COMBINING ABILITY FOR GRAIN YIELD AND AGRONOMIC TRAITS AMONG EARLY DROUGHT TOLERANT QUALITY PROTEIN MAIZE (QPM) INBRED LINES

RUTH NZISA MUSILA
B.SC. AGRIC. (Hons)

A dissertation submitted in partial fulfillment of the requirements for the award of a degree of Master of Science in Genetics and Plant Breeding

University of Nairobi
College of Agriculture and Veterinary Sciences
Department of Plant Science and Crop Protection

JULY 2008

DECLARATION

I declare that this dissertation is my own work. It is being submitted for the degree of ***Master of Science in genetics and plant breeding in the University of Nairobi.*** It has not been submitted before for any degree in any other university.

Ruth N. Musila ______________________ **date** 11/7/08

(Signature)

This dissertation has been submitted for examination with our approval as university supervisors.

Dr Kiarie Njoroge ______________________ **date** 11/7/08.

(Signature)

Dr S.M Githiri ______________________ **date** 11/7/08

(Signature)

Dr. Alpha Diallo ______________________ **date** 11/07/08

(Signature)

DEDICATION

To my family

ACKNOWLEDGEMENTS

Words alone cannot express my heartfelt thanks and sincere appreciation to my supervisors Dr. Kiarie Njoroge, Dr. S.M. Githiri and Dr. Alpha Diallo for their guidance in the project setting and thesis writing.

With great pleasure I express my sincere gratitude and appreciation to CIMMYT for the support they gave me during my field work. Special thanks go to Dr. Dan Makumbi for his assistance and advice in data analysis and all members of staff who showed great co-operation during my research work. Special note of thanks is extended to KARI staff in Kiboko, Embu and Kakamega for their assistance for allowing me to set my experiments at their stations.

With deep sense of appreciation and gratitude I thank the University of Nairobi for providing me with the scholarship to pursue my two-year M.Sc program.

I lovingly acknowledge the support and understanding of my Husband Eric and my dear son Dan and his cousin Ben. They have always been a constant source of inspiration through out the course of my study.

Finally and most of all, I am internally grateful to my Heavenly Father for giving me the life, strength and internal guidance to accomplish this task.

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLES

Table *Page*

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AD - Anthesis date

ASI – Anthesis-silking interval

CIMMYT – Centro Internacional De Mejoramiento De Maiz Y Trigo - International Center of Maize and Wheat Improvement

CML - CIMMYT Maize Lines

EA -Ear aspect

EPP - Ears per plant

ER - Ear rots

GY - Grain yield

GCA - General combining ability

NARS - National Agricultural Research Systems

OPV - Open pollinated variety

RL - Root lodging

SCA - Specific combining ability

SL - Stalk lodging

QPM- Quality protein maize

DEFINITION OF TERMS

Diallel hybrids – Single-crosses obtained from crossing fourteen inbred lines used in this study in a diallel mating design to generate a total of ninety one F_1 crosses.

Experimental checks – Single-crosses obtained from crossing some of the inbred lines used in this study using either CML144 or CML 159, and totaling eighteen in number.

F_1 hybrids (Entries) – First generation cross of the ninety one diallel hybrids, eighteen experimental checks and one reference check giving a total of 110 F_1 hybrids.

Managed drought condition – Trial grown during a rain-free period, with irrigation applied at the beginning of the season to establish good plant stand; Afterwards, irrigation is withheld so that the crop suffers drought stress during flowering and grain filling, resulting to at least 25% reduction in grain yield of the optimum condition.

Optimum condition – Standard agronomic practices recommended in maize production.

Reference check – A popular QPM single-cross hybrid (CML144xCML159) used by several maize breeding programmes in Eastern and Southern Africa region as a single cross female parent in three-way QPM hybrids.

Normal maize – Any maize genotype that does not have *opaque 2* gene.

ABSTRACT

Quality protein maize (QPM), a bio-fortified form of maize has twice the content of limiting amino acids, lysine and tryptophan, compared with conventional maize. It has been developed to, among other uses, help alleviate human malnutritition in areas where protein deficiency is a major problem in diets as in the dry areas of Eastern Kenya. Information about how F_1 hybrids produced from early drought tolerant QPM inbred lines compare with one of the popular QPM single-cross (CML144/CML159) is likely to speed up release of early drought tolerant QPM cultivars in this area. Prior knowledge on the combining ability of these inbred lines would be beneficial to breeders in deciding how to best develop single-crosses, three-way, double-cross hybrids and synthetic varieties. The objectives were to (i) compare grain yield and agronomic performance of F_1 hybrids produced from early drought tolerant QPM single-crosses with a reference QPM check (CML144/CML159); (ii) estimate general combining ability (GCA) and specific combining ability (SCA) among early drought tolerant QPM inbred lines for grain yield and other agronomic traits; (iii) assess the relative importance of general combining ability and specific combining ability in determining the progeny performance of the early drought tolerant QPM inbred lines; (iv) to predict grain yield of three-way and double-cross hybrids from data obtained from the early drought tolerant single-crosses; and (v) to establish the relationship between grain yield and other agronomic traits. Fourteen inbred lines were crossed in half diallel mating design. The 91 diallel hybrids together with 18 experimental checks and one reference check were planted in one trial and evaluated in five environments in Kenya including under four optimum and one drought condition. Data on grain yield, time to anthesis, time to silk, anthesis-silking interval, ears per plant, root lodging, stalk lodging, ear rots and ear aspect were recorded. The experimental checks yielded more grain than the diallel hybrids. One diallel hybrid entry 3 and one experimental check entry 72 had higher grain yields and were earlier in maturity than the reference check. The combined analysis of variance showed that the mean squares due to genotypes and general combining ability (GCA) were significant ($p<0.001$) for all the eight traits studied. However, the mean squares due to specific combining ability (SCA) was significant ($p<0.01$) for anthesis date only. Inbred Line 4 had superior GCA effects for grain yield. It was indeed a parent to twelve single-crosses among the selected top performing, dominant male parent to all the best predicted three-way hybrids and common parent to all the double-cross hybrids confirming its superiority in GCA effects. The same inbred had good GCA for shorter anthesis- silking interval, good alleles for increased number of ears per plant, resistance to ear rots and good ear aspect. Inbred Lines 5, 12, 7 and 9 had good alleles for reduced anthesis date. Line 6 and 10 had good alleles for root lodging and stalk lodging. Additive gene action appeared to have been more important than non additive gene action for grain yield and the other agronomic traits. Average grain yield for the single-crosses, predicted three-way and double-crosses was found to be the same, suggesting that the grain yield of the single-crosses may accurately reflect grain yield of the three-way and four-way crosses and should therefore be confirmed in field evaluations. An increase in grain yield was associated with a reduction in anthesis-silking interval and barrenness, and better ear aspect in the set of inbred lines used in this study.

CHAPTER ONE

INTRODUCTION

Maize is one of the three major cereal crops of worldwide economic importance ranking third after wheat and rice in world production (Morris, 1998). Globally it contributes 20% of world food calories and 15% (representing more than 50m tons) to the world's annual production of food crop protein (Anon, 1988). Maize is staple food through economic necessity in the developing countries of Latin America, Asia and Africa (Crow and Kermicle, 2002). In Eastern and Southern Africa, the cereal supplies up to 60% of the total daily calories and accounts for between 17 and 60% of the total daily protein supply for the humans (FAOSTAT, 2003). Consumption of maize in Kenya is high, supplying 36% of the total daily calories and accounting for 34% of the total daily protein supply of human individuals (FAOSTAT, 2003). However, normal maize is deficient in two amino acids, lysine and tryptophan, that are essential for monogastric animals and humans (Huang *et al.*, 2004); also the cereal is nutritionally poor with a biological value (BV) of 40-57% (Bressani, 1991). Fortunately, this poor nutritive value has been genetically corrected in the bio-fortified form known as quality protein maize (QPM) (Vasal, 2002; Prasanna *et al.,* 2001). QPM is a type of maize in which the *opaque-2* gene, along with necessary modifiers, has been incorporated and therefore contains twice the amount of lysine and tryptophan resulting in high protein biological value compared to normal maize endosperm (Krivanek *et al.*, 2007).

