.5	1.5	2.0	1.5
5x7	7.86	70.0	66.6	-3.5	195.1	114.9	85.4	0.0	1.17	2.8	2.3	1.5	2.5	2.7	2.0
5x8	6.58	70.5	67.8	-2.5	232.0	126.8	31.6	6.7	1.16	6.7	0.0	1.5	2.0	2.8	1.5
5x9	9.60	67.5	67.6	0.3	207.8	118.7	22.5	2.7	1.22	5.6	6.7	1.5	1.8	2.5	1.3
5x10	7.95	70.0	68.5	-1.2	212.2	127.7	8.9	0.0	1.18	0.0	0.0	1.5	2.0	2.5	1.3
5x11	8.66	67.1	65.0	-2.5	223.5	127.0	27.1	0.0	1.30	0.0	2.1	1.5	2.7	2.3	1.5
5x12	8.68	67.5	65.5	-1.9	223.0	144.2	17.8	0.0	1.33	0.0	2.4	1.4	2.1	2.7	1.8
5x13	8.73	71.5	70.0	-1.2	243.9	154.4	25.9	2.7	1.26	0.0	0.3	1.5	2.0	2.1	1.8
6x7	10.66	65.0	65.1	-0.1	198.2	105.9	19.1	0.0	1.09	9.5	2.2	1.5	2.0	2.7	1.0
6x8	8.05	67.5	67.4	0.0	209.0	107.8	8.0	0.0	1.27	13.9	0.1	1.5	1.8	2.2	1.3
6x9	8.93	65.0	65.6	0.5	201.3	87.1	3.6	0.0	1.11	10.6	1.9	1.5	1.7	2.2	3.5
6x10	8.59	65.0	65.3	0.0	201.6	109.1	5.0	0.0	1.05	0.0	0.1	1.5	2.5	2.6	1.8
6x11	9.48	65.0	65.4	0.6	205.4	122.0	12.0	0.0	1.08	36.5	0.0	1.5	2.5	1.8	1.0
6x12	8.73	68.5	66.4	-2.1	205.9	113.9	2.2	0.0	1.17	11.8	0.1	1.5	2.0	2.5	1.5
6x13	8.52	70.0	68.3	-1.9	217.4	123.2	21.6	0.0	1.03	0.0	0.0	1.5	2.0	2.3	1.5
7x8	10.22	70.5	70.6	0.1	219.3	109.0	42.2	2.8	1.11	16.0	5.2	1.5	2.2	3.0	2.0
7x9	6.05	69.0	66.6	-2.6	211.8	113.6	7.7	2.7	0.97	0.0	0.0	1.5	2.7	2.7	2.5
7x10	7.48	70.0	70.1	0.2	203.2	124.6	3.6	3.4	1.00	0.0	0.0	1.5	3.5	2.8	1.5
7x11	6.90	70.0	66.3	-3.5	214.5	119.0	30.9	0.0	1.06	0.0	2.8	1.5	3.1	2.5	1.8
7x12	6.08	67.5	69.4	1.9	231.3	119.4	21.4	0.0	1.00	16.7	2.7	1.5	2.7	3.0	1.8
7x13	10.12	71.5	67.6	-4.1	215.9	124.5	-1.2	2.7	1.14	2.8	0.0	1.5	2.5	2.1	1.3
8x9	8.10	68.5	66.9	-1.8	215.4	83.3	1.5	0.0	1.03	31.9	5.6	1.5	2.0	3.0	2.3
8x10	7.88	70.0	70.0	0.0	219.9	130.1	2.5	0.0	1.22	7.2	0.3	1.4	2.3	2.4	1.5
8x11	9.09	70.0	68.8	-1.3	247.3	131.0	15.0	0.0	1.11	3.6	3.1	1.5	3.0	2.5	1.3
8x12	7.76	67.5	67.8	0.4	224.9	120.0	3.3	0.0	1.13	17.8	0.5	1.7	2.8	2.7	1.5
8x13	8.80	71.5	71.4	-0.1	231.6	139.2	10.2	0.0	1.13	7.5	0.0	1.5	2.5	2.2	1.3
9x10	8.37	70.0	67.7	-2.2	210.7	111.3	2.9	0.0	1.18	3.2	0.2	1.5	2.5	2.3	1.3
9x11	7.50	70.0	66.2	-3.6	218.2	117.3	1.0	5.3	1.08	0.0	6.9	1.5	3.0	3.0	1.3
9x12	7.00	67.5	66.5	-1.1	219.1	107.9	0.8	0.0	1.10	4.8	7.5	1.5	2.7	3.0	1.8
9x13	7.34	70.0	67.3	-3.0	220.3	121.3	8.6	0.0	1.19	14.4	0.3	1.5	2.5	2.0	1.3
10x11	7.32	69.0	66.5	-2.5	219.0	104.1	1.6	0.0	1.00	0.0	0.0	1.5	3.5	2.6	1.5
10x12	7.52	69.0	69.7	0.6	210.8	111.7	0.9	7.2	1.12	0.0	1.9	1.5	2.7	2.8	1.5
10x13	8.75	70.5	70.6	0.0	232.2	149.9	15.9	0.0	1.29	3.0	0.0	1.5	3.2	2.3	2.0
11x12	6.42	69.0	68.2	-0.7	233.4	121.0	3.9	0.0	1.00	3.0	0.0	1.5	3.8	2.9	1.5
11x13	9.99	71.5	70.4	-0.9	239.1	140.5	38.5	0.0	1.06	2.7	0.0	1.5	2.5	1.4	2.0
12x13	10.11	70.0	69.9	0.0	239.1	137.0	5.9	0.0	1.00	7.5	0.0	1.5	2.3	1.7	2.0
Check 1	10.69	78.0	76.4	-1.5	261.8	134.3	26.4	0.0	1.11	0.0	3.1	1.8	1.7	1.5	1.8
Check 2	12.85	73.0	72.5	-0.3	210.1	133.6	9.8	0.0	1.17	7.5	1.9	1.5	1.8	1.8	2.3
	8.63	69.2	68.5	-0.7	222.6	121.0	19.0	1.4	1.12	11.8	1.8	1.5	2.4	2.4	1.7
	3.06	3.2	2.8	2.6	29.0	22.4	24.6	5.7	0.20	19.4	5.9	0.2	0.5	0.6	0.9
	17.76	2.3	2.0	-182.8	6.5	9.3	64.9	203.0	8.72	82.1	164.9	7.7	9.3	12.9	28.1
	5.22	65.0	64.8	-4.1	192.0	83.3	-1.2	0.0	0.97	0.0	0.0	1.4	1.5	1.4	1.0
	13.39	78.0	76.4	5.1	261.8	154.4	85.4	15.4	1.55	57.9	11.0	1.8	3.8	3.5	3.5

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Stem lodging; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; ET: *Exohilium turcicum*; EA: Ear aspect; PA: Plant aspect.

Check 1: CML144/CML159; Check 2: H513.

Appendix 2: Mean grain yield and agronomic traits for diallel hybrids at Embu under well-watered environment

ENTRY	CROSS	GY [†]	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	ET	EA	PA
1	1x2	7.90	69.0	70.0	1.0	240.4	121.9	0.0	0.0	0.95	16.7	0.2	1.4	2.5	2.5
2	1x3	5.55	67.5	69.3	1.9	231.0	119.4	0.0	15.6	0.85	8.3	2.3	1.5	2.7	2.7
3	1x3	6.23	66.0	68.1	1.9	246.5	120.7	0.0	1.8	1.12	23.6	0.2	1.6	3.0	2.7
4	1x5	5.89	66.5	66.4	0.0	213.9	116.0	3.5	0.7	0.88	3.0	0.1	1.5	2.5	2.6
5	1x6	5.05	64.0	64.6	0.5	207.8	106.8	4.1	0.0	0.94	0.4	0.0	1.7	3.1	1.7
6	1x7	5.28	66.5	67.5	1.0	217.9	109.1	2.7	5.5	0.91	0.2	0.1	1.5	2.7	1.7
7	1x8	6.64	66.0	67.1	1.1	246.6	121.8	15.4	3.3	0.91	0.1	2.5	1.7	2.8	2.8
8	1x9	5.62	68.0	68.2	0.1	219.7	109.9	19.4	0.0	1.02	0.5	5.0	1.7	2.8	2.2
9	1x10	6.04	67.5	68.0	0.2	216.2	119.0	7.1	5.4	0.92	11.4	0.0	1.4	2.0	2.5
10	1x11	4.58	66.5	66.1	-0.1	224.2	109.9	3.2	3.4	0.73	1.1	4.7	1.5	3.9	2.2
11	1x12	6.14	67.0	68.4	1.5	233.9	112.8	8.2	3.1	0.98	5.1	2.7	1.5	2.4	2.6
12	1x13	6.56	69.5	70.4	1.0	235.0	129.7	12.2	8.2	1.00	0.0	0.4	1.8	2.2	3.2
13	2x3	5.92	69.5	70.3	1.0	240.1	112.5	3.5	1.0	0.98	17.5	0.2	1.5	2.9	2.4
14	2x4	8.03	67.0	67.5	0.3	239.7	109.7	0.0	0.0	1.18	9.8	0.4	1.5	2.5	2.5
15	2x5	4.44	68.0	67.0	-1.0	248.3	128.4	2.5	0.0	0.78	0.6	0.0	1.5	2.9	2.5
16	2x6	6.40	63.5	64.1	0.5	239.7	102.0	3.5	1.6	1.09	15.4	0.0	1.5	2.8	1.9
17	2x7	5.66	67.5	68.0	0.5	240.9	109.6	4.8	0.0	0.92	1.9	0.2	1.5	2.8	2.0
18	2x8	7.04	66.5	68.9	2.5	258.9	107.3	6.7	1.8	0.93	30.3	7.7	1.5	3.2	2.1
19	2x9	5.29	67.0	66.6	-0.4	252.9	99.6	0.2	0.3	0.93	1.9	5.6	1.7	3.0	1.7
20	2x10	5.90	67.5	66.8	-0.5	244.7	104.8	0.0	0.0	0.81	4.0	3.7	1.5	2.6	2.5
21	2x11	6.44	68.0	68.6	0.5	241.5	113.6	1.7	0.2	0.89	1.7	2.6	1.5	2.9	2.2
22	2x12	5.89	67.5	66.7	-0.6	242.0	103.6	0.0	2.9	0.84	20.2	0.5	1.5	3.4	2.4
23	2x13	8.20	71.0	70.3	-0.5	258.8	135.6	0.4	0.4	1.03	8.0	2.8	1.5	2.0	3.2
24	3x4	4.73	62.5	64.4	2.0	232.9	110.0	24.2	2.7	0.88	18.8	0.1	1.5	3.3	2.5
25	3x5	5.24	66.5	65.4	-1.0	231.8	131.8	30.0	1.9	1.05	1.3	0.2	1.5	2.6	2.8
26	3x6	4.41	63.0	63.0	0.0	229.2	106.7	36.0	3.8	0.95	3.4	2.7	1.5	3.2	2.0
27	3x7	5.72	66.5	67.7	0.9	235.9	110.4	36.9	2.5	1.06	2.4	2.5	1.5	2.8	2.0
28	3x8	5.60	67.0	65.9	-1.5	264.0	111.5	0.0	0.8	0.92	0.4	5.6	1.5	2.8	1.9
29	3x9	6.06	65.0	65.5	0.5	236.3	103.4	41.9	12.2	1.11	0.3	2.0	1.5	2.5	2.1
30	3x10	4.57	63.5	65.1	1.6	264.6	113.9	6.8	0.8	0.99	9.9	0.0	1.6	3.3	2.5
31	3x11	4.34	65.5	65.2	-0.4	230.6	112.6	11.3	2.3	0.93	5.8	2.3	1.8	2.7	2.2
32	3x12	5.31	66.5	69.0	2.5	248.4	116.8	0.0	0.0	0.95	11.9	0.2	1.5	2.8	2.7
33	3x13	7.55	67.0	67.9	1.0	252.2	142.2	0.0	0.0	1.05	12.3	0.1	1.5	2.1	3.3
34	4x5	5.09	64.0	64.1	0.0	255.9	121.8	5.7	12.9	0.92	0.7	0.0	1.5	2.7	2.8
35	4x6	5.10	61.0	63.0	2.0	229.9	102.6	1.7	0.8	0.98	4.9	0.3	1.5	3.4	2.0
36	4x7	5.58	65.0	66.5	1.5	238.4	121.9	4.3	1.6	0.97	0.5	0.0	1.4	3.0	2.5
37	4x8	6.49	66.5	67.4	1.0	256.6	115.7	5.3	0.1	0.99	0.9	0.0	1.7	3.0	2.6
38	4x9	5.48	62.5	64.0	1.6	239.7	102.9	0.0	0.0	0.99	2.5	2.7	1.8	3.0	2.0
39	4x10	6.33	61.0	62.4	1.5	228.9	125.4	5.0	0.9	1.01	6.5	0.0	1.5	2.6	2.1
40	4x11	5.26	63.0	64.5	1.5	252.8	118.4	0.0	0.0	0.95	3.8	2.7	1.8	2.8	2.5
41	4x12	5.60	65.0	65.9	1.0	245.6	115.2	0.0	2.0	0.88	4.5	0.1	1.5	2.7	2.7
42	4x13	7.44	65.5	66.0	0.5	260.7	127.4	2.5	8.3	0.97	22.5	0.0	1.5	2.7	2.9
43	5x6	5.37	62.5	60.5	-2.0	230.9	115.0	28.7	3.8	1.04	0.4	2.0	1.5	2.8	2.3