A wide array of QPM gene pools and populations are available at the International Center of Maize and Wheat Improvement (CIMMYT). This germplasm has been reported to hold good potential for hybrid development (Vasal *et al.,* 1993a; Vasal *et al.,* 1993b). Moreover, QPM that has yielded grain yield to the normal maize counterparts and with significant reduction in ear rots and insect damage has been reported (Vasal, 2000). Currently the primary objectives in QPM breeding program for Eastern and Southern Africa, led by CIMMYT in collaboration with National Agricultural Research Systems (NARS), are to develop hybrids and synthetic OPV's suitable for use by resource poor farmers in the region. One of the approaches is based on pedigree breeding where inbred lines are extracted and superior parents are identified through diallel systems or top-cross evaluation for production of hybrids and/or synthetic OPV's. The second approach is testing already developed QPM inbred lines, (both early generation and elite lines such as CML's (CIMMYT Maize Lines) hybrids and OPV's, to identify the most adapted cultivars for direct release or use as breeding materials. Several countries in Eastern and Southern Africa have had the opportunity to utilize these inbred lines in their respective breeding programs. A case in point is Uganda where over 45,000 hectares of land is under QPM cultivars. Despite its nutritional superiority and improved agronomic performance, QPM cultivation and adoption is yet to gain significant momentum in Kenya. Currently only 12 hectares of land is under QPM cultivars in this country (Krivanek *et al.,* 2007).

The CIMMYT QPM program in East Africa has given priority to developing short maturing stress tolerant cultivars thus targeting the proper agro-ecological zones where QPM is likely to have maximum impact such as the dry mid-altitude ecology, mainly occupying the dry areas of Eastern Kenya (CIMMYT, 2003). Previously, CIMMYT had developed early QPM inbred lines extracted from Pool15-QPM-SR (A.O. Diallo, personal communication). During their development, these lines were simultaneously improved for drought and low nitrogen tolerance for better adaptation to the drought prone agro-ecological niches of East Africa. The end products were early drought and low nitrogen tolerant QPM inbred lines. Information on the grain yield and agronomic performance of F_1 hybrids from these inbred lines in relation to one of the popular QPM single-cross (CML144/CML159) frequently used as female parent in many three-way hybrids released in Eastern and Southern Africa (CIMMYT, 2003), is likely to speed up the identification and release of early drought tolerant QPM cultivars in this area. Prior knowledge on the combining ability of these inbred lines would be beneficial to breeders in deciding how to best develop single-crosses, three-way, double-cross hybrids and synthetic varieties. Many countries in Sub Saharan Africa in addition to Kenya will stand to benefit from this information by developing early drought tolerant QPM hybrids in their respective breeding programs in a bid to reduce malnutrition and attain self-sufficiency in food production.

Problem statement and justification

Maize is the most basic staple food in the dry mid-altitude ecology of Kenya with a large proportion of the population depending on the cereal as the only source of protein. Poverty levels are such that most farmers cannot afford meat, eggs and other high protein rich diets. At the same time crops such as beans and other legumes that are naturally rich in protein, are more expensive to buy, cost more to grow, yield less and their poor digestibility entails that they be restrained from small children up to a certain age. In addition, drought and low soil fertility are the major abiotic stresses limiting maize production (Diallo *et al*., 2004) with drought being prioritized as the most important constraint that adversely affect maize production in this area (ASARECA, 1997). For instance over the last three decades the frequency of drought has resulted in major crop failures (Anon, 2004) and it has also been noted that maize yields are seriously reduced by drought in at least six out of ten years (Banziger and Diallo, 2004). As a result hunger and malnutrition wreaks havoc among the inhabitants of this area. Therefore the need to breed for early drought tolerant QPM varieties has been recognized as a major viable strategy to alleviate the intertwined problems of hunger and malnutrition experienced in this eco-zone.

Genetic variation for grain yield and other agronomic traits has been encountered in QPM germplasm. Diallel analysis results indicate that CIMMYT QPM populations and pools hold good potential for QPM hybrid development (Vasal *et al.*, 1993a; Vasal *et al.*, 1993b) as stated earlier. Promising early drought tolerant inbred lines that can be utilized for the formation of QPM hybrids and QPM synthetic OPV's are already available, but their combining abilities and *per se* performance of their inbred progenitors are obscure. The need to precisely determine the combining abilities of these inbred lines and to identify the best combiners is a major priority, towards increased nutrition and food security in the dry mid-altitude ecology and hence better and more food will be available. It will not be necessary to change the eating habits of the people as may be demanded by other approaches of relieving protein shortages such as consumption of exotic legumes, algae and food supplements.

Objectives of the study

Broad objective

To determine the magnitude of useful phenotypic and genetic variance present in fourteen early drought tolerant quality protein maize inbred lines from Pool15-QPM-SR and known to be good performers, in order to help in the choice of effective selection method for grain yield and other agronomic traits.

Specific objectives

1. Compare grain yield and agronomic performance of early drought tolerant QPM single-crosses to the QPM reference check (CML144/CML159);
2. estimate general combining ability (GCA) and specific combining ability (SCA) among early drought tolerant QPM inbred lines for grain yield and other agronomic traits and to identify suitable lines to generate single-cross hybrids and/or synthetic OPV's;
3. assess the relative importance of various genetic effects in determining the progeny performance of the early drought tolerant QPM inbred lines; and
4. predict grain yield of three-way and double-cross hybrids from data obtained from the early drought tolerant single-crosses.

Hypotheses

1. There should exist superior performing early drought tolerant QPM single-crosses in terms of grain yield and other desirable agronomic traits compared to QPM reference check (CML144/CML159);
2. there exists variability between and within GCA and SCA estimates for grain yield and other agronomic traits among early drought tolerant QPM inbred lines which could be used to identify suitable lines to generate single-cross hybrids and/or synthetic OPV's;

3. there exists differences in the relative importance of various genetic effects in determining the progeny performance of the early drought tolerant QPM inbred lines; and
4. superior single-crosses confer superior double-crosses and three-way crosses.

CHAPTER TWO

REVIEW OF LITERATURE

Progress in breeding quality protein maize

Quality protein maize was developed by researchers from CIMMYT using two genetic systems, *opaque-2* and genetic modifiers in order to overcome the obvious problems associated with soft endosperm maize developed earlier (Bjarnason and Vasal, 1992). Both in population improvement and in conversion programs, a multi-trait selection procedure using independent culling levels was employed to accumulate modifiers, maintain protein quality, increase yield, increase resistance to ear rots and improve other traits in which *opaque-2* germplasm is defective (Bjarnason and Vasal, 1992). By early 1980's, a wide array of CIMMYT's tropical and subtropical pools and populations had been converted to QPM versions. These QPM versions had grain yields comparable to the normal commercial varieties. Owing to the availability of QPM germplasm in en-masse, QPM hybrid development was introduced at CIMMYT in 1985. In collaboration with National Agricultural Research Programs (NARS) in about forty other countries, multinational testing was started. In 1999, superior QPM hybrids were evaluated in thirty countries in a multinational testing and the results were outstanding. Good hybrids had a yield advantage of one ton or more per hectare over the best normal maize hybrids (CIMMYT, 1999). In Mexico, a superior tropical x subtropical three-way cross hybrid yielded 8% more than the best normal check. Results from tropical white hybrids evaluated in Latin America, Asia and Africa showed that the grain yield of the best single-cross (CML142xCML146) was 6.7 tons/ha compared to 5.6 tons/ha that of the normal check. In Africa a popular QPM single-cross hybrid (CML144xCML159) which has since been released in three-way cross hybrids in several countries including Ethiopia, Tanzania and Kenya, and the main reference check in this study, topped the trials with a mean grain yield of 6.4 tons/ha, 12% more than non-QPM hybrid checks. It also had superior resistance to diseases and better agronomic traits than the checks (CIMMYT, 1999). In 2003 CIMMYT identified two hybrids CML144xCML159//CML181 and CML144xCML159//CML182 for pre-release in Kenya (CIMMYT, 2003). They have since been released as KH500Q and KH631Q respectively (Krivanek *et al.,* 2007). Both are early to intermediate maturing cultivars with flint texture and are recommended for the mid-altitude areas. Later a popular three-way hybrid CML144xCML159//CML179 was released in Ethiopia as BHQPS42 'Gabissa' and in Tanzania as Lishe-H1. This hybrid is also early to intermediate in maturity (Krivanek *et al.,* 2007).

In 2002, CIMMYT-Kenya began developing early and extra early QPM hybrids suitable for use by resource poor farmers in the dry areas. At their disposal was Pool15-QPM-SR. Pool15-QPM-SR is a white, early semi dent germplasm with tropical adaptation. It has a whole protein quality of 9.1%, 0.94% tryptophan and 4.2% lysine (Vasal, 2002) and an added advantage of maize streak resistance. By 2003, through the African Maize Stress (AMS) project, 800 full sib (FS) families had been generated from this pool and tested under drought, low nitrogen and optimum conditions. The selected best performing 20% were analyzed for quality protein (total protein, nitrogen and tryptophan), and these families were chosen and planted to form S1 progenitors and advanced to S3. In 2005 a top-cross evaluation was conducted for the best 192 inbred lines and a few were identified for combining ability testing. Development of early and extra early inbred lines has been going on simultaneously with screening and testing under stress conditions to obtain lines resistant and tolerant to both abiotic and biotic stress respectively. Currently, numerous early inbred lines along with OPV's have been developed and distributed to collaborators through the ECAMAW (East and Central Africa Maize and Wheat Network) regional testing (Krivanek *et al.,* 2007). The current study was therefore designed to evaluate some of these, early drought tolerant QPM inbred lines, along with the popular QPM female single-cross (CML144xCML159) as well as determining their combining ability for further breeding work.

Combining ability

Sprague and Tatum (1942) developed the concept of combining ability, defined as the ability of an individual, when crossed, to produce progeny with strong expression of a particular trait. They further divided the concept into two categories, general and specific. General combining ability (GCA) is the average performance of a line in hybrid combination and specific combining ability (SCA) is the deviation of particular crosses from average performance of the lines involved. General combining ability is associated with additive gene effects while specific combining ability is associated with non additive gene effects (Falconer, 1989). The attraction to know the combining abilities is based on its ability to provide an empirical summary of complex observations and a reasonable base for forecasting the performance of yet untested crosses without making genetic assumptions (Simmonds, 1989). An estimation of GCA and SCA effects allows identification of superior parents and prior knowledge on the extent of genetic divergence when selecting populations for hybrid production and for reciprocal recurrent selection.

Prior assessment of the combining ability of a genotype is thus an important criterion in developing improved hybrids thereby assisting breeding programs (Egesel *et al.,* 2003). For this reason combining ability analysis is viewed as a powerful tool in identifying the better combiners which may be hybridized to exploit heterosis and to select better crosses for direct use or for further breeding work (Allard, 1960).

Combining ability studies designed to determine the future usefulness of QPM inbred lines for hybrid breeding, has been investigated by several authors. Vasal *et al.* (1993a) evaluated ten CIMMYT tropical late maturity QPM pools and populations in a diallel mating design for grain yield and days to silking at eight environments in Mexico. They reported significant GCA effects for both traits and positive and significant GCA effects for two of the pools and one of the populations. SCA effects were significant for days to silking but no significant SCA effects were found for grain yield. Vasal *et al.* (1993b) reported positive GCA effects for grain yield in two QPM pools and two QPM populations in ten CIMMYT subtropical QPM pools and populations grown in eight environments in Mexico and in the USA and noted that SCA effects were less important. Bhatnagar *et al.* (2004) evaluated seven white and nine yellow QPM inbred lines in two separate diallel experiments for grain yield, days to silking, root lodging and stalk lodging in five southern U.S environments. Among the white inbred lines, they reported significant GCA effects for all the traits except grain yield whereas SCA effects were significant for grain yield and root lodging. Negative and significant GCA effects for days to silking and stalk lodging were reported in two inbred lines. Among the yellow inbred lines, GCA effects were significant for all the traits except grain yield while SCA effects were significant for grain yield and root lodging. Negative and significant GCA effects were found in one of the yellow inbred lines. Xingming *et al.* (2004) reported significant GCA and SCA effects for grain yield in a diallel cross among ten yellow inbred lines evaluated in three different environments in Yunnan province and Guangxi Autonomous region of China.

Combining ability has also been investigated by several authors in normal maize. Nigussie and Zelleke (2001) evaluated eight elite maize populations in a diallel mating scheme for grain yield, days to tasseling, days to silking and number of ears per plant in three environments for two years in Ethiopia. They reported that the magnitude of GCA variance was higher than SCA and thus additive effects were more important in the inheritance of these traits. Menkir and Ayodele (2005) evaluated twenty four inbred lines using Design II mating design for grain yield, days to silking, ear rots and ear aspect in five environments in Nigeria. They reported that GCA effects were more important than the SCA effects for all the traits. Betrán *et al.* (2003) evaluated seventeen inbred lines crossed in a diallel design under stressed and non-stressed environments and reported significant GCA and GCA x environment interaction effects for grain yield. SCA effects were significant while the interaction with environment was not. Glover *et al.* (2005) evaluated ten inbred lines in a diallel mating system for grain yield in five environments in U.S. and reported that GCA variance was more important than SCA variance for grain yield. Positive and significant GCA effects were observed for two of the inbred lines. Vacaro *et al.* (2002) reported predominance of additive gene effects over non additive gene effects for grain yield, ears per plant, root lodging and stalk lodging in a diallel cross involving twelve maize populations evaluated in two environments in Brazil. Dorrance *et al.* (1998) reported that GCA was more important than SCA in the inheritance of diplodia ear rots resistance or susceptibility in a seven parent diallel cross evaluated in Virginia for two years. Rossouw *et al.* (2002) observed a high GCA: SCA ratio for *Stenocarpella maydis* ear rots in a ten parent diallel cross evaluated in three localities in South Africa. They concluded that inheritance of *Stenocarpella maydis* ear rots was mainly controlled by additive gene effects.

Diallel mating design and analysis

A set of crosses involving *n* lines made in all possible combinations is designated a diallel cross and the analysis of such crosses is known as diallel analysis. Information on the magnitude of useful genetic variances present in a population is essential for an effective selection method for grain yield and other desirable traits to be chosen. The diallel analysis technique therefore, is extensively considered as one of the most powerful tools used to understand the gene action involved in the expression of quantitative characters (Baker, 1978). Hence, it provides a sensitive approach to large studies of quantitative characters that yields reliable information on the components of variance and on general combining ability and specific combining ability variances and effects, thus helping in the selection of suitable parents for hybridization as well as in the choice of appropriate breeding procedures (Simmonds, 1989). The two main approaches used for diallel analysis are Hayman (1954) approach based on the estimation of the components of variation and Griffing (1956) numerical approach based on the estimation of general combining ability and specific combining ability variances and effects. Griffing (1956) has given four different methods for diallel analysis depending on whether parents and reciprocals are retained or excluded from a particular design. Often referred to as experimental methods 1-4 whereby method 1 involves parents (*n*), F_1's [*n* (*n-1*)/*2*] and reciprocals; Method 2 involves parents and F_1's only, method 3 involves F_1's and reciprocals and method 4, employed in this study, entails F_1's only. Griffing's methodology is certainly the most frequently used, because its analysis is easy to perform and to interpret (Singh, 1995).

The choice of parents included to make crosses has a major implication in the interpretations made from the analysis of the diallel mating design and two models are mainly used in the interpretation of the data. As applied to diallel cross, 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. In model II (random model) the parents are assumed to be an unselected sample from some reference population. Inferences can therefore be made about the parameters of that population. In an analysis based on random model, inferences are to be 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).