Appendix 2 (continued): Mean grain yield and agronomic traits for diallel hybrids at Embu under well-watered environment continued

ENTRY	CROSS	GY [†]	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	ET	EA	PA
44	5x7	5.20	66.0	65.4	-0.5	221.8	125.7	8.0	3.3	0.87	1.0	0.0	1.5	2.8	2.7
45	5x8	6.10	65.5	65.6	-0.1	252.6	121.8	2.7	0.9	1.01	2.6	4.5	1.8	2.8	2.7
46	5x9	3.55	65.5	63.2	-2.4	223.1	115.7	8.0	1.4	0.80	0.0	0.2	1.8	3.2	2.6
47	5x10	4.85	64.5	63.9	-0.5	230.3	113.3	0.0	0.0	0.98	0.4	0.5	1.5	2.9	2.0
48	5x11	5.98	66.0	64.8	-1.1	236.7	119.9	5.4	5.4	1.05	0.4	4.1	1.5	2.8	2.6
49	5x12	5.47	64.0	63.5	-0.9	245.6	128.9	21.3	6.0	1.02	3.4	0.0	1.5	2.2	2.9
50	5x13	6.49	64.0	67.6	3.4	251.2	140.0	10.8	2.6	1.00	0.0	2.4	1.6	2.1	3.4
51	6x7	5.52	62.0	63.0	1.0	218.9	103.6	0.0	0.0	0.97	0.0	0.3	1.5	2.7	2.0
52	6x8	5.42	64.0	63.7	-0.4	213.1	107.2	3.7	1.6	1.11	0.0	0.3	1.5	2.9	2.2
53	6x9	4.20	62.5	62.4	0.0	230.5	107.1	6.6	0.1	0.91	0.0	0.5	1.5	3.2	1.5
54	6x10	4.22	60.5	61.4	0.8	202.4	95.2	26.4	0.2	0.83	4.0	6.1	1.5	3.3	1.8
55	6x11	4.92	61.5	61.0	-0.5	218.8	98.4	0.0	0.4	0.98	2.6	2.6	1.5	3.0	1.6
56	6x12	5.50	63.5	63.1	-0.5	234.5	105.0	1.0	0.3	1.05	4.9	0.1	1.5	2.4	2.1
57	6x13	6.17	64.0	64.3	0.5	235.8	122.8	0.1	4.7	1.00	0.5	0.1	1.5	2.0	2.5
58	7x8	7.04	65.5	68.2	2.6	244.5	114.3	8.7	0.6	1.00	2.3	0.0	1.5	2.8	2.1
59	7x9	4.24	64.5	63.7	-0.9	213.4	99.4	18.0	6.0	0.90	0.0	3.0	2.0	2.9	2.0
60	7x10	6.14	65.0	66.3	1.1	212.2	104.5	2.8	0.0	0.93	3.9	0.0	2.0	2.3	2.0
61	7x11	5.11	66.5	65.3	-1.0	225.9	111.3	2.1	0.2	0.82	0.6	3.1	1.6	3.0	2.6
62	7x12	6.59	65.5	67.9	2.5	233.6	111.1	4.3	1.2	0.98	5.9	0.3	1.5	2.1	2.3
63	7x13	6.46	68.5	67.6	-1.0	240.2	127.6	2.0	2.7	0.88	0.5	0.0	1.5	2.6	2.5
64	8x9	4.63	64.5	64.3	-0.4	221.9	91.9	13.5	1.1	0.97	2.0	2.6	2.0	3.1	1.8
65	8x10	4.92	66.0	67.4	1.5	228.0	114.4	6.9	2.2	0.90	14.8	2.6	1.5	3.2	2.4
66	8x11	5.18	65.0	66.0	1.0	250.4	116.0	24.5	5.1	1.03	0.0	9.6	1.5	3.1	2.3
67	8x12	5.44	65.5	66.9	1.5	238.3	109.6	0.1	0.1	0.93	9.7	3.0	1.6	2.9	2.4
68	8x13	6.77	68.5	68.8	0.5	246.8	124.7	6.7	0.9	0.96	16.7	0.3	1.6	2.7	3.3
69	9x10	4.80	65.0	64.7	-0.4	217.4	97.9	6.0	12.6	0.97	0.0	0.0	1.5	2.5	1.9
70	9x11	3.68	65.5	65.7	0.4	226.7	102.4	4.0	1.1	0.74	1.1	6.9	1.5	3.7	1.9
71	9x12	6.08	64.5	64.5	0.0	245.2	99.9	8.1	1.3	1.03	0.1	2.0	1.5	2.1	2.1
72	9x13	5.93	67.0	65.8	-1.4	235.9	122.1	0.0	0.0	0.90	30.7	2.6	1.5	3.0	2.7
73	10x11	5.96	64.5	64.2	-0.1	220.2	111.1	0.9	2.7	1.00	8.2	0.3	1.5	2.3	2.0
74	10x12	5.75	65.5	66.0	0.6	231.6	118.9	0.0	3.0	0.97	46.1	0.2	1.8	2.8	2.7
75	10x13	6.42	67.0	68.5	1.4	249.3	131.4	0.4	12.2	0.93	3.2	0.0	1.5	2.3	3.5
76	11x12	6.82	64.5	65.2	0.5	244.9	105.7	0.0	0.0	1.00	0.0	0.0	1.7	2.5	2.4
77	11x13	6.94	68.0	66.7	-1.1	243.5	122.0	0.0	0.0	1.00	0.0	0.0	1.5	2.8	3.2
78	12x13	7.33	67.0	67.3	0.5	259.1	129.3	4.1	12.3	0.97	7.9	0.2	1.5	2.1	3.0
79	Check 1	3.92	68.0	67.0	-1.0	234.1	121.3	0.0	0.0	0.69	0.0	0.0	1.5	3.1	2.9
80	Check 2	7.31	69.5	71.1	1.6	265.7	143.0	0.0	0.1	1.09	2.3	0.0	1.5	1.8	3.7
Mean		5.74	65.6	66.1	0.4	236.9	114.8	6.7	2.4	0.95	5.7	1.5	1.6	2.8	2.4
LSD (0.05)		1.56	2.3	2.0	2.3	21.5	14.3	23.7	8.7	0.21	14.1	6.0	0.2	0.7	0.5
CV		13.55	1.7	1.5	277.6	4.5	6.2	178.0	182.8	11.02	122.5	203.2	7.8	13.6	11.3
Min		3.55	60.5	60.5	-2.4	202.4	91.9	0.0	0.0	0.69	0.0	0.0	1.4	1.8	1.5
Max		8.20	71.0	71.1	3.4	265.7	143.0	41.9	15.6	1.18	46.1	9.6	2.0	3.9	3.7

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Stem lodging; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; EA: Ear aspect; PA: Plant aspect.
Check 1: CML144/CML159; Check 2: H513.

Appendix 3: Mean grain yield and agronomic traits for diallel hybrids at Namulonge under random drought

ENTRY	CROSS	GY [†]	AD	ASI	PH	EH	EPP	HC	ER	GLS	ET	EA	PA	SD
1	1x2	1.82	64.6	3.4	88.4	49.5	1.33	30.9	30.9	1.0	1.7	4.1	3.6	69.1
2	1x3	1.23	64.8	5.2	91.7	53.0	1.00	24.1	24.8	1.0	2.2	3.7	4.0	70.7
3	1x3	2.85	62.0	3.7	102.4	57.4	1.00	2.6	0.0	1.0	1.8	3.1	3.4	66.3
4	1x5	1.02	65.4	5.0	82.7	44.2	0.88	0.0	0.0	1.0	1.6	3.7	4.0	70.5
5	1x6	2.05	61.7	3.1	80.1	40.7	1.06	0.0	0.0	1.0	1.6	3.0	3.6	65.2
6	1x7	0.75	66.7	7.7	65.5	31.3	1.23	12.6	0.2	1.0	2.0	4.4	4.3	73.6
7	1x8	1.36	65.3	2.3	84.7	39.7	1.02	0.8	0.2	1.0	1.8	2.8	3.2	67.2
8	1x9	2.63	65.0	-0.1	119.4	56.7	1.55	0.3	0.0	1.0	1.7	2.5	3.3	64.9
9	1x10	1.33	65.8	8.9	94.3	50.3	0.88	0.0	0.0	1.0	1.6	2.5	3.7	74.5
10	1x11	2.46	64.1	1.8	79.8	47.4	1.28	0.0	4.2	1.0	1.9	3.1	3.5	65.2
11	1x12	1.68	62.6	4.7	112.2	65.2	0.87	0.6	0.1	1.0	1.9	2.6	3.2	66.3
12	1x13	1.60	66.3	2.9	125.6	63.8	0.88	0.0	0.0	1.0	2.0	3.1	3.2	68.9
13	2x3	0.48	70.1	9.0	68.9	32.5	1.00	0.6	0.2	1.0	1.9	4.4	4.1	78.0
14	2x4	2.28	62.0	5.1	130.7	73.9	1.07	0.5	3.3	1.0	1.6	2.8	3.1	67.5
15	2x5	1.52	64.2	-0.2	112.8	63.2	1.21	12.6	4.2	1.0	1.6	3.4	3.7	64.9
16	2x6	1.05	62.7	5.6	92.1	43.2	0.96	9.0	8.4	1.0	1.4	4.1	3.7	67.5
17	2x7	1.57	65.1	0.1	93.2	48.1	0.89	17.6	0.1	1.0	2.0	3.3	3.4	65.6
18	2x8	1.62	64.9	1.7	135.2	61.3	1.17	45.0	18.9	1.0	1.6	3.7	3.5	67.2
19	2x9	2.50	60.5	1.0	128.7	65.9	1.03	25.3	23.8	1.0	2.1	2.5	2.9	61.6
20	2x10	1.63	63.3	4.1	125.8	58.7	1.10	0.9	5.6	1.0	1.6	3.2	3.4	67.6
21	2x11	1.16	63.6	3.4	105.2	53.9	0.79	4.7	9.6	1.0	2.1	3.4	3.6	66.6
22	2x12	1.16	65.0	2.8	141.4	66.0	1.28	0.0	0.3	1.0	1.8	2.8	3.5	68.5
23	2x13	2.01	66.0	0.5	131.2	68.3	0.84	1.0	0.4	1.0	1.8	2.3	3.1	66.5
24	3x4	1.45	58.0	3.4	110.4	65.0	1.16	53.8	11.4	1.0	1.7	3.1	3.3	61.5
25	3x5	1.92	60.4	1.8	128.0	73.2	0.91	11.2	3.6	1.0	1.9	2.3	3.0	61.7
26	3x6	0.87	62.6	6.6	102.4	48.7	1.00	7.1	14.4	1.0	1.9	3.8	4.0	69.3
27	3x7	0.91	63.0	4.3	93.9	47.1	0.80	19.2	9.9	1.0	2.0	4.0	3.9	66.7
28	3x8	1.17	63.8	4.1	99.1	44.0	1.21	21.9	12.3	1.0	1.9	3.7	3.6	68.2
29	3x9	1.45	61.1	1.9	115.2	53.9	0.89	24.7	3.1	1.0	1.9	2.9	3.4	62.7
30	3x10	1.59	62.0	3.0	111.0	55.7	0.89	0.0	0.3	1.0	1.7	3.5	3.8	65.0
31	3x11	1.34	61.7	2.9	100.6	54.2	1.02	29.8	25.5	1.0	2.3	3.5	3.7	64.2
32	3x12	1.32	63.3	8.3	116.4	52.0	1.05	0.7	4.7	1.0	2.1	3.8	3.6	70.5
33	3x13	0.99	65.4	2.8	126.2	63.9	1.00	23.5	0.0	1.0	1.7	2.4	3.5	68.5
34	4x5	1.46	59.7	0.7	144.4	83.2	0.89	0.0	0.0	1.0	1.5	3.1	3.5	60.1
35	4x6	1.97	55.4	3.6	120.0	55.7	1.04	0.5	8.0	1.0	1.8	3.2	3.3	59.1
36	4x7	0.92	61.6	6.2	86.5	44.9	1.00	18.4	32.2	1.0	2.1	3.7	3.7	68.1
37	4x8	1.18	67.6	6.5	121.1	55.2	0.94	1.4	0.3	1.0	1.7	3.7	3.8	73.1
38	4x9	0.81	67.3	0.6	83.5	39.0	0.99	0.2	0.9	1.0	2.0	3.5	3.7	68.1
39	4x10	0.70	63.4	5.3	91.4	42.5	0.63	0.3	0.4	1.0	1.5	4.4	4.2	68.1
40	4x11	1.13	61.1	3.3	113.4	56.8	1.10	0.0	0.0	1.0	1.7	3.2	3.4	65.1
41	4x12	2.15	63.6	2.6	124.9	58.5	0.95	3.7	0.0	1.0	1.8	3.5	3.6	66.1
42	4x13	1.82	63.2	6.8	153.0	83.0	0.93	0.0	0.0	1.0	1.7	2.9	3.2	69.1
43	5x6	1.45	58.8	1.3	96.9	44.8	1.00	0.3	21.1	1.0	1.8	3.1	3.3	59.1

Appendix 3 (continued): Mean grain yield and agronomic traits for diallel hybrids at Namulonge under random drought continued