Drought stress

Drought is defined as any duration without rainfall long enough to reduce plant growth (Njoroge *et al.,* 1997). Drought is the major constraint of maize production in the mid-altitude dry and dry transitional zones of Kenya (Njoroge *et al.,* 1997). The effects of drought can be overcome through developing early maturing cultivars as a drought escaping mechanism and/or incorporating drought tolerance into maize genotypes which is the ability to produce high grain yields despite showing symptoms of water deficits (Edmeades *et al.,* 1997). The unreliable nature of drought dictates that cultivars must perform well in both good and stressed environments. Evaluation under both conditions provides an opportunity to eliminate those genotypes that do not meet this criterion (Dass *et al.,* 1997). Genetic variation is the key to effective improvement of any trait. Variation for drought tolerance has been encountered in all types of maize germplasm including OPV's, hybrids and inbred lines. Breeding for maize tolerant to drought has been going on at CIMMYT and germplasm tolerant to the stress has been developed and the associated progress well documented (Diallo *et al.,* 1997; San Vincente *et al.,* 1997; Bolaños and Edmeades, 1997).

In a classical study, Diallo *et al.* (1997) evaluated maize inbred lines under both stressed and non-stress environments. These workers reported significant differences among lines for grain yield, days to silking, and ears per plant in both environments. Mean grain yield varied from 4.50 to 5.00 tons/ha under severe and natural environments respectively. They observed that under drought stress, there was a delay in days to silking and reduction in ears per plant; the earliest line gave the highest yield under drought stress and that lines which performed well under severe drought also performed well under natural conditions. They concluded that drought stress could be used to identify stable lines under both drought and natural conditions. San Vincente *et al.,* 1997 in a study to assess the genetic variability among tropical late yellow inbred lines under drought stress at Tlaltizapan, Mexico, reported significant differences for grain yield, anthesis-silking interval, ears per plant and ear aspect and observed a wide range of values for these traits that indicated useful variation among the lines for grain yield and the other secondary traits. Srinvasan *et al.* (1997) reported significant differences for grain yield, ears per plant anthesis date, root lodging and anthesis-silking interval among S_1 early maturing lines of tropical adaptation under drought stress in Mexico. They found existence of variability among the inbred lines for drought tolerance and expression of traits related to drought tolerance. They concluded that there was ample opportunity for improving tolerance in early maize via selection. Bolaños and Edmeades (1997) evaluated maize inbred progenies in their S_1 generation in fifty yield trials under well watered and severe drought. They reported grain yield average of 2.49 and 0.35 tons/ha under well watered and severe drought respectively. The drought treatment imposed reduced yield by 14% over well watered levels and markedly increased barrenness as ears per plant averaged 0.95 and 0.46 under well watered and drought levels respectively. Days to 50% anthesis were unaffected by the experiment conditions but the duration from sowing to days to 50% silking was progressively delayed. Anthesis-silking interval increased from 2.3 d to 8.3 d under well watered and severe drought respectively. Manda and Mwambula (1999) reported genetic variability for drought tolerance among elite tropical maize germplasm. Bias *et al.* (1997) reported variation for grain yield, silking date and anthesis date and anthesis-silking interval among early flowering varieties. Betrán *et al.,* (2003) evaluated seventeen inbred lines crossed in a diallel design under 12 stressed and non-stressed environments. They reported significant genotype and genotype x environment interaction effects for grain yield of hybrids and inbred lines. Grain yield for hybrids ranged from 1.14 tons/ha to 9.18 tons/ha under severe drought and well watered conditions respectively, with an average of 6.01 tons/ha across environments whereas mean grain yield for the inbred lines was 2.27 tons/ha ranging from 0.15 tons/ha to 3.95 tons/ha under severe drought and well watered conditions respectively.

Prediction of three-way and double cross hybrids

Basically three types of crosses have been used commercially: double-crosses, three-way crosses and single crosses. A single-cross is a cross between two inbred lines and gives maximum degree of hybrid vigor and plant and ear uniformity but the kernels are usually very small in size and poorly developed seeds that involve high cost of seed production on commercial scale. This type of cross is usually commercially undesirable but needed primarily as foundation hybrids for double and three-way crosses and prediction of their performance (Hallauer and Miranda, 1988). The practical difficulties associated with the production of single- crosses are overcome by the three-way and double-cross scheme. A three-way cross is a cross between a single cross as a female parent and an inbred line as a pollen parent. Thus the seed is produced on a high yielding single-cross hybrid parent and an inbred line that may not always be a reliable pollen producer, and this has probably been a restriction to the wide use of three-way cross. Double-crosses are the most widely used commercial hybrids. They are usually formed as a cross between two single-crosses that involve a combination of similar or related inbred lines in the single-cross and different or distantly related inbred lines in the double-cross. Their main advantage is that seed parents give high yields without any increase in the cost of production. They can therefore be produced in large quantities thus meeting farmer's seed demand at a reasonable price. They have wide variability which, though often viewed as a disadvantage by some breeders has an advantage in that they give the hybrids wide adaptability compared to the single-crosses (Hallauer and Miranda, 1988, Singh, 1995 and Falconer, 1989). The performance of three-way and double-cross hybrids can be reliably predicted from the performance of single-crosses of the constituent lines provided there is minimum epistatic interaction. The double-cross and three-way cross prediction system is therefore viewed as an important tool that breeders have continually used to develop superior hybrids. This way, enormous time, labor and money is saved from first predicting the hybrid performance of yet untested combinations (Smith *et al.,* 1999).

Lynch *et al.* (1973) compared the performance of single-crosses, three-way and double- cross maize hybrids in Canada. They reported that the average yield of single-crosses was significantly greater than the average yield of the three-way crosses. Weatherspoon (1970) evaluated thirty-six single, three-way and double-crosses involving nine unrelated inbred lines at two environments. He reported that the average grain yield of the single-crosses was greater than that for the three-way crosses and the average grain yield of the three-way crosses was greater than that of double-crosses. Springfield (1950) in a study carried out using all single, three-way and double-crosses from four maize inbred lines reported that the average grain yield of three-way crosses was equal to the average single-cross grain yield. Saleh *et al.* (2002) compared ten single-crosses, four three-way and four double-crosses. They reported that the average performance between single-crosses, double-crosses and three-way crosses did not differ. Pixley and Bjarnason (2002) compared eighteen single-crosses, eighteen three-way crosses and eighteen double-cross hybrids made from nine QPM inbred lines evaluated in thirteen tropical environments. They reported that the mean grain yield of the single-crosses, three-way and double-crosses did not differ. They suggested this was due to lack of heterosis among the single- crosses and that for the three-way and double-crosses a greater likelihood existed of including at least two lines with complementary gene action. Thus contrary to the work of Lynch *et al.* (1973) and others many studies indicate that the grain yield performance of single crosses may not significantly differ from their three-way and four-way crosses.

Correlations among traits

Falconer (1989) defined correlation as the association between any two metric characters whose values are correlated either positively or negatively in the individuals of a population, the main causes of correlation being genetic and environmental sources. There are three types of correlation: namely phenotypic correlation which is the directly observable correlation between two characters and it includes both the genetic and environmental effects, genetic correlation that is due to the pleiotropic gene action and lastly the environmental correlation entirely due to the environment (Falconer, 1989; Hallauer and Miranda, 1988; Singh, 1995). The matching of crop development to the environment and more especially to the pattern of rainfall is perhaps the single most important goal for successful breeding in rain-fed environments (Edmeades *et al.,* 1997). For instance a high yielding genotype will have limited use in the semi arid areas of Kenya if it is late maturing and has a larger anthesis-silking interval. An ideal genotype for this area should be early maturing since earliness allows the crop to avoid terminal drought and may also allow the crop to avoid coincidence between flowering and the dry spell. It is only natural therefore that attention should be given to associations among traits during selection and testing of genotype (Hallauer and Miranda, 1988).