ENTRY	CROSS	GY†	AD	ASI	PH	EH	EPP	HC	ER	GLS	ET	EA	PA	SD
44	5x7	1.90	63.6	-0.3	98.1	46.1	0.98	0.0	0.0	1.0	2.3	2.3	3.6	63.8
45	5x8	2.08	62.2	0.2	137.4	67.8	0.97	1.2	0.3	1.0	1.5	2.8	3.1	62.8
46	5x9	2.65	60.4	-2.1	138.7	71.7	1.09	0.3	6.5	1.0	1.4	2.1	2.9	57.9
47	5x10	1.58	62.8	2.5	104.0	50.4	0.94	11.7	5.3	1.0	1.5	3.5	3.5	65.3
48	5x11	1.66	62.1	-0.6	120.7	63.2	1.06	4.1	5.9	1.0	2.0	3.0	3.3	62.6
49	5x12	1.33	63.2	-0.3	124.9	61.4	1.09	0.0	5.2	1.0	1.6	3.0	3.5	63.4
50	5x13	1.27	68.5	2.4	122.5	68.7	1.00	12.3	12.4	1.0	1.6	3.4	3.6	71.8
51	6x7	1.34	60.0	0.8	103.0	44.2	1.14	0.2	14.8	1.0	2.2	3.1	3.7	61.3
52	6x8	1.49	64.3	3.9	106.9	54.4	1.01	4.1	0.6	1.0	1.5	3.2	3.6	67.8
53	6x9	1.26	59.3	0.4	117.4	49.2	1.17	0.0	12.1	1.0	1.7	3.7	3.6	60.7
54	6x10	1.11	64.3	0.5	67.0	32.4	0.61	0.7	0.1	1.0	1.7	3.9	4.1	64.4
55	6x11	0.46	62.8	2.9	92.2	41.1	0.91	0.6	0.4	1.0	1.8	4.3	4.0	65.3
56	6x12	1.20	65.7	2.5	92.0	53.5	1.05	1.0	0.4	1.0	1.5	3.6	3.2	67.0
57	6x13	1.59	60.7	1.1	126.8	61.7	0.82	0.1	11.2	1.0	1.7	3.2	3.2	62.1
58	7x8	2.11	62.8	2.7	125.0	70.5	0.88	0.0	5.3	1.0	1.7	2.7	3.0	64.5
59	7x9	1.48	61.3	0.7	115.3	53.2	1.07	0.6	0.7	1.0	2.0	2.1	2.9	62.1
60	7x10	0.99	62.4	3.8	111.0	50.2	1.00	0.3	0.0	1.0	2.2	2.6	3.7	66.9
61	7x11	1.48	63.0	1.0	97.1	54.0	1.14	13.4	5.9	1.0	2.1	3.5	3.6	63.7
62	7x12	2.38	61.6	3.0	114.0	52.5	1.01	4.3	-0.1	1.5	2.4	2.5	3.2	64.9
63	7x13	0.77	67.0	6.7	96.9	56.4	0.86	7.7	0.4	1.0	1.8	4.0	3.7	72.7
64	8x9	1.51	61.1	0.8	92.2	39.1	1.09	20.5	6.5	2.0	2.5	3.3	3.4	62.8
65	8x10	1.69	63.4	5.9	114.1	61.3	1.07	8.2	0.7	1.0	1.8	3.2	3.2	70.0
66	8x11	2.39	63.2	2.7	156.5	69.3	1.00	0.0	-0.2	1.0	2.2	3.3	3.5	66.7
67	8x12	1.81	61.4	4.2	108.3	47.0	1.32	4.9	-0.4	1.0	2.0	3.1	3.1	66.2
68	8x13	0.96	68.8	8.4	118.9	57.9	0.84	11.6	13.8	1.0	1.7	3.6	3.8	77.1
69	9x10	1.39	66.6	0.0	109.3	44.5	1.00	1.0	0.5	1.0	1.9	3.3	3.4	66.4
70	9x11	0.90	62.4	1.3	127.8	58.2	0.89	13.7	0.4	1.0	2.0	3.7	3.0	63.1
71	9x12	1.99	60.7	-0.7	130.0	23.6	1.05	6.5	-0.1	1.0	1.5	2.5	3.2	60.7
72	9x13	1.78	64.8	-1.4	127.2	64.0	1.29	37.4	10.4	1.0	2.1	2.9	3.2	63.6
73	10x11	1.64	65.5	5.4	99.5	53.5	0.83	0.5	0.8	1.0	2.0	3.5	4.1	70.5
74	10x12	1.49	63.5	2.8	118.5	65.0	0.93	0.8	0.6	1.0	2.0	3.1	3.4	65.5
75	10x13	1.14	64.0	3.4	116.0	64.0	0.74	7.1	0.1	1.0	2.0	3.4	3.1	65.5
76	11x12	1.72	59.1	2.1	121.3	62.5	0.87	0.0	17.5	1.0	2.1	3.3	3.0	60.5
77	11x13	1.01	67.2	4.5	95.0	46.7	0.94	4.3	6.1	1.0	2.1	3.6	3.9	71.5
78	12x13	2.09	65.1	2.6	126.9	71.7	0.85	0.0	-0.2	1.0	2.3	2.2	3.0	67.5
79	Check 1	0.77	74.6	10.0	117.6	74.5	0.99	0.0	0.0	1.0	1.8	4.2	3.6	84.5
80	Check 2	0.56	69.7	4.7	85.8	56.2	1.71	16.7	6.3	1.0	1.7	4.3	3.9	73.5
Mean		1.49	63.6	3.1	110.1	55.2	1.01	7.4	5.4	1.0	1.9	3.3	3.5	66.0
LSD (0.05)		1.33	5.5	5.5	34.9	22.8	0.50	21.8	17.6	0.4	0.5	1.5	0.6	7.0
CV		44.48	4.3	88.7	15.9	20.6	24.89	147.6	163.0	17.3	13.3	22.6	8.7	5.0
Min		0.46	55.4	-2.1	65.5	23.6	0.61	0.0	-0.8	1.0	1.4	2.1	2.9	5.0
Max		2.85	74.6	10.0	156.5	83.2	1.71	53.8	32.2	2.0	2.5	4.4	4.3	84.5

† GY: Grain yield; AD: Anthesis date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; ET: *Exohilium turcicum*; EA: Ear aspect; PA: Plant aspect; SD: Silking date.
 Check 1: CML144/CML159; Check 2: H513.

Appendix 4: Mean grain yield and agronomic traits for diallel hybrids at Kiboko under managed drought

ENTRY	CROSS	GY [†]	AD	ASI	PH	EH	RL	SL	EPP	HC	SEN	EA	SD
1	1x2	3.78	64.7	1.0	229.1	119.0	0.0	41.7	0.89	0.4	0.8	2.6	65.5
2	1x3	2.37	64.5	3.5	199.7	113.3	0.1	29.6	0.82	4.4	0.8	3.4	68.0
3	1x3	2.43	64.0	2.0	217.6	126.3	0.0	35.7	0.73	4.3	0.7	3.0	66.0
4	1x5	2.98	65.7	1.0	221.9	129.3	0.0	43.0	1.10	0.8	0.8	2.1	66.5
5	1x6	2.77	62.5	2.5	201.2	104.9	5.5	17.9	0.77	0.1	0.8	2.9	65.0
6	1x7	2.25	64.6	4.0	212.2	112.8	0.2	31.9	0.85	-0.8	0.7	2.5	68.5
7	1x8	3.30	63.7	2.0	243.8	127.2	0.0	30.0	0.85	3.5	0.9	3.2	65.5
8	1x9	2.67	65.9	1.5	232.9	111.4	0.0	50.5	0.86	0.2	0.8	2.6	67.5
9	1x10	2.21	64.2	4.0	202.1	119.2	0.0	47.7	0.68	0.4	0.8	2.8	68.0
10	1x11	2.12	64.3	2.5	215.1	115.2	2.8	29.7	0.65	1.3	0.8	3.7	67.0
11	1x12	2.29	65.0	2.5	223.6	118.3	0.0	29.1	0.62	0.0	0.7	2.8	67.5
12	1x13	1.95	66.5	4.5	233.0	129.5	5.4	36.9	0.63	0.6	0.7	2.7	71.0
13	2x3	3.02	65.4	1.0	239.9	115.2	0.0	30.9	0.85	2.7	0.8	2.5	66.5
14	2x4	3.16	61.5	3.0	236.8	110.4	0.1	33.4	0.71	2.6	0.8	2.3	64.4
15	2x5	3.44	65.2	-1.0	240.5	121.6	0.0	40.2	0.92	0.0	0.7	2.1	64.0
16	2x6	2.07	63.3	0.5	223.1	101.9	0.0	11.7	0.80	0.8	0.7	2.8	64.0
17	2x7	1.55	65.1	10.5	219.4	106.9	2.7	13.2	0.39	1.4	0.6	2.9	75.5
18	2x8	2.56	63.6	3.5	217.1	106.3	5.3	9.6	0.55	1.3	0.8	3.2	67.0
19	2x9	2.55	64.1	0.5	229.6	100.9	0.1	38.3	0.98	1.3	0.8	2.8	64.5
20	2x10	2.17	64.9	2.0	223.4	120.2	5.9	33.6	0.60	1.2	0.8	2.7	67.0
21	2x11	3.76	65.1	1.0	233.1	117.0	5.4	48.3	0.86	0.0	0.8	2.7	66.0
22	2x12	2.31	64.5	4.0	232.1	109.7	0.0	35.2	0.64	8.5	0.6	3.0	68.5
23	2x13	2.95	67.9	0.0	238.4	126.0	3.1	11.1	0.61	1.8	0.7	2.3	68.0
24	3x4	1.73	61.8	2.5	222.1	117.7	0.1	50.5	0.90	19.0	0.9	3.6	64.5
25	3x5	2.74	64.5	1.0	230.2	131.4	0.2	44.0	0.89	0.0	0.9	2.7	65.5
26	3x6	2.59	61.7	1.0	207.1	103.6	0.1	29.4	0.69	2.1	0.9	3.1	62.5
27	3x7	1.10	64.0	9.5	195.0	102.0	2.8	7.4	0.48	0.2	0.8	3.9	73.5
28	3x8	3.02	62.1	3.0	223.1	103.9	0.2	41.6	1.04	23.4	0.8	2.9	65.0
29	3x9	2.27	63.5	2.5	231.4	109.9	0.0	38.7	0.75	3.4	0.8	2.8	66.0
30	3x10	2.65	61.1	2.0	218.8	118.3	0.0	56.9	0.94	3.9	0.8	3.1	63.0
31	3x11	2.40	62.5	0.5	223.8	114.1	0.0	43.1	0.79	0.0	0.8	3.7	63.0
32	3x12	1.46	63.8	11.5	230.0	115.5	0.1	19.4	0.42	4.0	0.8	3.2	75.0
33	3x13	3.17	66.0	2.0	240.8	138.9	0.0	61.7	1.05	0.0	0.8	3.0	68.0
34	4x5	2.81	62.7	0.5	250.5	143.0	0.0	40.0	0.90	1.1	0.8	2.6	63.5
35	4x6	1.56	61.0	1.5	223.3	112.4	0.0	30.7	0.92	3.2	0.9	3.3	62.5
36	4x7	2.50	63.5	5.0	243.2	128.4	0.1	8.5	0.57	6.3	0.7	2.6	68.5
37	4x8	2.33	63.8	5.0	238.0	112.8	0.3	2.7	0.69	8.0	0.8	3.7	69.0
38	4x9	3.36	62.3	3.0	238.3	114.5	5.7	43.2	0.85	0.1	0.8	2.9	65.4
39	4x10	2.63	61.0	1.0	216.9	117.0	0.1	34.4	0.88	1.6	0.9	3.0	62.0
40	4x11	3.82	62.6	3.0	248.4	122.4	2.6	30.2	1.03	3.4	0.8	3.1	65.6
41	4x12	2.75	61.8	4.0	240.8	124.5	0.2	42.6	0.92	7.6	0.7	2.7	66.0
42	4x13	2.93	65.3	2.0	253.0	148.7	0.1	28.9	0.78	0.3	0.8	2.8	67.5
43	5x6	2.29	62.3	-1.0	217.8	114.9	0.1	23.4	0.94	0.1	0.9	2.5	61.4

Appendix 4 (continued): Mean grain yield and agronomic traits for diallel hybrids at Kiboko under managed drought continued