In any breeding program grain yield is regarded as the primary character with the main breeding objective in all crops being high yields. But direct selection for yield is not sufficiently effective due to its low heritability and therefore the use of secondary traits such as maturity, stalk quality, resistance to pests and diseases, and so on, as indirect selection criteria for higher yields has often been suggested. Correlation analysis has therefore been used as one of the tools in determining the value of secondary traits in relation to grain yield (Hallauer and Miranda, 1988; Singh, 1995; Edmeades *et al.,* 1997). Various studies and analysis on correlation have been successful in determining the usefulness of secondary traits. Edmeades *et al.* (1997) conducted a correlation analysis to determine the value of secondary traits in selecting for drought tolerance in tropical maize. They found a strong correlation (0.5-0.9) between grain yield and ears per pant, time to silk, and anthesis-silking interval suggesting that selecting for a combination of these traits with grain yield should result in faster improvement in yield and yield stability under drought compared to selection for grain yield alone. In a correlation analysis to determine traits indicative of improved performance under drought, Manda and Mwambula (1999) reported that anthesis-silking interval and ears per plant were the only secondary traits that significantly correlated to grain yield. Negative correlation between anthesis-silking interval and grain yield was observed indicating that grain yield increased as anthesis-silking interval of genotypes became shorter. San Vicente *et al.* (1997) found that grain yield correlated negatively with anthesis-silking interval and ear aspect and positively with ears per plant indicating that increase in grain yield under drought condition was associated with a reduction in anthesis- silking interval, a better ear aspect and increase in the number of ears per plant.

CHAPTER THREE

MATERIALS AND METHODS

Germplasm

Fourteen inbred lines (Table 1) extracted from Pool15-QPM-SR at the S_4 generation were used in this study. The fourteen inbred lines were crossed in a diallel mating design. A total of 91 F_1 crosses were generated from crossing the inbred lines, 18 experimental checks and one reference check were planted in one trial. The reference check used in this study is a popular QPM single-cross hybrid (CML144xCML159) used by several maize breeding programs in Eastern and Southern Africa as a single-cross parent in three-way QPM hybrids (see paragraph 1, page 7). The experimental checks were single-crosses between some of the fourteen QPM inbred lines used in this study

Table 1: Inbred lines used in making diallel crosses

Inbred Line	Pedigree	Inbred Line	Pedigree
1	Pool15QPMFS440-B-5-B-B	8	Pool15QPMFS788-B-3-B-B
2	Pool15QPMFS461-B-7-B-B	9	Pool15QPMFS478-B-3-B-B
3	Pool15QPMFS51-B-3-B-B	10	Pool15QPMFS594-B-1-B-B
4	Pool15QPMFS538-B-3-B-B	11	Pool15QPMFS80-B-2-B-B
5	Pool15QPMFS761-B-2-B-B	12	Pool15QPMFS319-B-2-B-B
6	Pool15QPMFS462-B-4-B-B	13	Pool15QPMFS593-B-1-B-B
7	Pool15QPMFS309-B-1-B-B	14	Pool15QPMFS324-B-3-B-B

Source: A.O. Diallo (personal communication)

Table 2: Eighteen experimental checks used in the study

Cross	Check	Cross	Check
2xA	Pool15QPMFS461-B-7-B-B x CML144	7xB	Pool15QPMFS309-B-1-B-B x CML159
2xB	Pool15QPMFS461-B-7-B-B x CML159	8xA	Pool15QPMFS788-B-3-B-B x CML144
3xA	Pool15QPMFS51-B-3-B-B x CML144	8xB	Pool15QPMFS788-B-3-B-B x CML159
3xB	Pool15QPMFS51-B-3-B-B xCML159	13xA	Pool15QPMFS593-B-1-B-B x CML144
4xA	Pool15QPMFS538-B-3-B-B x CML144	13xB	Pool15QPMFS593-B-1-B-B x CML159
4xB	Pool15QPMFS538-B-3-B-B x CML159	1xB	Pool15QPMFS440-B-5-B-B x CML159
6xA	Pool15QPMFS462-B-4-B-B x CML144	5xB	Pool15QPMFS761-B-2-B-B x CML159
6xB	Pool15QPMFS462-B-4-B-B x CML159	11xB	Pool15QPMFS80-B-2-B-B x CML159
7xA	Pool15QPMFS309-B-1-B-B x CML144	10xB	Pool15QPMFS594-B-1-B-B x CML159

Source: A.O. Diallo (personal communication) and either CML 144 or CML 159 (Table 2). Line CML 144 belongs to heterotic group A, has flint texture, with 10.5% protein and 1.02% tryptophan in the grain. Line CML 159 belongs to heterotic group B, has dent texture, with 8.4% protein and 1.0% tryptophan in the grain. In this study CML144 was referred to as inbred line A while CML 159 was referred to as inbred line B (See Table 2).

Diallel crossing

Diallel crosses were made among the fourteen inbred lines in the 2005 crop season (September to December) at Kiboko in a half-diallel mating system. The experimental plots were 4 m long, with a spacing of 75 cm between rows and 20 cm between plants. Plots were planted with 2 seeds per hill and later thinned to one plant per hill. During planting, Diammonium Phosphate (DAP) was applied at a rate of 200 kg per ha. For control of cut worms and other soil borne diseases, furadan was applied at a rate of 0.5 g per hill. Six weeks after planting Calcium Ammonium Nitrate (CAN) was top dressed at a rate of 200 kg per ha. Maize stalk borer was effectively controlled using a synthetic pyrethroid. Weeds were controlled by hand weeding. Prior to initiation of flowering the inbred lines were checked daily for signs of ear shoot emergence and pollen shed. Before the silks emerged, the ear shoot on the plant to be pollinated (female plant) was covered with a semitransparent shoot bag to avoid unwanted pollination. Inbred lines to be used as pollen sources (male parent) were covered with tassel bag to prevent foreign pollen from landing on the anthers the night before pollen was required. On the day of pollination the pollen was bulked and used to pollinate the female parent. Pollination of each ear was carried out rapidly and carefully to avoid contamination from undesirable pollen. Each inbred line was crossed with the other and a reciprocal cross was also made. The pollinated ears were covered with tassel bags until harvest. Harvesting was done by hand. At harvest, selection was done for the best ears with viable seeds and showing no signs of ear rots. Ears from each cross and the reciprocal cross were bulked to form one set of hybrids since it was assumed that there were no maternal effects (A.O. Diallo, Personal communication). With 14 parents, 91 single-cross hybrids were produced as $n (n - 1)/2 = 91$ where n=number of parents. This is method 4 of Griffing (1956), whereby only the F_1 hybrids are produced and evaluated. Immediately after harvest the cobs were shelled, cleaned and seed sun dried to constant moisture.

Sites and environments

The trials were planted at three sites namely Embu, Kakamega and Kiboko (Table 3). Kiboko is at a lower elevation and receives half or less than half the amount of rainfall as the other two sites. The hybrids were evaluated in the 2006 long rains season (March to August) under two growing conditions:

1) Optimum condition
2) Managed drought stress condition.

Table 3: Characteristics of the sites used to evaluate hybrids

Site				Rainfall	Temperature (°c)		Soil
	Longitude	Latitude	Elevation	(mm)	Min	Max	Texture
Kiboko	37°75^{1}E	2°15^{1}S	975	530	14.3	35.1	Sandy clay
Embu	37°42^{1}E	0°449^{1}S	1510	1200	14.1	25.0	Clay loam
Kakamega	34°45^{1}E	0°16^{1}N	1585	1916	12.8	28.6	Sandy loam

Two trials under optimum conditions were grown at Kiboko and one each at Embu and Kakamega. One trial was planted under drought conditions at Kiboko.

Experimental design, field and stress management

The 91 F_1 diallel hybrids, 18 experimental checks and one reference check giving a total of 110 entries (F_1 hybrids) were planted in one trial in a 10 x 11 alpha lattice design (Patterson and William, 1976) with two replications. The trials were evaluated in five environments (see sites and environments page 21). Under optimum conditions, spacing and standard agronomic practices (see page 20 under Diallel crossing) were followed. The drought trial was grown during rain-free period and irrigation was applied at the beginning of the growing season to establish a good plant stand. Two weeks before silking to the end of the flowering period, irrigation was withheld so that the crop suffered drought stress during flowering. To ensure that the small amount of grain formed filled adequately, additional irrigation was necessary and this was calculated using application of irrigation after flowering stress guidelines given by Banziger *et al.* (2000). For this trial, average anthesis-silking interval was 5 days and therefore additional irrigation was administered two weeks after the last male flowering. During harvest, the ears from plants at each side of the plot were discarded because these plants were differentially stressed as a result of more accessibility to water in the alley and less competition. Spacing, fertilizer application, weeding and control of maize stalk borer were as under optimum condition.

Standard field measurements

Data were recorded in each plot on the following traits: anthesis date (number of the days from planting until 50% of the plants shed pollen), silking date (number of days from planting until 50% of the plants flower), anthesis-silking interval (ASI) was calculated as the difference in days between the days to pollen shed and days to silking), number of ears per plant (number of ears with at least one fully developed grain divided by number of harvested plants, root lodging (percent plants leaning at an angle greater than 45^0 from the vertical), stalk lodging (percent plants with broken stalks at or below the main ear at maturity), ears were visually rated for ear rots on a scale of 1 (no visual presence of ear rots) to 5 (most of the ears with ear rots present), ear aspect was visually rated from 1 (good, large ears with well filled kernels, no cracks and vitreous appearance) to 5 (poor, small ears with poorly filled kernels and opaque appearance), grain moisture (g kg^{-1} moisture of grain at harvest, measured using a moisture meter), grain weight (g, measured for the number of ears harvested using a weighing scale) and grain yield (shelled grain weight per plot adjusted to 12.5% grain moisture and converted to tons per hectare) calculated as:

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

Statistical analyses

Individual analyses of variance per environment and across environments were conducted using PROC GLM of SAS (2003) and where hybrids were considered fixed effects and environments and replications random effects. The hybrids source of variation was partitioned into variation due to Diallel hybrids and due to Experimental checks. A contrast between diallel hybrids and experimental checks was carried out. Diallel analysis was done using the DIALLEL-SAS program (Zhang and Kang, 1997) according to the following linear model for individual environments (Hallauer and Miranda, 1988):

$$Xijk = \mu + rk + gi + gj + sij + pijk$$

where $Xijk$ = is the performance of the cross between i^{th} and j^{th} genotypes in the k^{th} replicate;

μ = the population mean;

rk = the replication effect;

gi = the GCA effect for the i^{th} parent;

gj = the GCA effect for the j^{th} parent;

sij = the SCA effect for the cross between i^{th} and j^{th} parents;

$pijk$ = experimental error for the $Xijk$ observation ($k = 1, 2, \dots, r$; $I = j = 1, 2, \dots, n$).

The analysis of variance and expected mean square took the form presented in Table 4.

General combining ability (GCA) effects of the parents and specific combining

Table 4: Diallel analysis of variance for a fixed model

Source	df†	SS	MS	Expected mean square
Replication	r-1			
Crosses	[n(n-1)/2] -1	SS2	M2	σ2 +rk2c
GCA	n-1	SS21	M21	σ2+(n-2)/(n-1)]k2GCA
SCA	n(n-3)/2	SS22	M22	σ2+2r/[n(n-3)] k2SCA
Error	(r-1) {[n(n-1)/2] -1}	SS1	M1	σ2

† r and n and refer to number of replications and parents, respectively.

ability (SCA) effects of the crosses as well as their mean squares at each environment and across environments were estimated following Griffing's method 4 model 1 diallel analysis (Griffing, 1956). The relative importance of GCA to SCA was estimated according to Baker (1978) as the ratio $2\sigma^2$GCA/ ($2\sigma^2$GCA + σ^2SCA) where $2\sigma^2$GCA and σ^2SCA are the variance components for GCA and SCA, respectively.

The performance of the three-way cross (A x B) x P was predicted from the mean performance of the non-parental crosses as 0.5[(A x P) + (B x P)], where, A and B are the parents of the single-cross parent of the three-way cross (Fehr, 1993). The performance of double-cross (A x B) (P x Q) was predicted from the performance of the non-parental crosses (A x P), (A x Q), (B x P) and (B x Q) as 0.25[(A x P) + (A x Q) + (B x P) + (B x Q)] (Fehr, 1993).

Simple linear phenotypic correlations were computed between traits using SAS (2001).

CHAPTER FOUR

RESULTS AND DISCUSSION

Mean performance of F_1 hybrids

Mean grain yield and agronomic traits for the 110 F_1 hybrids across environments and per environment are presented in appendix tables A to F whereas mean performance of the best twenty diallel and seven experimental checks inclusive of the QPM reference check (CML144/CML159) for grain yield (per environment and across optimum environments) and one drought environment and other agronomic traits are presented in (Table 5). Mean grain yield for the hybrids was highest at Embu (5.40 tons/ha) and lowest at Kakamega (1.35 tons/ha). The same trend was observed for diallel hybrids and experimental checks; thus Embu was the highest yielding environment and Kakamega was the lowest yielding environment. The higher yields at Embu could have been attributed to reduced average anthesis-silking interval, low percentage of root and stalk lodging and reduced ear rots (Appendix B) compared to Kakamega (Appendix C) where these traits were higher and hence adversely reduced the grain yields. The highest and lowest yielding diallel hybrid and experimental check at each environment were entry 43 (8.48 tons/ha) and 53 (7.16 tons/ha) at Embu, entry 43 (3.48 tons/ha) and 52 (5.35 tons/ha) at Kakamega, entry 44 (4.08 tons/ha) and 53 (4.17 tons/ha) at Kiboko-1 and entry 3 (4.81 tons/ha) and 73 (5.25 tons/ha) at Kiboko-2, respectively. Mean grain yield across environments for the hybrids was 3.39 tons/ha (ranging from 2.33 to 5.22 tons/ha). The experimental checks with a mean grain yield of 4.12 tons/ha significantly out yielded the diallel hybrids by 21%. Mean grain yield for the QPM reference check across environments was 4.40 tons/ha. The highest yielding diallel hybrid across environments

Table 5: Average performance of the best twenty diallel hybrids, best six experimental checks and one reference check (CML144/CML159) for grain yield (per environment and across optimum environments) and one drought environment and other agronomic traits evaluated in 2006†