ENTRY	CROSS	GY [†]	AD	ASI	PH	EH	RL	SL	EPP	HC	SEN	EA	SD
44	5x7	2.10	64.5	0.5	212.3	123.6	2.6	26.8	0.62	0.9	0.8	2.6	65.0
45	5x8	2.41	64.8	0.0	230.5	120.4	0.0	33.6	0.96	0.0	0.8	2.7	64.6
46	5x9	2.41	63.0	-1.5	220.6	116.6	0.0	51.2	0.86	0.7	0.8	2.1	61.4
47	5x10	2.10	64.9	0.0	213.7	126.1	0.0	41.0	0.94	1.1	0.8	3.2	65.0
48	5x11	2.89	65.0	0.0	220.1	122.6	0.0	38.6	0.97	0.0	0.8	2.7	65.0
49	5x12	2.21	64.4	0.5	231.1	129.9	0.0	44.4	0.90	0.0	0.9	3.0	65.0
50	5x13	3.18	66.4	-0.5	239.2	137.4	0.0	53.3	0.53	0.0	0.8	2.1	66.0
51	6x7	1.64	61.6	3.5	192.2	102.2	0.0	27.7	0.71	0.7	0.7	2.9	65.0
52	6x8	1.83	61.0	2.5	221.2	105.9	0.0	21.0	0.79	8.7	0.8	3.5	63.5
53	6x9	2.12	63.2	1.0	206.2	94.0	0.0	28.0	0.54	3.9	0.7	3.3	64.0
54	6x10	2.00	60.7	0.5	199.5	101.0	0.0	28.4	0.85	1.1	0.9	3.4	61.5
55	6x11	2.06	63.0	0.0	204.0	101.9	0.1	9.6	0.82	2.6	0.8	3.7	63.0
56	6x12	1.61	62.3	3.5	214.7	104.0	0.2	11.8	0.53	0.0	0.8	3.7	66.0
57	6x13	1.76	63.4	1.5	226.6	126.4	0.0	48.3	0.77	0.4	0.7	2.6	64.6
58	7x8	1.12	64.7	8.5	219.7	113.5	5.3	12.1	0.49	4.9	0.7	3.8	73.5
59	7x9	1.44	62.9	2.5	208.7	103.3	0.0	55.2	0.66	2.0	0.8	2.8	65.5
60	7x10	1.72	64.3	4.0	203.2	123.9	0.0	38.9	0.71	0.0	0.8	3.2	68.1
61	7x11	2.25	63.8	3.5	223.2	114.8	0.0	38.9	0.59	0.8	0.8	3.2	67.5
62	7x12	1.65	64.5	9.5	211.9	103.9	0.1	7.2	0.40	8.7	0.6	3.2	74.0
63	7x13	0.96	65.4	3.0	221.4	122.3	10.4	18.2	0.35	0.0	0.7	3.1	68.5
64	8x9	2.16	63.1	1.0	203.2	95.4	0.1	40.2	0.73	2.8	0.8	3.6	64.0
65	8x10	2.08	63.8	3.5	209.9	114.8	0.1	26.6	0.59	6.6	0.8	3.6	67.5
66	8x11	3.41	63.0	0.5	238.4	112.3	0.1	45.0	0.94	0.0	0.9	3.9	63.6
67	8x12	1.06	63.5	5.5	229.2	106.2	2.6	21.5	0.48	20.7	0.7	3.6	69.0
68	8x13	3.14	65.4	3.0	242.1	126.1	0.1	35.6	0.88	10.9	0.7	2.8	68.5
69	9x10	2.61	63.4	1.0	214.6	110.3	0.2	53.4	0.78	0.0	0.7	2.4	64.5
70	9x11	1.95	64.8	0.0	222.0	110.0	0.1	46.6	0.57	1.6	0.8	3.6	65.0
71	9x12	1.66	63.6	3.0	226.3	101.8	0.1	43.2	0.71	11.6	0.8	3.7	66.5
72	9x13	3.16	67.8	-1.5	226.0	121.6	0.0	51.6	0.85	0.3	0.7	2.9	66.5
73	10x11	2.23	63.5	0.5	213.7	121.3	0.0	41.7	0.74	0.0	0.8	3.5	64.0
74	10x12	2.32	64.9	6.5	226.1	123.7	2.9	18.8	0.75	8.4	0.7	3.4	71.5
75	10x13	1.54	66.2	3.5	209.3	128.7	0.2	36.3	0.74	0.0	0.8	3.3	69.5
76	11x12	3.30	64.3	2.5	232.3	112.4	0.0	44.1	0.95	5.1	0.6	3.2	66.6
77	11x13	1.91	66.1	2.0	230.1	131.9	0.0	59.5	0.59	0.0	0.8	2.6	68.0
78	12x13	2.01	65.1	4.5	240.0	123.0	7.7	44.5	0.71	15.8	0.7	2.7	69.5
79	Check 1	0.68	75.1	8.0	218.3	121.0	0.0	33.6	0.39	0.0	0.7	4.3	83.0
80	Check 2	2.88	67.8	4.5	248.7	142.6	8.1	15.1	0.62	3.5	0.7	2.5	72.5
Mean	2.35	64.1	2.6	223.9	116.9	1.1	33.7	0.75	2.9	0.8	3.0	66.7	
LSD (0.05)	1.45	1.6	4.6	23.7	13.9	6.9	27.2	0.41	8.1	0.2	0.9	4.8	
CV	30.78	1.2	88.6	5.3	5.9	313.7	40.4	27.17	139.7	10.1	14.4	3.6	
Min	0.68	60.7	-1.5	192.2	94.0	0.0	2.7	0.35	0.0	0.6	2.1	61.4	
Max	3.82	75.1	11.5	253.0	148.7	10.4	61.7	1.10	23.4	0.9	4.3	83.0	

† GY: Grain yield; AD: Anthesis date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Shoot lodging; EPP: Ears per plant; HC: Husk cover; SEN: Senescence; EA: Ear aspect; SD: Silking date.

Check 1: CML144/CML159; Check 2: H513.

Appendix 5: Mean grain yield and agronomic traits for diallel hybrids at Kiboko under well-watered management

ENTRY	CROSS	GY†	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	EA	MOD
1	1x2	11.82	56.7	57.6	1.0	211.3	111.6	2.9	0.0	1.12	0.0	2.5	1.4	1.4
2	1x3	11.90	56.2	58.0	2.0	208.3	108.7	0.4	0.0	1.00	33.5	0.0	1.6	1.5
3	1x3	10.22	54.4	57.1	2.5	224.5	119.7	17.7	0.0	1.12	15.8	0.0	1.9	1.4
4	1x5	10.06	57.9	58.2	0.0	235.3	126.9	59.0	0.0	1.14	3.4	0.0	1.6	1.0
5	1x6	9.40	53.0	56.1	3.0	180.5	93.7	0.0	0.0	1.00	0.0	0.0	2.2	1.6
6	1x7	9.41	56.9	58.1	1.0	213.5	118.2	8.8	0.0	0.98	0.5	0.0	2.0	1.3
7	1x8	11.19	56.7	58.6	1.5	218.0	118.8	0.0	0.0	1.05	0.6	0.1	2.2	1.6
8	1x9	8.00	57.2	57.9	0.5	195.8	94.0	0.0	0.0	1.00	2.2	4.9	2.5	1.7
9	1x10	10.20	57.2	58.8	1.5	209.0	110.2	0.0	0.0	0.98	0.0	2.7	1.7	1.2
10	1x11	8.52	57.0	58.2	1.0	191.8	101.1	1.2	0.0	1.00	0.0	0.0	2.3	1.5
11	1x12	8.12	56.5	58.5	2.0	205.3	103.0	0.0	0.0	1.00	1.5	0.1	2.2	1.3
12	1x13	11.97	58.3	59.7	1.5	210.3	124.0	1.3	0.0	1.00	0.0	2.6	1.5	1.4
13	2x3	10.04	56.6	58.0	1.5	224.0	100.2	1.4	0.0	0.95	32.8	12.2	2.0	1.4
14	2x4	9.56	54.6	56.5	2.5	231.5	104.8	0.8	0.0	1.00	0.7	0.0	2.2	2.5
15	2x5	9.32	55.7	55.8	0.0	222.5	108.1	1.9	0.0	0.98	0.6	2.3	1.7	1.3
16	2x6	8.44	55.5	56.3	1.0	202.0	87.3	0.0	0.0	0.98	11.3	0.0	2.4	2.0
17	2x7	8.79	58.0	59.9	1.5	215.0	97.9	0.8	0.0	1.08	21.8	0.1	2.3	1.5
18	2x8	10.40	55.9	56.2	0.5	217.5	90.6	2.0	0.0	0.98	62.6	2.5	2.4	2.9
19	2x9	8.43	54.8	56.2	1.5	212.5	79.3	0.0	0.0	1.00	15.2	4.8	2.8	1.7
20	2x10	7.69	57.8	59.0	1.5	215.0	95.7	0.3	0.0	0.88	0.0	0.0	2.4	1.6
21	2x11	10.11	56.7	57.6	1.0	214.5	98.0	0.0	0.0	1.00	2.9	7.1	2.2	1.9
22	2x12	7.39	57.6	59.4	2.0	229.3	97.3	0.9	0.0	0.90	39.4	5.2	2.5	1.8
23	2x13	11.49	59.0	59.3	0.5	221.5	112.2	0.1	0.0	0.95	7.1	0.0	1.6	1.9
24	3x4	7.78	52.2	54.0	1.5	195.3	89.9	1.3	0.0	0.98	27.0	0.1	3.0	2.9
25	3x5	9.91	56.7	57.2	0.5	227.8	128.6	0.0	0.0	1.20	7.3	1.9	2.2	1.2
26	3x6	9.16	53.2	54.2	1.0	194.8	89.1	0.0	0.0	0.98	3.6	5.0	2.7	1.6
27	3x7	10.71	55.9	56.3	1.0	207.0	103.9	0.0	0.0	1.00	23.0	4.7	2.0	1.4
28	3x8	8.37	54.4	55.5	1.0	205.8	88.2	0.0	0.0	0.91	10.8	2.7	2.5	1.5
29	3x9	8.51	54.6	55.1	0.5	205.3	84.9	5.1	0.0	1.00	1.9	7.4	2.0	1.5
30	3x10	8.31	54.9	56.2	1.5	211.5	110.5	0.0	2.4	1.06	19.0	0.0	2.2	1.6
31	3x11	8.61	53.1	54.6	1.0	192.3	87.2	0.0	0.0	0.98	4.1	0.0	2.5	1.7
32	3x12	9.17	56.2	58.1	2.0	227.0	97.9	3.7	0.0	1.05	58.8	4.9	2.4	1.1
33	3x13	8.86	57.0	57.5	0.0	218.0	112.3	0.0	0.0	0.95	12.2	0.0	2.3	1.8
34	4x5	8.63	55.1	54.9	0.0	224.5	121.5	18.6	2.7	1.03	6.4	0.0	2.5	1.4
35	4x6	8.22	52.3	53.6	1.5	203.5	87.9	0.0	0.0	0.93	30.3	8.6	2.9	2.0
36	4x7	7.89	54.4	56.5	2.0	229.0	115.1	23.8	0.0	1.00	5.6	0.0	2.7	1.5
37	4x8	8.47	54.1	56.3	2.5	226.3	99.5	0.0	0.0	1.01	10.0	5.3	2.6	2.6
38	4x9	7.33	53.8	56.4	2.5	200.0	88.6	4.1	0.0	1.00	11.2	0.1	2.8	2.1
39	4x10	7.97	52.4	53.4	1.0	211.5	96.5	0.6	0.0	1.08	2.9	2.3	2.8	2.1
40	4x11	8.05	53.6	55.5	2.0	209.0	103.5	0.1	2.5	0.95	17.4	10.3	2.9	3.3
41	4x12	8.75	52.6	56.6	4.0	210.0	96.3	0.0	0.0	1.00	15.6	0.0	2.4	1.3
42	4x13	9.65	55.5	57.1	1.5	249.3	135.8	45.5	0.0	1.15	2.6	2.4	2.4	3.2
43	5x6	8.35	52.3	52.6	0.5	194.0	92.3	0.0	0.0	0.98	3.6	5.3	2.5	1.0

Appendix 5 (continued): Mean grain yield and agronomic traits for diallel hybrids at Kiboko under well-watered management continued

ENTRY	CROSS	GY [†]	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	EA	MOD
44	5x7	9.11	57.0	56.1	-0.5	211.5	130.0	0.1	2.7	1.00	8.7	0.0	2.1	1.2
45	5x8	8.52	56.2	55.8	0.0	223.0	110.4	0.0	0.0	1.01	29.2	10.2	3.1	1.9
46	5x9	9.95	54.9	55.9	1.0	217.0	112.1	6.1	2.7	1.08	10.5	0.0	2.1	1.4
47	5x10	7.96	57.3	56.6	-0.5	215.3	117.9	17.9	0.0	1.03	0.5	2.4	2.2	1.3
48	5x11	7.87	56.7	56.3	-0.5	216.0	115.2	18.0	0.0	0.93	0.9	2.8	2.3	1.2
49	5x12	7.33	57.3	57.8	0.0	227.5	114.8	4.3	0.0	1.00	1.9	2.4	3.0	1.2
50	5x13	10.58	56.7	58.0	1.5	231.8	145.1	0.8	0.0	1.05	0.0	0.0	2.1	2.6
51	6x7	7.70	53.8	54.9	1.0	188.5	82.5	0.3	0.0	0.95	0.0	0.0	2.4	1.5
52	6x8	9.26	54.6	55.8	1.0	210.0	99.8	0.1	0.0	1.03	5.5	2.4	2.6	3.1
53	6x9	7.07	54.2	56.3	2.0	197.8	85.4	0.4	0.0	1.01	2.1	2.7	2.9	2.5
54	6x10	6.98	52.9	54.2	1.0	184.5	88.6	0.2	0.0	1.03	1.8	0.1	2.9	1.7
55	6x11	7.92	53.3	54.6	1.0	188.8	87.0	0.2	0.0	1.00	0.7	2.6	3.0	2.4
56	6x12	7.16	54.5	56.5	2.0	203.0	86.2	2.6	0.0	1.05	2.6	0.0	2.7	2.0
57	6x13	9.74	56.1	57.0	1.0	200.8	110.6	0.0	0.0	1.03	5.6	0.0	2.0	2.2
58	7x8	8.16	56.4	58.0	1.5	201.3	101.3	7.7	12.5	1.04	16.0	0.0	2.7	1.7
59	7x9	8.12	57.0	57.7	0.5	189.3	92.8	0.4	0.0	1.05	0.0	2.4	2.5	0.9
60	7x10	7.73	56.1	57.8	2.0	195.3	103.7	0.0	0.0	1.09	2.4	0.0	2.5	1.4
61	7x11	8.57	57.9	58.8	1.0	199.3	101.7	0.9	0.0	1.00	0.0	2.6	2.7	1.5
62	7x12	5.92	55.8	59.3	3.5	197.8	89.1	2.7	0.0	1.10	27.0	0.0	3.3	1.0
63	7x13	8.51	57.9	57.8	0.0	211.5	121.7	0.2	0.0	0.98	4.9	0.0	1.9	1.3
64	8x9	8.90	53.9	54.8	1.5	205.3	80.7	0.1	2.5	0.88	17.2	8.3	2.7	3.4
65	8x10	9.32	56.1	57.8	1.5	209.5	104.6	3.9	0.0	1.12	31.0	0.0	2.6	1.8
66	8x11	9.37	55.8	56.8	1.5	202.0	94.4	0.0	0.0	1.00	7.5	2.4	2.9	3.5
67	8x12	8.18	54.0	56.6	2.5	223.3	95.6	0.0	0.0	0.98	42.6	0.0	2.9	1.4
68	8x13	10.71	57.3	58.1	0.5	227.5	129.2	0.0	0.0	1.03	19.9	2.7	2.4	3.1
69	9x10	6.86	54.8	56.3	1.5	198.5	99.9	2.2	0.0	0.93	7.7	0.0	2.8	1.3
70	9x11	7.64	57.3	58.1	0.5	200.0	91.8	3.7	0.0	1.00	4.2	2.5	2.9	2.1
71	9x12	5.18	56.4	59.6	3.0	226.0	90.7	0.0	0.0	0.90	4.8	0.0	3.2	1.4
72	9x13	9.47	57.6	58.8	1.0	222.0	116.6	0.0	0.0	1.07	7.7	2.2	2.3	2.5
73	10x11	8.73	55.5	55.9	0.5	203.8	104.6	0.0	0.0	1.00	0.9	0.0	2.5	1.5
74	10x12	8.31	57.2	59.7	2.5	215.8	109.8	0.7	0.0	1.08	45.0	2.4	3.0	1.5
75	10x13	8.71	58.1	59.3	1.0	224.3	132.8	0.0	0.0	1.00	0.0	0.0	2.5	1.8
76	11x12	7.47	55.8	58.3	3.0	210.5	89.9	0.0	0.0	1.00	4.6	0.0	3.0	2.0
77	11x13	9.38	57.6	59.2	1.0	229.5	117.5	11.9	0.0	1.06	0.7	2.4	2.6	3.2
78	12x13	9.82	57.1	59.1	1.5	229.3	122.5	3.1	0.0	0.98	19.6	2.5	2.2	2.4
79	Check 1	10.76	63.2	62.5	0.0	242.5	124.8	0.8	2.5	0.98	0.0	0.0	2.1	2.6
80	Check 2	11.53	59.0	60.9	2.0	236.0	131.7	0.2	0.0	1.03	12.7	2.6	1.6	1.0
Mean		8.87	55.9	57.1	1.3	212.1	104.5	3.2	0.4	1.01	10.8	2.1	2.4	1.8
LSD (0.05)		1.38	1.9	2.0	2.0	17.5	12.0	18.2	4.5	0.15	15.3	6.4	0.6	0.6
CV		7.78	1.7	1.8	77.9	4.1	5.7	284.3	588.2	7.21	70.9	153.1	12.3	17.1
Min		5.18	52.2	52.6	-0.5	180.5	79.3	0.0	0.0	0.88	0.0	0.0	1.4	0.9
Max		11.97	63.2	62.5	4.0	249.3	145.1	59.0	12.5	1.20	62.6	12.2	3.3	3.5

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Shoot lodging; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; EA: Ear aspect; MOD: Modification.
Check 1: CML144/CML159; Check 2: H513.

Appendix 6: Mean grain yield and agronomic traits for diallel hybrids at Kiboko under low nitrogen

ENTRY	CROSS	GY [†]	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	EA
1	1x2	1.84	57.3	60.4	3.4	195.7	91.3	0.0	2.8	0.95	12.9	0.0	3.2
2	1x3	2.31	55.4	59.8	4.0	203.5	100.8	0.4	0.0	0.92	5.2	0.0	3.0
3	1x3	1.85	55.4	58.6	3.8	207.1	100.8	0.0	8.4	0.97	12.4	0.0	3.7
4	1x5	2.14	55.4	58.0	2.9	186.2	92.0	0.0	0.0	1.01	12.2	0.0	3.4
5	1x6	2.84	54.7	59.2	4.4	191.9	87.9	0.0	2.8	0.80	1.0	0.0	3.2
6	1x7	1.67	55.7	63.1	7.6	181.8	87.5	0.2	2.7	0.95	2.9	0.0	3.4
7	1x8	2.19	55.6	60.2	4.7	208.6	101.9	0.5	0.0	0.86	13.6	3.6	3.5
8	1x9	1.08	58.0	63.3	5.7	193.1	83.9	0.0	0.0	0.70	4.8	0.0	3.5
9	1x10	1.88	55.4	62.7	7.4	194.8	90.2	0.0	0.0	1.03	0.0	2.7	3.3
10	1x11	1.34	58.7	65.9	7.1	186.2	89.9	0.0	0.0	0.67	2.4	3.4	4.2
11	1x12	2.11	56.3	61.7	5.1	196.5	90.6	1.3	0.0	0.92	7.9	6.0	3.4
12	1x13	1.53	57.7	66.6	7.8	217.6	107.3	0.1	0.0	1.01	13.0	0.0	3.2
13	2x3	1.92	56.2	61.6	4.6	211.1	93.7	2.8	0.0	0.97	11.7	11.8	3.0
14	2x4	2.54	54.4	58.8	4.4	228.5	102.3	0.5	0.0	0.88	13.4	0.0	2.9
15	2x5	2.49	55.9	55.1	-1.0	203.3	100.7	1.1	0.0	0.92	2.4	5.6	2.8
16	2x6	0.81	55.0	63.4	8.2	190.4	78.6	0.0	0.0	0.83	15.4	0.0	4.0
17	2x7	0.39	56.1	68.2	12.5	195.1	81.6	0.7	0.0	0.47	4.3	0.0	4.1
18	2x8	1.83	55.8	61.0	5.7	210.0	92.3	0.0	0.0	0.90	44.9	0.0	3.5
19	2x9	0.92	54.8	65.4	10.5	202.1	84.3	0.4	0.0	0.66	16.7	0.0	3.6
20	2x10	0.44	56.8	-	-	212.0	91.6	0.0	0.0	0.42	8.6	4.6	4.4
21	2x11	1.62	57.9	61.7	3.8	212.2	91.7	0.0	0.0	0.80	0.0	0.0	3.9
22	2x12	1.63	56.6	62.9	5.8	203.9	90.8	0.2	0.0	0.67	14.0	0.0	3.6
23	2x13	1.02	58.2	65.6	7.8	220.8	105.7	0.0	0.0	0.80	18.9	0.0	3.9
24	3x4	2.07	51.7	55.5	3.6	195.0	89.0	4.8	0.0	1.06	17.5	0.0	3.2
25	3x5	2.73	55.1	55.3	0.0	198.2	104.6	0.0	0.0	1.02	0.0	0.0	2.6
26	3x6	2.38	53.4	56.5	3.7	179.9	82.2	0.0	0.0	0.96	10.8	8.4	3.2
27	3x7	1.34	54.1	62.7	8.5	180.4	81.2	0.1	2.8	0.83	17.8	0.0	3.3
28	3x8	2.36	53.4	57.3	3.6	191.3	86.8	0.0	0.0	0.94	0.5	0.0	3.1
29	3x9	1.44	56.2	63.7	7.5	204.7	90.3	0.0	0.0	0.84	13.3	2.8	3.0
30	3x10	1.82	52.8	56.9	4.4	189.2	91.3	0.2	0.0	0.97	39.1	5.9	2.9
31	3x11	2.96	54.8	57.8	2.5	196.5	90.0	0.1	0.0	0.98	8.9	0.0	2.7
32	3x12	2.12	56.1	61.2	5.4	212.7	96.6	0.2	0.0	0.81	7.1	0.0	2.4
33	3x13	2.36	57.4	59.9	2.7	223.5	107.4	3.1	0.0	1.05	11.7	2.5	2.9
34	4x5	2.21	54.0	55.1	1.0	215.4	117.2	1.1	8.8	0.98	7.4	0.0	3.3
35	4x6	2.36	52.3	56.1	4.3	188.4	86.7	0.0	0.0	1.03	5.1	5.2	3.9
36	4x7	2.20	53.4	57.8	4.0	207.7	101.2	0.1	0.0	0.89	22.1	3.0	3.5
37	4x8	1.65	56.1	63.8	8.0	208.2	91.8	0.2	0.0	0.68	21.4	0.0	3.5
38	4x9	1.44	54.5	63.7	9.4	204.8	90.8	0.2	0.0	0.77	13.7	0.0	3.7
39	4x10	2.13	51.9	57.4	5.5	194.9	99.3	5.7	15.8	0.63	19.0	0.0	3.5
40	4x11	3.33	53.5	57.6	3.2	215.8	101.6	0.0	0.0	0.97	0.1	8.1	3.0
41	4x12	2.97	53.5	57.6	4.5	212.9	100.7	0.0	10.6	1.00	4.2	0.0	2.4
42	4x13	2.40	56.1	61.3	5.0	240.7	124.8	0.0	5.3	0.98	10.7	0.0	3.0
43	5x6	2.57	53.2	54.2	1.1	181.7	87.6	0.1	0.0	1.01	4.2	8.4	2.8

Appendix 6 (continued): Mean grain yield and agronomic traits for diallel hybrids at Kiboko under low nitrogen continued

ENTRY	CROSS	GY [†]	AD	SD	ASI	PH	EH	RL	SL	EPP	HC	ER	EA
44	5x7	1.71	55.8	57.1	1.4	178.6	91.2	2.3	0.0	0.95	12.7	5.6	3.6
45	5x8	2.66	55.5	55.0	0.0	203.7	98.2	0.2	0.0	0.95	8.2	0.0	2.9
46	5x9	2.01	55.3	55.6	0.6	194.5	87.0	0.2	0.0	0.97	7.6	0.0	2.9
47	5x10	1.48	55.0	56.2	1.0	179.5	89.9	0.0	0.0	0.98	4.8	0.0	3.7
48	5x11	2.41	56.4	55.9	-0.9	209.4	104.4	0.3	0.0	0.97	2.9	0.0	2.9
49	5x12	1.73	56.9	57.4	0.7	217.2	105.4	4.2	0.0	1.01	2.4	0.0	3.0
50	5x13	1.74	57.5	57.2	-0.9	214.2	112.3	0.0	0.0	0.98	0.0	0.0	3.3
51	6x7	1.65	52.0	55.3	3.8	174.5	83.3	0.0	0.0	0.91	8.1	3.4	3.3
52	6x8	2.32	53.6	60.8	7.6	191.6	85.6	0.1	0.0	0.81	43.7	0.0	3.6
53	6x9	1.84	53.7	58.9	5.8	190.1	77.8	0.0	0.0	0.84	12.0	0.0	3.3
54	6x10	1.20	51.8	60.4	8.6	159.2	73.1	0.4	0.0	0.76	8.6	0.0	3.8
55	6x11	2.75	53.1	54.2	1.1	176.4	81.1	0.1	0.0	0.96	1.4	0.0	3.0
56	6x12	2.10	54.8	75.1	20.0	201.6	90.2	0.0	0.0	0.92	11.2	0.0	2.5
57	6x13	1.00	55.7	62.5	6.9	200.1	97.4	1.1	0.0	0.81	10.9	0.0	4.1
58	7x8	1.08	53.8	64.5	9.8	189.6	83.8	0.0	0.0	0.64	20.9	0.0	3.7
59	7x9	0.95	55.6	65.5	9.9	181.7	81.5	1.1	0.0	0.66	6.0	0.0	2.9
60	7x10	1.01	54.6	65.2	10.8	184.9	93.7	0.0	0.0	0.78	10.1	0.0	3.8
61	7x11	1.73	56.7	58.7	2.5	196.0	94.9	0.2	0.0	0.92	4.1	0.0	3.2
62	7x12	0.68	55.7	70.4	15.1	180.4	82.9	0.0	0.0	0.81	11.5	3.4	3.8
63	7x13	1.00	57.3	67.7	10.4	199.5	99.5	0.0	0.0	0.83	17.2	0.0	3.5
64	8x9	0.83	53.5	64.8	11.5	195.0	76.8	0.1	0.0	0.50	20.9	0.0	3.8
65	8x10	1.05	55.6	60.2	5.0	202.2	93.6	0.0	0.0	0.89	54.6	0.0	3.9
66	8x11	1.83	56.0	59.8	3.9	214.7	93.2	0.1	0.0	0.95	10.7	0.0	3.2
67	8x12	0.60	56.1	65.2	9.3	207.5	83.6	1.6	0.0	0.50	13.1	0.0	4.1
68	8x13	1.89	56.4	62.7	6.4	221.2	101.4	0.0	0.0	0.90	29.1	0.0	3.5
69	9x10	1.92	54.8	60.6	5.2	198.9	86.5	0.2	0.0	0.95	5.8	0.0	2.7
70	9x11	2.13	56.4	58.8	2.5	201.2	90.7	0.2	0.0	0.92	6.1	0.0	2.7
71	9x12	0.94	55.3	64.9	8.7	218.4	88.7	3.9	0.0	0.68	16.1	0.0	3.8
72	9x13	0.99	56.8	64.2	7.2	206.7	99.5	5.0	0.0	0.97	30.8	0.0	3.7
73	10x11	2.03	56.2	59.7	3.9	198.6	93.7	0.1	0.0	0.92	5.7	0.0	2.8
74	10x12	1.19	56.1	63.7	8.2	205.6	94.9	0.0	0.0	0.71	13.2	0.0	3.3
75	10x13	1.22	56.8	64.7	7.6	214.9	117.4	0.0	0.0	0.84	16.8	0.0	3.8
76	11x12	2.20	54.8	58.1	3.6	212.6	95.6	0.2	0.0	0.94	0.0	0.0	2.9
77	11x13	1.69	57.8	61.9	3.9	218.0	105.7	0.5	0.0	0.98	6.7	0.0	3.5
78	12x13	1.77	57.2	64.2	6.2	234.2	112.0	0.5	0.0	0.95	4.1	3.0	3.0
79	Check 1	1.14	63.0	68.2	5.0	219.2	100.3	0.1	3.0	0.91	1.7	0.0	3.6
80	Check 2	1.97	58.8	63.7	5.5	216.9	110.3	0.2	0.0	0.95	6.2	0.0	2.8
Mean	1.77	55.5	60.9	5.5	201.3	93.9	0.5	0.8	0.87	11.4	1.2	3.3	
LSD (0.05)	1.04	1.3	6.5	6.2	16.7	10.2	3.3	5.9	0.25	16.1	6.5	0.9	
CV	29.49	1.2	5.3	56.9	4.2	5.4	367.7	378.9	14.66	70.3	269.4	12.8	
Min	0.39	51.7	54.2	-1.0	159.2	73.1	0.0	0.0	0.42	0.0	0.0	2.4	
Max	3.33	63.0	75.1	20.0	240.7	124.8	5.7	15.8	1.06	54.6	11.8	4.4	

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; PH: Plant height; EH: Ear height; RL: Root lodging; SL: Shoot lodging; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; EA: Ear aspect.