		Grain yield						Agronomic traits						
		Optimum					DTR							
Cross	Entry	EMB	KAK	KIB-1	KIB-2	Across	KIB-3	AD	ASI	EPP	RL	SL	ER	EA
		tons/ha						d	d	#	%	%	%	Sc-1-5
Diallel hybrids														
1X4	3	7.50	2.67	3.89	4.81	4.72	1.57	70.54	0.53	0.80	5.76	8.24	14.60	1.88
4X6	43	8.48	3.48	2.90	3.58	4.61	1.53	69.05	3.76	0.76	8.71	1.50	9.60	1.94
4X8	45	8.09	2.07	3.68	4.07	4.48	1.03	70.37	5.80	0.80	15.48	5.03	14.69	1.88
4X11	48	5.43	3.09	3.97	4.20	4.17	1.22	69.23	1.60	0.81	4.62	2.84	11.61	1.80
3X4	29	6.47	2.52	3.16	3.97	4.03	0.51	69.09	4.01	0.71	5.79	8.05	13.25	1.67
2X4	16	6.86	2.91	3.11	3.22	4.02	1.32	68.88	4.14	0.79	5.85	3.97	0.58	1.45
4X7	44	5.89	2.17	4.08	3.67	3.95	1.16	69.01	2.80	0.81	8.12	5.83	6.82	1.92
4X12	49	7.14	2.03	3.83	2.77	3.94	1.06	66.63	4.85	0.75	6.90	9.91	11.54	2.08
4X9	46	6.76	1.05	2.98	4.47	3.81	0.80	67.00	2.37	0.72	4.94	10.49	9.01	2.09
4X14	51	6.47	2.12	2.96	3.38	3.73	0.89	69.60	5.86	0.83	6.46	3.99	7.73	2.18
7X10	76	6.08	0.95	3.83	3.93	3.70	1.28	66.73	2.90	0.72	7.25	19.50	14.68	2.20
4X13	50	7.01	2.27	3.27	2.16	3.68	0.62	69.68	6.48	0.71	13.78	1.66	14.82	2.26
1X14	13	5.90	1.10	2.39	5.26	3.66	1.03	68.54	2.80	0.76	11.05	9.04	12.16	2.72
1X2	1	5.04	1.92	3.32	4.35	3.66	0.99	69.39	1.79	0.84	1.78	7.93	14.26	2.45
1X7	6	6.18	0.89	2.88	4.58	3.63	0.66	67.24	3.42	0.77	13.65	15.88	11.74	2.42
1X8	7	5.41	0.79	3.54	4.78	3.63	0.92	70.32	2.65	0.70	6.90	7.01	23.65	2.23
4X5	42	6.41	1.96	2.45	3.65	3.62	1.09	68.47	5.31	0.76	4.67	2.63	11.62	2.13
8X11	85	7.09	1.43	3.25	2.59	3.59	1.68	69.91	3.99	0.75	10.96	3.31	12.13	2.28
2X11	23	5.74	1.87	3.16	3.59	3.59	1.57	67.03	3.58	0.78	2.94	5.89	9.91	1.70
7X12	78	5.57	0.71	3.37	4.61	3.56	1.31	64.86	2.59	0.73	10.76	16.61	11.83	2.31
Experimental checks														
4XA	52	6.81	5.35	3.61	5.11	5.22	1.18	74.26	0.35	0.86	2.24	3.57	6.61	1.93
4XB	53	7.16	4.12	4.17	4.72	5.04	0.71	71.26	5.98	0.77	5.73	4.17	9.89	2.45
2XA	27	6.53	4.99	3.89	4.71	5.03	0.60	73.02	1.68	0.84	1.72	5.19	9.09	1.30
6XB	73	6.77	2.85	4.00	5.25	4.72	0.83	69.92	2.12	0.79	4.66	5.19	12.06	2.17
6XA	72	8.13	2.96	3.07	4.23	4.60	1.22	67.48	2.06	0.81	2.07	8.74	9.21	2.07
7XA	81	6.75	2.97	3.55	4.29	4.39	1.07	71.42	2.23	0.88	3.82	12.35	15.00	2.34
AXB	110*	5.76	3.37	3.41	5.06	4.40	0.07	73.55	2.52	0.76	9.16	4.28	11.91	2.20
Hybrids mean		**5.40**	**1.35**	**3.02**	**3.81**	**3.39**	**0.99**	**67.84**	**3.77**	**0.73**	**7.11**	**9.96**	**17.28**	**2.33**
Diallel HYB mean		**5.28**	**1.09**	**2.94**	**3.67**	**3.24**	**1.01**	**67.69**	**3.31**	**0.86**	**2.83**	**4.76**	**9.83**	**2.39**
Exp HYB mean		**6.00**	**2.57**	**3.42**	**4.48**	**4.12**	**0.91**	**71.39**	**2.09**	**0.94**	**3.32**	**3.46**	**9.83**	**2.36**
LSD (0.05)		**1.64**	**0.92**	**1.00**	**1.59**	**0.66**	**0.96**	**1.62**	**2.60**	**0.12**	**7.81**	**13.39**	**18.55**	**0.52**
Min		**3.34**	**0.20**	**1.95**	**2.10**	**2.33**	**0.07**	**62.90**	**0.35**	**0.52**	**1.17**	**0.86**	**0.58**	**1.30**
Max		**8.48**	**5.35**	**4.36**	**6.43**	**5.22**	**1.80**	**74.50**	**8.49**	**0.88**	**20.04**	**58.44**	**63.99**	**3.38**

*Reference check (CML144/CML159)

†EMB, Embu; KAK, Kakamega; KIB, Kiboko; DTR, drought; EXP, experimental; HYB, hybrids. AD, anthesis date; ASI, anthesis-silking interval; EA, ear aspect; EPP, ears per plant; ER, ear rots; RL, root lodging; SL, stalk lodging

was entry 3 with grain yields of 4.72 tons/ha. Entry 52 (5.22 ton/ha) was the highest yielding experimental check and was statistically better than the reference check by 19%. Apart from entry 3, two other diallel hybrids, entries 43 and 45 out-yielded the reference check by 5% and 2% respectively. Entry 52 was the only experimental check that significantly out-yielded the reference check. Grain yields of the resulting single-crosses from either CML144 or CML159 and the diallel parents yielded higher than when the single-cross was made up of the diallel parents alone. For instance the best three diallel hybrids and the best two experimental checks had Line 4 as a common parent yet the experimental checks out-yielded the diallel hybrids. The ability of the experimental checks to yield more than the diallel hybrids suggests existence of heterosis between the diallel parents and the parents of the reference check and lack of the same between the diallel parents. The heterosis observed between the diallel parents and parents of the reference check could also be investigated for further breeding work. It was noted that Line 4 was used as a parent in twelve crosses among the selected diallel hybrids and the best two experimental checks had Line 4 as a common parent suggesting good general combining ability for this line compared to the other lines.

Grain yield among the entries was not statistically different under drought conditions. Mean grain yield for the hybrids was 0.99 tons/ha and ranging from 1.8 tons/ha to 0.07 tons/ha (Table 5). The diallel hybrids with a grain yield of 1.01 tons/ha out-yielded the experimental checks by 100 kg/ha, which was not significant ($P<0.05$). The diallel hybrids performed remarkably better than the experimental check and could possess drought tolerant alleles which should be investigated for further breeding work. This also confirms that progress has been made towards drought tolerance in the diallel hybrids compared to the checks. Grain yield for the hybrids under drought was 29% that of across mean grain yield under optimum conditions. For the diallel hybrids and experimental checks it was 31% and 22% respectively. Such levels of reductions due to intensity of drought stress fall within those observed by several workers. Edmeades *et al.* (1997) reported grain yield reduction of 32% among tropical maize hybrids. Bolaños and Edmeades (1997) reported that drought treatments reduced grain yield by 24% that of well watered treatments among $S_{2,3}$ progenies while Betrán *et al.* (1997) reported that severe drought reduced grain yields by between 33% and 34% of well watered conditions among tropical top crosses. The performance of the reference check was quite disappointing as it had the lowest grain yield of 0.07 tons/ha among the hybrids. This may be attributed to longer period of anthesis date compared to the other hybrids. The highest yielding hybrid in the diallel cross under optimum conditions also performed well under drought conditions with a mean grain yield of 1.57 tons/ha. The earliest diallel hybrid, entry 78, among those selected had a mean grain yield of 1.31 tons/ha out-yielding the reference check by 1.24 tons/ha. Perhaps the early maturity of this particular hybrid allowed it to escape some consequences of water stress. Other early maturing (67 d) entries that were statistically better than the reference check were 49, 76, 23 and 72. Mean anthesis date for the hybrids across environments was 68 days (ranging from 63 to 75 d). The diallel hybrids flowered earlier than the experimental checks by 3 days (68 vs 71 d). Mean anthesis date for the reference check was 74 days. All the selected diallel hybrids and experimental checks were found to significantly flower earlier than the reference check except for two experimental checks entries 52 and 27. Mean anthesis-silking interval for the experimental hybrids was 3.8 d (range 0.4 to 8.5 d). Mean anthesis-silking interval for the diallel hybrids was slightly longer by one day (3.3 d) than for the experimental checks (2.1d); this extra day was not significant ($P<0.05$). Among the selected diallel and experimental checks, the highest yielding hybrids had the shortest silking interval of 0.5 d and 0.4 d respectively. This suggested that proper synchronization of the male and female flowering compared to the other hybrids contributed to superior grain yields for these two hybrids. Eighty percent of the selected diallel hybrids and all the selected experimental checks, except for entry 53, had anthesis-silking interval not statistically different from the reference check (2.5 d). It was observed that diallel hybrid entry 3 and experimental hybrid entry 72 had higher grain yields both under optimum and drought conditions, reduced anthesis date and a shorter anthesis-silking interval than the reference check and are therefore worthy for improvement to be released in the mid-altitude eco-zone. Mean ears per plant (EPP) for the F_1 hybrids was 0.7 EPP. Mean ears per plant for the experimental checks was slightly higher (0.94 EPP) than for the diallel hybrids (0.86 EPP). All the selected F_1 hybrids had ears per plant not statistically different from the reference check (0.76 EPP). The same trend was observed for stalk lodging and ear rots except for diallel hybrid entry 76 which was statistically worse off than the reference check for root lodging. One diallel hybrid entry 1 and three experimental checks entries 52, 27 and 72 had their stalk lodging statistically better than for the reference check. Two diallel hybrids entries 29 and 16 and one experimental check entry 27 had their ear aspect scores statistically better than the reference check.