Check 1: CML144/CML159; Check 2: H513.

Appendix 7: Mean grain yield and agronomic traits for line by tester hybrids at Kiboko under managed drought

ENTRY	CROSS	GY [†]	AD	ASI	SD	RL	SL	EPP	HC	ER	SEN	EA
1	1x1	0.93	69.3	4.7	74.0	3.6	0.3	0.25	0.3	0.0	7.4	3.3
2	1x2	1.57	69.4	2.2	71.5	8.8	0.0	0.45	0.2	0.0	6.9	3.1
3	2x1	1.09	68.0	2.0	70.0	11.3	0.0	0.55	0.1	0.0	6.4	3.8
4	2x2	1.20	66.4	2.9	69.0	7.6	0.0	0.45	4.8	3.2	5.8	3.3
5	3x1	1.30	67.6	2.5	70.0	0.1	0.0	0.51	30.1	0.0	7.3	3.4
6	3x2	0.87	67.4	-	-	11.8	0.0	0.29	6.1	0.0	7.5	4.0
7	4x1	1.17	67.6	3.8	71.5	6.1	0.2	0.50	2.3	0.0	6.9	3.6
8	4x2	2.34	65.4	4.0	69.5	17.0	0.4	0.45	0.1	0.0	7.1	3.0
9	5x1	0.35	70.4	-	-	3.3	3.0	0.40	0.0	0.0	7.5	4.6
10	5x2	2.01	69.2	2.7	72.0	3.0	0.0	0.46	5.8	0.0	7.1	3.4
11	6x1	1.54	70.1	3.1	73.0	-0.1	2.7	0.33	1.6	0.0	7.4	3.0
12	6x2	1.34	69.6	5.4	75.0	7.7	0.0	0.32	0.0	0.0	6.9	3.4
13	7x1	0.91	71.7	4.5	76.0	31.7	0.2	0.34	3.6	0.0	8.1	3.5
14	7x2	1.76	70.4	3.0	73.5	11.0	0.0	0.51	5.8	0.0	5.4	3.4
15	8x1	1.29	71.1	2.9	74.0	15.4	0.0	0.28	0.0	0.0	8.3	4.0
16	8x2	1.68	69.3	6.8	76.0	11.2	0.0	0.40	0.7	0.1	8.6	3.9
17	9x1	0.71	70.9	-	-	13.3	0.0	0.23	0.0	0.0	8.3	3.6
18	9x2	2.42	71.5	0.6	72.0	2.7	0.3	0.53	0.0	0.0	6.5	3.4
19	10x1	1.19	68.5	2.2	70.5	4.4	0.0	0.48	0.4	0.0	7.4	3.3
20	10x2	0.71	68.8	6.0	75.0	6.0	0.4	0.27	0.0	0.0	8.7	4.1
21	11x1	0.66	71.0	-	-	8.9	0.0	0.29	0.0	0.0	7.6	4.0
22	11x2	0.56	68.5	-	-	0.4	0.0	0.37	0.0	0.0	7.7	3.5
23	12x1	0.49	70.9	-	-	8.7	0.1	0.19	0.2	0.0	8.1	4.2
24	12x2	0.55	68.4	-	-	0.0	0.0	0.22	0.2	0.3	7.9	4.2
25	13x1	1.23	69.7	0.9	70.5	14.1	0.7	0.56	0.1	0.0	5.9	3.3
26	13x2	2.09	68.4	1.0	68.0	3.0	3.5	0.51	0.0	0.0	6.8	3.8
27	14x1	0.48	71.1	-	-	11.3	0.0	0.13	0.2	0.3	7.8	3.8
28	14x2	0.75	71.0	4.1	75.0	7.9	0.3	0.38	0.0	0.0	6.9	3.5
29	15x1	0.32	73.0	2.9	76.0	24.6	5.6	0.21	0.1	0.0	7.1	3.8
30	15x2	0.68	70.2	4.0	74.0	11.9	2.0	0.49	0.2	0.3	6.4	3.6
31	16x1	0.42	71.1	-	-	30.0	0.0	0.20	0.0	0.1	8.4	4.0
32	16x1	1.85	71.1	4.3	75.5	13.2	3.5	0.81	0.0	0.0	7.0	3.3
33	17x1	0.55	72.0	-	-	31.9	0.0	0.25	0.0	0.0	7.0	3.1
34	17x2	1.45	71.5	4.0	75.5	11.7	0.3	0.55	2.3	0.0	7.1	3.5
35	18x1	0.25	73.1	-	-	11.8	0.0	0.18	0.2	0.1	7.9	4.2
36	18x2	1.36	70.7	2.4	73.0	7.3	0.3	0.49	0.5	0.1	7.6	3.8
37	19x1	0.86	73.9	-	-	27.2	0.0	0.28	0.1	0.0	8.7	3.7
38	19x2	1.63	69.9	6.0	76.0	3.7	3.3	0.45	0.0	0.0	5.9	3.3
39	20x1	0.39	72.0	-	-	12.9	0.5	0.13	0.2	0.1	8.6	3.7
40	20x2	0.57	67.5	-	-	7.7	0.4	0.22	0.0	0.0	8.3	4.0
41	21x1	0.01	69.0	-	-	-0.6	2.7	0.16	0.0	0.0	7.6	4.4
42	21x2	0.71	69.1	-	-	3.4	0.1	0.19	0.4	0.0	7.4	4.6
43	22x1	0.39	74.0	-	-	3.1	6.2	0.22	0.1	0.0	7.8	3.7

Appendix 7 (continued): Mean grain yield and agronomic traits for line by tester hybrids at Kiboko under managed drought continued

ENTRY	CROS S	GY†	AD	ASI	SD	RL	SL	EPP	HC	ER	SEN	EA
44	22x2	1.33	71.1	-	-	11.2	0.0	0.33	0.4	0.0	8.0	4.0
45	23x1	0.73	-	-	-	11.4	0.0	0.29	0.0	0.0	7.1	3.7
46	23x2	1.06	71.5	11.5	83.0	0.5	3.1	0.47	0.2	0.0	7.8	3.6
47	24x1	0.75	72.9	7.0	80.0	7.9	0.5	0.29	0.1	0.3	8.0	3.7
48	24x2	1.17	72.1	-	-	0.0	0.0	0.27	0.0	0.0	8.3	3.3
49	25x1	0.81	-	-	-	5.1	0.0	0.35	0.1	0.0	7.5	3.9
50	25x1	0.04	71.1	9.0	80.0	8.5	0.0	0.62	0.0	0.0	6.3	3.2
51	26x1	0.89	74.9	-	-	0.4	1.8	0.31	0.2	0.0	7.4	4.0
52	26x2	-0.06	71.9	-	-	0.0	0.0	0.08	0.4	0.0	7.1	3.6
53	27x1	0.28	69.4	-	-	14.2	2.7	0.18	0.0	0.1	7.9	3.8
54	27x2	1.33	69.6	5.2	75.0	3.2	0.4	0.47	0.5	0.1	7.9	3.6
55	28x1	1.96	70.5	2.5	73.0	11.1	0.0	0.33	0.0	0.0	6.5	3.1
56	28x2	0.37	67.6	-	-	3.0	0.1	0.25	0.4	0.1	8.3	3.9
57	29x1	1.68	65.5	0.4	66.0	18.4	5.5	0.59	0.0	0.0	8.7	3.1
58	29x2	0.65	65.4	3.2	68.5	13.5	0.1	0.58	0.3	0.0	9.0	3.4
59	30x1	1.48	71.1	1.8	73.0	37.7	0.3	0.56	0.1	0.0	5.9	3.7
60	30x2	2.40	70.1	3.1	73.0	3.4	6.0	0.50	2.7	0.3	6.9	3.3
61	31x1	1.52	72.5	0.4	73.0	8.7	0.4	0.64	0.0	0.0	7.1	3.8
62	31x2	1.32	72.4	2.6	75.0	12.2	5.3	0.46	0.2	0.0	7.8	3.9
63	32x1	0.52	71.0	-	-	14.2	0.0	0.17	0.0	0.0	8.6	3.9
64	32x2	0.64	67.5	5.8	73.0	19.4	0.0	0.42	3.3	0.1	7.8	3.4
65	33x1	0.07	68.6	7.4	76.0	14.8	3.7	0.28	0.0	0.0	7.0	3.8
66	33x2	1.04	66.1	6.0	72.0	0.1	0.0	0.33	0.5	0.1	8.7	3.5
67	34x1	1.12	68.5	3.6	72.0	0.2	17.1	0.40	0.1	0.0	7.0	3.8
68	34x2	1.30	67.3	4.6	71.5	3.2	0.3	0.34	13.4	0.0	8.1	3.6
69	35x1	0.48	69.3	-	-	30.5	2.8	0.20	0.3	0.0	7.6	4.1
70	35x2	0.20	67.3	-	-	0.1	0.0	0.18	0.0	0.0	9.0	4.7
71	36x1	0.82	69.4	4.5	74.0	0.8	6.2	0.33	0.1	0.0	7.3	4.0
72	36x2	1.76	67.1	2.4	69.5	5.0	2.3	0.71	0.0	0.0	6.8	3.0
73	37x1	1.05	70.2	-2.2	68.0	19.8	0.0	0.48	0.0	0.1	7.9	3.3
74	37x2	1.40	66.5	7.1	73.5	14.9	0.0	0.49	0.6	0.0	7.8	2.9
75	38x1	1.17	70.8	-	-	0.0	0.6	0.21	0.1	0.0	7.3	3.2
76	38x2	0.78	68.7	14.3	83.0	0.0	0.0	0.12	0.5	0.0	8.8	4.3
77	39x1	1.11	66.9	5.2	72.0	32.0	0.0	0.38	0.1	0.0	6.8	3.2
78	39x2	0.94	67.2	-	-	5.7	0.0	0.25	3.4	0.0	7.3	3.4
79	40x1	0.69	67.6	5.6	73.0	10.7	0.0	0.25	0.2	0.3	8.2	4.2
80	40x2	1.07	67.4	-	-	11.4	0.0	0.27	0.2	0.0	7.2	3.5

Appendix 7 (continued): Mean grain yield and agronomic traits for line by tester hybrids at Kiboko under managed drought continued

ENTRY	CROSS	GY†	AD	ASI	SD	RL	SL	EPP	HC	ER	SEN	EA
81	41x1	0.38	67.9	-	-	20.1	0.0	0.20	0.1	0.0	7.9	3.9
82	41x2	0.55	65.1	-	-	0.3	2.7	0.28	0.2	0.0	7.9	4.2
83	42x1	0.93	70.9	-	-	5.9	0.2	0.25	0.0	0.0	7.5	4.3
84	42x2	1.45	70.0	5.3	75.0	12.1	0.2	0.64	1.5	0.0	7.3	3.5
85	43x1	1.77	65.7	3.9	69.5	17.0	0.4	0.57	0.0	0.0	6.0	2.8
86	43x2	1.82	65.0	4.0	69.0	6.5	0.0	0.59	0.0	0.0	7.8	3.5
87	44x1	1.86	68.6	3.0	71.5	2.4	0.2	0.54	1.5	0.0	7.0	3.5
88	44x2	0.81	67.6	-	-	3.3	3.9	0.22	0.0	0.0	8.3	3.2
89	45x1	1.80	69.0	0.0	69.0	10.6	2.7	0.53	0.2	0.3	7.4	3.5
90	45x2	1.76	69.1	-0.4	68.5	13.9	0.1	0.43	0.4	0.0	7.6	3.4
91	46x1	0.03	66.1	4.9	71.0	8.1	5.4	0.41	0.0	0.3	6.6	3.5
92	46x2	0.93	65.2	10.0	75.0	3.0	0.6	0.37	0.3	0.0	8.5	3.6
93	47x1	1.54	68.7	6.3	75.0	2.7	0.5	0.47	0.1	0.3	7.5	3.1
94	47x2	1.07	65.9	6.1	72.0	5.5	0.1	0.44	0.1	0.0	7.6	2.1
95	48x1	1.07	69.2	10.1	80.0	12.8	8.5	0.37	0.1	0.0	6.9	3.2
96	48x2	1.49	67.6	9.6	76.2	3.4	0.3	0.48	0.0	0.0	4.9	3.0
97	49x1	0.63	68.0	1.1	69.0	23.5	0.0	0.52	0.0	2.7	7.7	3.5
98	49x2	0.97	66.3	-	-	0.0	0.0	0.25	0.0	0.0	8.7	3.7
99	50x1	0.77	67.4	10.4	78.0	-0.2	0.1	0.18	0.0	0.0	7.0	3.4
100	50x2	0.42	65.6	-	-	5.6	0.0	0.17	0.3	0.0	8.2	3.9
101	51x1	0.64	68.5	-	-	0.5	0.0	0.27	0.0	0.0	7.5	4.2
102	51x2	2.16	64.9	4.1	69.0	0.1	0.1	0.41	7.8	3.3	7.2	3.3
103	52x1	2.22	70.0	1.0	71.0	0.8	0.3	0.54	0.0	0.0	6.3	3.3
104	52x2	1.07	68.7	6.6	75.0	3.1	0.5	0.27	1.6	0.0	6.5	3.5
105	53x1	0.15	68.4	3.0	71.5	12.8	0.2	0.23	0.0	0.0	7.7	3.9
106	53x2	1.21	69.9	3.0	74.8	5.9	2.8	0.41	0.3	3.3	7.7	3.6
107	54x1	1.98	70.4	-	-	0.3	0.0	0.38	0.0	0.0	6.2	4.2
108	54x2	0.52	71.9	-	-	0.1	0.1	0.14	0.1	0.0	8.1	4.2
09	55x1	1.92	66.5	1.2	68.0	20.0	0.2	0.67	0.1	0.0	5.4	2.8
10	55x2	1.88	65.1	11.5	76.5	8.5	0.3	0.66	0.2	0.1	5.6	3.1
11	56x1	0.85	73.2	-	-	9.2	0.5	0.15	0.4	0.0	8.5	3.7
12	56x2	0.40	70.5	-	-	1.0	0.5	0.18	0.0	0.0	8.4	3.3
13	57x1	1.67	65.5	3.8	69.0	16.6	0.4	0.65	0.4	0.0	6.8	3.2
14	57x2	1.01	65.0	2.9	67.8	15.7	0.0	0.49	0.1	0.0	8.1	3.5
15	58x1	0.58	68.5	15.1	82.8	-0.1	0.0	0.18	0.4	0.0	7.8	3.6
16	58x2	0.39	67.0	3.6	70.5	5.8	0.0	0.57	0.4	15.7	8.1	4.3
17	59x1	0.87	68.5	2.8	71.5	2.8	0.1	0.35	0.0	0.0	6.1	3.6
18	59x2	0.32	66.9	-	-	0.1	0.0	0.31	0.1	0.0	8.7	2.6
19	60x1	1.34	70.8	3.3	74.0	11.2	0.1	0.32	0.4	0.0	7.2	3.5
20	60x2	0.89	70.4	-	-	5.7	0.0	0.36	0.0	0.0	7.7	4.0
21	61x1	1.13	72.6	-	-	13.6	0.3	0.22	0.0	0.3	8.1	3.8

Appendix 7 (continued): Mean grain yield and agronomic traits for line by tester hybrids at Kiboko under managed drought continued

ENTRY	CROSS	GY [†]	AD	ASI	SD	RL	SL	EPP	HC	ER	SEN	EA
122	61x2	0.95	72.1	0.9	73.0	13.0	3.0	0.39	0.1	0.0	9.2	3.6
123	62x1	1.27	73.0	1.8	75.0	24.8	0.4	0.71	0.1	16.7	6.4	3.3
124	62x2	0.58	68.9	-	-	0.1	0.0	0.25	0.0	0.0	8.2	4.3
125	63x1	0.58	67.6	-	-	-0.2	0.3	0.10	0.0	0.0	6.9	4.4
126	63x2	1.21	65.3	6.8	72.0	7.3	6.5	0.81	0.3	0.0	8.0	3.4
127	64x1	0.74	73.9	-	-	23.4	8.4	0.27	0.0	0.0	7.9	3.7
128	64x2	1.19	72.0	-	-	0.7	6.2	0.35	0.1	0.0	7.9	3.8
129	65x1	0.78	66.5	-	-	2.6	0.3	0.16	0.1	0.0	6.2	3.5
130	65x2	0.87	65.1	2.7	68.0	2.7	0.3	0.33	0.3	0.0	7.6	3.8
131	Check 1	1.04	70.5	12.3	83.0	3.2	0.3	0.32	0.0	0.0	7.7	3.5
132	Check 2	0.84	74.4	-	-	0.3	0.2	0.30	0.3	0.0	7.6	3.7
Mean		1.03	69.2	4.5	73.1	8.7	1.1	0.37	0.8	0.3	7.5	3.6
LSD (0.05)		1.10	2.1	3.9	3.7	19.6	6.8	0.35	8.2	5.7	1.9	0.9
CV		53.99	1.5	42.8	2.5	113.4	320.4	47.41	527.0	828.7	12.7	11.9
Min		0.01	64.9	-2.2	66.0	0.0	0.0	0.08	0.0	0.0	4.9	2.1
Max		2.42	74.9	15.1	83.0	37.7	17.1	0.81	30.1	16.7	9.2	4.7

† GY: Grain yield; AD: Anthesis date; ASI: Anthesis-silking interval; SD: Silking date; RL: Root lodging; SL: Shoot lodging; EPP: Ears per plant; HC: Husk cover; ER: Ear rots; SEN: Senescence; EA: Ear aspect.

Check 1: Pool15QPMFS38-B-3-B-B-B-B/CML159; Check 2: CML144/CML159

-: no values were recorded since the hybrids did not attain 50% silking.

Appendix 8: Mean grain yield and agronomic traits for line by tester hybrids across well-watered sites

ENTRY	CROSS	GY [†]	AD	SD	ASI	EPP	PH	EH	HC	ER	GLS	ET	EA	PA
1	1x1	7.54	67.2	66.0	-1.2	1.1	213.9	101.2	3.1	1.4	1.9	2.1	2.4	2.6
2	1x2	6.82	66.4	66.6	0.2	1.0	201.3	92.4	20.7	3.3	1.6	2.1	3.1	2.8
3	2x1	7.65	65.8	65.1	-0.7	1.1	215.4	108.1	14.7	3.6	2.1	2.3	2.9	2.5
4	2x2	6.21	66.1	67.0	0.9	1.0	198.8	90.8	21.5	6.7	1.8	2.6	3.4	3.0
5	3x1	7.29	66.6	66.2	-0.4	1.1	224.1	111.9	13.9	2.2	1.9	2.1	2.8	2.8
6	3x2	5.92	66.8	67.3	0.5	1.0	197.4	99.6	33.8	2.6	1.8	2.4	3.4	2.8
7	4x1	6.59	66.3	65.3	-1.0	1.0	193.2	93.6	15.8	1.4	1.8	2.2	2.8	2.8
8	4x2	6.15	64.6	65.8	1.2	1.0	182.3	82.2	24.5	3.9	1.8	2.2	3.2	2.8
9	5x1	6.86	66.7	65.5	-1.2	1.0	195.1	96.7	2.1	0.7	1.9	2.4	2.4	2.9
10	5x2	6.65	67.1	67.3	0.2	1.0	189	91.1	9.4	0.0	1.7	2.5	2.7	3.1
11	6x1	7.43	66.1	65.5	-0.6	1.0	201.9	98.6	6.7	0.0	2.1	2.1	2.7	2.5
12	6x2	7.18	66.1	66.8	0.7	1.0	200.4	99.3	15.1	2.2	1.9	2.2	2.7	2.6
13	7x1	7.26	70.5	69.5	-1.0	1.1	201.3	105.8	4.6	1.8	1.6	2.0	2.7	2.9
14	7x2	5.73	69.3	68.6	-0.7	1.0	183	90	32.3	1.7	1.6	2.3	3.1	3.1
15	8x1	6.73	69.3	68.3	-1.0	1.1	196.1	100.1	10.7	4.0	1.8	2.2	2.9	3.1
16	8x2	6.36	67.8	67.5	-0.3	1.1	204.5	98.3	18.7	4.6	1.5	2.6	3.2	3.0
17	9x1	6.52	67.7	66.4	-1.3	1.1	181.7	87.6	5.2	2.4	1.9	2.4	2.9	3.0
18	9x2	6.16	68.2	67.8	-0.4	1.0	181.9	71.3	25.4	5.5	1.6	2.5	3.3	2.8
19	10x1	6.74	66.1	65.7	-0.4	1.0	202.8	105.9	14.6	1.9	1.8	2.3	2.9	2.6
20	10x2	6.45	66.1	66.9	0.8	1.0	191.6	95.1	20.5	4.8	1.6	2.5	3.0	2.8
21	11x1	7.21	66.6	65.8	-0.8	1.0	200.1	101.1	19.1	1.3	1.6	2.2	2.9	2.8
22	11x2	6.94	65.6	67.2	1.6	1.0	194.6	89.9	24.3	5.9	1.8	2.1	3.0	2.5
23	12x1	7.19	66.2	65.2	-1.0	1.0	206.3	104.4	9.7	1.1	1.8	2.2	3.0	2.8
24	12x2	6.24	66.6	67.8	1.2	1.0	194.6	92.8	20	0.0	1.8	2.4	3.2	3.1
25	13x1	6.41	66.7	66.5	-0.2	1.1	204.9	97.3	16.9	0.7	1.7	2.1	2.9	2.8
26	13x2	6.45	66.0	66.2	0.2	1.0	189.6	93.7	17.1	1.7	1.7	2.3	3.1	2.9
27	14x1	6.99	66.8	66.3	-0.5	1.0	212.5	114.3	16.6	3.0	1.6	2.1	2.7	2.6
28	14x2	6.27	66.6	67.2	0.6	1.0	199.5	103.7	25.3	1.6	1.6	2.3	3.0	3.1
29	15x1	6.76	69.0	69.1	0.1	1.1	200.5	104.1	8.8	2.5	1.8	2.1	2.9	2.8
30	15x2	6.50	68.4	68.5	0.1	1.0	194.6	95.6	18.8	9.1	1.6	2.2	3.3	3.0
31	16x1	7.35	68.9	69.3	0.4	1.1	207.3	103.3	4.1	1.2	2.0	2.1	2.7	2.7
32	16x2	5.95	68.5	69.1	0.6	1.0	193.4	90	15.6	3.7	1.7	2.1	3.3	2.8
33	17x1	7.15	68.7	68.4	-0.3	1.0	205.4	103.2	6.3	2.1	1.6	2.1	2.6	2.8
34	17x2	6.65	67.5	68.7	1.2	1.0	191.4	92.1	17.6	2.9	1.6	2.3	3.2	2.9
35	18x1	7.26	69.0	68.8	-0.2	1.1	206.1	103	4.9	0.0	1.8	2.4	2.7	2.5
36	18x2	6.67	67.5	68.4	0.9	1.0	195.2	91.1	23.1	4.5	1.6	2.2	3.0	2.8
37	19x1	6.85	68.0	68.1	0.1	1.0	195.3	101.5	8.1	0.6	1.9	2.2	2.7	2.7
38	19x2	6.40	68.1	68.9	0.8	1.0	190.1	94.1	14.7	1.3	1.8	2.0	3.1	2.9
39	20x1	7.70	69.8	67.4	-2.4	1.0	199	97.6	5.5	1.3	1.7	2.1	2.7	2.6
40	20x2	6.00	67.9	68.1	0.2	1.0	197.5	84.1	28.4	11	1.6	2.1	3.0	2.9
41	21x1	6.68	68.4	68.1	-0.3	1.0	191.8	83.3	10.8	2.7	1.7	2.1	2.9	2.7
42	21x2	6.09	67.1	68.1	1.0	1.0	195.9	90.2	20.7	2.9	1.5	2.4	3.2	2.8
43	22x1	6.27	70.7	70.4	-0.3	1.0	208.9	113.7	18	1.4	1.8	2.1	3.1	3.3

Appendix 8 (continued): Mean grain yield and agronomic traits for line by tester hybrids across well-watered sites continued

ENTRY	CROSS	GY†	AD	SD	ASI	EPP	PH	EH	HC	ER	GLS	ET	EA	PA
44	22x2	6.24	70.3	71.1	0.8	1.0	200.3	102.4	14.5	1.6	1.6	2.3	2.8	3.1
45	23x1	7.38	70.7	70.3	-0.4	1.0	193.6	101.5	5.5	3.4	1.9	2.3	2.8	2.9
46	23x2	6.12	69.2	70.9	1.7	1.0	196	96.9	18.1	5.9	1.8	2.2	3.1	2.9
47	24x1	7.41	69.9	69.0	-0.9	1.0	197.5	104.1	4.4	1.9	2.0	2.1	2.7	2.9
48	24x2	5.91	69.5	70.5	1.0	1.0	189.4	96.7	9.9	1.8	1.7	2.5	2.9	3.0
49	25x1	7.40	70.0	69.7	-0.3	1.1	198.6	102.8	2.4	3.4	1.7	2.2	2.8	2.8
50	25x1	5.80	69.8	71.4	1.6	1.0	191.8	96.6	12.6	5.1	1.5	2.1	3.1	3.1
51	26x1	7.57	69.2	69.0	-0.2	1.0	191.4	96.4	6.1	1.4	1.8	2.3	2.7	3.0
52	26x2	5.41	69.5	71.2	1.7	1.0	186.6	92.7	9.5	2.0	1.6	2.2	3.1	3.2
53	27x1	6.90	67.6	67.4	-0.2	1.1	195.9	98.1	0.6	0.6	1.6	2.0	2.5	2.6
54	27x2	6.85	67.0	67.5	0.5	1.1	199.2	95.4	18.5	9.2	1.7	2.5	3.2	2.8
55	28x1	7.56	68.0	67.3	-0.7	1.0	208.7	105.2	8.5	1.3	1.8	2.1	2.6	2.4
56	28x2	6.46	67.4	67.3	-0.1	1.0	199.8	90.4	21.4	6.0	1.6	2.2	3.0	2.5
57	29x1	8.08	63.3	63.0	-0.3	1.1	214.4	98.7	1.5	1.0	1.6	2.0	2.5	2.5
58	29x2	7.27	62.8	63.2	0.4	1.0	193.8	90.1	19.4	2.2	1.8	2.2	3.1	2.6
59	30x1	7.98	66.1	65.2	-0.9	1.1	193.9	92.9	12.4	1.2	1.7	2.2	2.7	2.9
60	30x2	7.63	65.9	66.5	0.6	1.0	202.4	99.2	15.6	9.8	1.9	2.2	3.0	2.8
61	31x1	6.63	69.6	69.0	-0.6	1.1	223.6	107.7	8.8	0.0	1.6	1.9	2.8	2.7
62	31x2	5.48	70.5	69.9	-0.6	1.0	205.6	98.1	19.9	7.0	1.7	2.1	3.3	2.9
63	32x1	7.57	67.2	66.2	-1.0	1.1	215.3	106.4	14.5	0.9	1.8	2.4	3.0	2.7
64	32x2	6.06	66.5	66.6	0.1	1.0	212.4	98.6	30.4	2.4	1.8	2.4	3.2	2.9
65	33x1	6.99	65.8	65.6	-0.2	1.1	193	89.1	16.2	1.1	1.6	2.4	2.5	2.9
66	33x2	5.63	64.2	64.4	0.2	1.0	169.6	83.2	15.4	4.1	1.5	2.5	3.1	2.9
67	34x1	5.67	65.8	65.9	0.1	0.9	180.3	86.1	13.6	1.5	1.9	2.4	3.0	3.0
68	34x2	4.59	65.8	66.6	0.8	0.9	175.7	76	22.6	8.2	1.9	2.4	3.6	2.9
69	35x1	6.45	68.6	68.7	0.1	1.1	198.2	106.9	22.7	1.9	2.1	1.9	3.0	2.9
70	35x2	7.26	67.2	67.7	0.5	1.0	197.3	99.3	22.1	10.7	1.9	2.0	3.0	2.7
71	36x1	6.88	66.3	65.8	-0.5	1.1	201.1	99.9	12.8	2.6	1.8	2.1	2.7	2.8
72	36x2	6.28	65.9	66.8	0.9	1.0	193.1	93.9	29.8	6.8	1.8	2.2	3.1	2.9
73	37x1	7.42	66.1	64.2	-1.9	1.2	206.8	100.4	12.9	4.0	1.9	2.0	2.6	2.6
74	37x2	6.56	65.4	65.4	0.0	1.1	190.3	88.4	29.5	4.6	1.8	1.9	3.0	2.6
75	38x1	7.06	69.6	70.8	1.2	1.0	197.7	91.6	8.6	1.8	2.3	2.0	3.0	2.8
76	38x2	7.10	68.0	69.3	1.3	0.9	206.8	91.8	20.8	3.8	1.9	2.4	3.0	2.8
77	39x1	8.26	66.3	65.1	-1.2	1.0	199.4	100.3	36.2	0.6	1.7	2.0	2.8	2.6
78	39x2	5.91	66.1	67.4	1.3	1.1	185.4	85.9	33.3	7.8	1.7	2.3	3.3	2.7
79	40x1	7.98	65.6	65.1	-0.5	1.1	203.8	101.8	2.6	2.3	1.8	2.0	2.7	2.6
80	40x2	6.71	66.2	67.0	0.8	1.0	189.9	92.6	8.3	2.9	1.7	2.3	3.2	2.6

Appendix 8 (continued): Mean grain yield and agronomic traits for line by tester hybrids across well-watered sites continued

ENTRY	CROSS	GY†	AD	SD	ASI	EPP	PH	EH	HC	ER	GLS	ET	EA	PA
81	41x1	5.99	65.7	65.4	-0.3	1.0	196.4	94.9	8.2	1.5	1.6	2.2	2.9	2.8
82	41x2	6.15	64.8	65.8	1.0	1.0	191.5	89.8	11.7	2.0	1.6	2.2	3.2	3.0
83	42x1	6.02	69.7	69.0	-0.7	1.1	195.8	97.2	3.2	2.5	2.1	2.0	3.0	2.9
84	42x2	6.34	68.5	68.7	0.2	1.0	187.9	87.4	19.7	2.9	1.8	2.4	3.2	2.7
85	43x1	7.96	64.1	64.4	0.3	1.1	212.4	105.6	20.7	3.6	1.6	2.1	2.7	2.6
86	43x2	6.81	62.5	63.9	1.4	1.0	200.1	90.9	20.3	1.9	1.7	2.1	3.3	2.6
87	44x1	7.75	66.7	64.1	-2.6	1.1	207.9	110.6	15.1	3.0	2.0	2.3	2.7	2.7
88	44x2	7.05	65.8	65.3	-0.5	1.0	216.2	107	26	5.3	1.9	2.3	3.0	2.8
89	45x1	7.47	66.3	65.5	-0.8	1.2	203.7	109.3	5.8	0.0	1.8	2.2	2.4	2.9
90	45x2	7.33	66.5	65.0	-1.5	1.0	203.2	107.1	6.5	2.5	1.7	2.0	2.7	2.8
91	46x1	7.44	63.8	63.8	0.0	1.1	187.6	89.3	3.7	2.3	1.6	1.9	2.7	2.7
92	46x2	5.81	63.2	64.7	1.5	1.0	181.3	83.5	11.8	5.9	1.6	2.1	3.1	3.0
93	47x1	6.85	66.7	65.4	-1.3	1.1	192	97.1	1.1	1.3	1.9	2.0	2.5	2.7
94	47x2	7.19	65.1	65.4	0.3	1.0	185.1	87.6	9.3	0.0	1.9	2.1	2.7	2.8
95	48x1	6.81	67.0	67.4	0.4	1.0	180.1	91.6	7.6	2.2	1.8	2.2	2.6	2.9
96	48x2	6.67	65.8	66.8	1.0	1.0	177.8	85.0	14.2	3.9	1.8	2.5	2.8	2.8
97	49x1	6.96	66.2	65.9	-0.3	1.0	199.1	99.0	3.7	3.4	1.8	1.9	3.1	2.9
98	49x2	7.3	64.3	65.9	1.6	1.1	195.9	95.6	13.1	3.9	1.6	1.9	3.3	2.6
99	50x1	5.65	65.4	66.4	1.0	1.0	186.8	85.4	9.5	0.6	1.8	2.5	3.2	2.9
100	50x2	6.04	63.9	65.4	1.5	1.0	179.3	78.1	33.7	16.2	1.8	2.5	3.2	3.1
101	51x1	6.88	66.0	66.3	0.3	1.0	207.1	109.6	8.2	3.9	1.6	2.1	2.7	2.7
102	51x2	6.15	64.4	65.8	1.4	1.0	184.7	85.8	17.4	3.3	1.7	2.5	3.1	2.9
103	52x1	7.63	68.2	67.5	-0.7	1.0	199	103.4	27.6	5.9	1.9	2.2	2.9	2.8
104	52x2	6.58	67.2	67.1	-0.1	1.0	191.8	92.8	48.5	8.1	1.8	2.6	3.5	3.1
105	53x1	6.34	66.2	66.3	0.1	1.0	197.7	97.6	9.6	3.3	1.6	2.0	2.8	2.9
106	53x2	5.95	67.6	67.8	0.2	1.0	198.6	93.6	23.0	4.3	1.6	2.1	3.2	2.9
107	54x1	5.08	69.0	68.6	-0.4	1.0	186	93.1	11.0	3.5	1.8	2.2	3.0	2.9
108	54x2	5.26	67.6	68.9	1.3	0.9	173.6	83.4	14.8	6.9	1.6	2.1	3.2	3.0
109	55x1	6.53	64.9	64.4	-0.5	1.0	186	85.9	8.2	2.6	1.9	2.3	3.1	2.9
110	55x2	5.73	63.2	64.9	1.7	0.9	179.1	81.8	3.9	4.0	1.8	2.4	3.3	3.1
111	56x1	6.38	68.5	67.8	-0.7	1.1	209.7	100.9	10.6	3.1	2.2	2.2	2.8	2.7
112	56x2	6.35	66.9	67.6	0.7	1.0	198.8	88.6	17.2	3.1	2.3	2.3	2.9	3.2
113	57x1	7.7	62.8	62.6	-0.2	1.1	190.4	89.4	5.8	1.2	1.9	2.2	2.5	2.7
114	57x2	7.47	62.4	63.4	1.0	1.0	185.8	82.4	17.4	5.3	1.8	2.5	2.9	2.6
115	58x1	7.46	67.3	66.6	-0.7	1.2	210.6	91.0	9.4	1.7	1.8	2.1	2.8	2.8
116	58x2	6.58	66.8	67.5	0.7	1.0	200.5	93.0	24.3	4.4	1.5	2.2	3.1	2.9
117	59x1	7.29	66.9	66.4	-0.5	1.1	199.1	99.3	5.7	2.9	1.6	2.3	2.7	2.8
118	59x2	6.87	65.5	66.4	0.9	1.0	193.7	94.3	25.4	9.5	1.8	2.2	3.0	2.7
119	60x1	7.16	68.7	68.6	-0.1	1.1	208	96.7	2.7	2.3	1.7	2.2	2.7	2.6
120	60x2	6.25	68.3	67.8	-0.5	1.1	200.4	93.3	9.5	2.7	1.7	2.2	3.0	2.7

Appendix 8 (continued): Mean grain yield and agronomic traits for line by tester hybrids across well-watered sites continued

ENTRY	CROSS	GY†	AD	SD	ASI	EPP	PH	EH	HC	ER	GLS	ET	EA	PA
121	61X1	7.22	70.5	68.8	-1.7	1.2	204.9	106.9	10.1	2.8	1.7	2.1	2.8	2.8
122	61x2	6.63	69.1	68.2	-0.9	1.0	208.1	101.4	9.1	1.4	1.7	2.4	2.8	2.8
123	62x1	7.35	68.9	68.1	-0.8	1.1	206.4	112.1	3.5	0.6	1.7	2.3	2.5	2.7
124	62x2	5.55	69.1	68.8	-0.3	1.0	189.3	96.0	22.1	5.8	1.6	2.6	3.1	3.0
125	63x1	6.38	66.5	66.3	-0.2	1.0	196.1	91.7	8.2	7.2	2.1	2.1	2.9	2.6
126	63x2	5.98	63.8	64.9	1.1	1.0	179.3	80.6	15.3	7.0	1.9	2.4	3.1	2.8
127	64x1	7.54	70.0	70.3	0.3	1.1	211.4	111.8	3.6	3.6	1.8	1.9	2.7	2.5
128	64x2	6.83	68.4	68.9	0.5	1.0	195.5	102.7	3.8	0.7	1.9	2.2	3.2	2.6
129	65x1	7.03	64.8	65.5	0.7	1.0	193.1	97.0	7.1	0.0	1.8	2.0	2.7	2.8
130	65x2	6.1	65.0	65.7	0.7	1.0	195.8	91.7	11.7	3.4	1.8	2.3	3.0	2.8
131	Check 1	8.07	67.6	67.0	-0.6	1.0	212.8	107.9	21.9	0.8	1.8	2.0	2.8	2.6
132	Check 2	6.76	70.4	70.4	0.0	1.0	204.5	100.0	12.1	2.9	1.8	2.2	2.9	2.9
Mean		6.72	67.02	67.08	0.06	1.03	197.02	95.98	14.42	3.28	1.77	2.21	2.93	2.81
LSD (0.05%)		0.83	1.15	1.32	1.03	0.09	12.43	9.82	9.28	4.59	0.22	0.28	0.3	0.34
CV		13.99	1.96	2.25	19.93	9.66	6.42	10.42	73.3	142.41	12.67	13.01	11.47	12.19
Min		4.59	62.4	62.6	-2.6	0.9	169.6	71.3	0.6	0	1.5	1.9	2.4	2.4
Max		8.26	70.7	71.4	1.7	1.2	224.1	114.3	48.5	16.2	2.3	2.6	3.6	3.3

† GY: Grain yield; AD: Anthesis date; SD: Silking date; ASI: Anthesis-silking interval; EPP: Ears per plant; PH: Plant height; EH: Ear height; HC: Husk cover; ER: Ear rots; GLS: Grey leaf spot; ET: *Exohilium Turcicum*; EA: Ear aspect; PA: Plant aspect.
 Check 1: Pool15QPMFS538-B-3-B-B-B-B/CML159; Check 2: CML144/CML159