Analysis of variance among F_1 hybrids per environment

Mean squares due to hybrids were highly significant ($P<0.001$) for grain yield, anthesis date, root lodging and ear aspect and significant ($P<0.05$) for ears per plant and ear rots at Embu (Table 6). The single degree of freedom contrast (diallel hybrids vs. experimental checks) was highly significant ($P<0.01$) for grain yield, anthesis date, anthesis-silking interval, ears per plant and root lodging. Significant differences observed among hybrids and the contrast (diallel hybrids vs. experimental checks) indicated that there was variation between diallel hybrids and experimental checks for the traits mentioned. Partition of hybrids into sources due to diallel hybrids and experimental checks revealed significant ($P<0.05$) differences between diallel hybrids for grain yield, anthesis date, anthesis-silking interval and ear aspect whereas among the experimental checks significant differences were observed for grain yield and root lodging. Significant source of variation among experimental checks suggests inconsistency in performance among the checks. Significant source of variation among diallel hybrids suggests significant variation among GCA effects among the diallel hybrids. Partition of diallel hybrids into genetic components revealed highly significant ($P<0.01$) GCA variance for grain yield, anthesis date, anthesis-silking interval, ears per plant, ear rots and ear aspect and significant ($P<0.05$) for root lodging suggesting the importance of additive gene effects for these traits in these materials. Specific combining ability was not significant for all traits implying that non additive effects were less important than additive effects for all traits studied except for root lodging where none of them was important. Specific combining ability mean squares were consistently smaller that GCA means squares for all the traits.

There were highly significant differences ($P<0.01$) among hybrids for grain yield, anthesis date, ears per plant and root lodging at Kakamega (Table 7). In addition signifi-

Table 6: Analysis of variance and means for grain yield and other agronomic traits of 110 QPM F_1 hybrids at Embu in 2006†

Source of variation	df	Mean squares							
		GY *tons/ha*	AD *d*	ASI *d*	EPP *#*	RL *%*	SL *%*	ER *%*	EA *score 1-5*
Reps	1	12.73**	0.07	0.65	0.03*	0.34	3.46	1632.00***	8.21***
Hybrids	109	2.31***	16.33***	4.40	0.01*	31.11***	33.04	153.723*	0.45***
Diallel hybrids	90	2.20**	8.94***	2.97*	0.10	4.15	26.52	139.76	0.46***
GCA	13	9.49***	45.26***	9.14***	0.01**	7.11*	44.65	432.63***	1.71***
SCA	77	0.97	2.81	1.93	0.01	3.65	23.45	90.32	0.25
Exp checks	18	2.07*	17.83	9.46	0.01	153.83*	63.15	214.30	0.44
Diallel hybrids vs Exp checks	1	16.30***	653.80***	41.27**	0.07***	248.70***	78.34	320.00	0.43
Error	109	1.12	5.48	0.65	0.01	11.80	33.87	108.20	0.23

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

† AD, anthesis date; ASI, anthesis-silking interval; EA, ear aspect; EPP, ears per plant; ER, ear rots; GCA, general combining ability; GY, grain yield; RL, root lodging; SCA, specific combining ability; SL, stalk lodging

Table 7: Analysis of variance and means for grain yield and other agronomic traits of 110 F_1 QPM hybrids at Kakamega in 2006†

Source of variation	df	Mean squares							
		GY *tons/ha*	AD *d*	ASI *d*	EPP *#*	RL *%*	SL *%*	ER *%*	EA *Score 1-5*
Rep	1	3.28***	39.31***	36.82	0.00	979.88**	0.54	3603.34***	15.43***
Hybrids	109	1.87***	6.74***	14.68	0.12***	161.10**	745.66*	403.56*	0.36*
Diallel hybrids	90	0.87***	6.15**	14.43	0.10*	177.79**	846.86*	397.97	0.29
GCA	13	4.60***	21.32***	46.80***	0.37***	372.50***	2191.47***	1033.44***	0.65***
SCA	77	0.24*	3.59	8.96	0.52	144.91	619.85	289.96	0.23
Exp checks	18	3.14***	2.73	10.08***	0.07	81.82	208.79***	421.39*	0.52
Diallel hybrids vs Exp checks	1	68.96***	132.56***	120.14**	2.62***	85.74	1300.92	571.98	3.59***
Error	109	0.22	3.12	12.84	0.06	101.67	477.89	277.57	0.24

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

† AD, anthesis date; ASI, anthesis-silking interval; EA, ear aspect; EPP, ears per plant; ER, ear rots; GCA, general combining ability; GY, grain yield; RL, root lodging; SCA, specific combining ability; SL, stalk lodging

Table 8: Analysis of variance and means for grain yield and other agronomic traits of 110 F_1 QPM hybrids at Kiboko-1 in 2006†

Source of variation	**df**	**Mean squares**							
		GY *tons/ha*	**AD** *d*	**ASI** *d*	**EPP** *#*	**RL** *%*	**SL** *%*	**ER** *%*	**EA** *Score 1-5*
Rep	1	4.14**	26.95***	22.91*	0.02	3.98	5.01	1.42	2.62**
Hybrids	109	0.60**	13.99***	6.27**	0.01***	1.91	119.03**	4.12	0.53***
Diallel hybrids	90	0.50*	7.26***	5.54	0.02	2.39**	0.13	3.73	0.43*
GCA	13	0.88**	36.38***	15.43**	0.03***	2.27	353.06***	6.19*	1.06***
SCA	77	0.43	2.35*	3.87	0.01*	1.73	74.85	3.32	0.33
Exp checks	18	0.77	17.17***	7.14	0.02	2.47	145.46*	6.27	0.93**
Diallel hybrids vs Exp checks	1	7.26***	562.31***	56.58***	0.00	1.03	2.50	0.01	2.12**
Error	109	0.37	1.78	4.01	0.01	2.21	68.80	0.37	0.29

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

† AD, anthesis date; ASI, anthesis-silking interval; EA, ear aspect; EPP, ears per plant; ER, ear rots; GCA, general combining ability; GY, grain yield; RL, root lodging; SCA, specific combining ability; SL, stalk lodging

Table 9: Analysis of variance and means for grain yield and other agronomic traits of 110 F_1 QPM hybrids Kiboko-2 in 2006†

Source of variation	**df**	**Mean squares**							
		GY *tons/ha*	**AD** *d*	**ASI** *d*	**EPP** *#*	**RL** *%*	**SL** *%*	**ER** *%*	**EA** *Score 1-5*
Rep	1	95.41***	5.89	140.80***	0.08*	4.65	0.13	4.23	13.75***
Hybrids	109	1.34	24.81*	8.27***	0.02	2.39**	0.13	44.24	0.42
Diallel hybrids	90	1.06	19.19	8.48***	0.02	1.47	0.15	44.56	0.44
GCA	13	1.90	23.90	31.41***	0.05*	2.18	0.15	114.06**	0.37
SCA	77	0.91	18.40	4.61	0.02	1.36	0.15	32.83	0.45
Exp checks	18	1.70	26.63**	7.34	0.02	6.48**	0.00	43.26	0.32
Diallel hybrids vs Exp checks	1	20.58***	497.33***	6.58	0.08*	11.66**	0.03	33.05	0.06
Error	109	1.24	16.43	3.58	0.02	1.53	0.13	44.8	0.41

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

† AD, anthesis date; ASI, anthesis-silking interval; EA, ear aspect; EPP, ears per plant; ER, ear rots; GCA, general combining ability; GY, grain yield; RL, root lodging; SCA, specific combining ability; SL, stalk lodging

cant differences ($P<0.05$) were observed for stalk lodging, ear rots and ear aspect. The single degree of freedom, diallel hybrids vs experimental checks contrast, was significant for grain yield, anthesis date, anthesis-silking interval, ears per plant and ear aspect. Significant hybrid and contrast sources of variation suggested differences in performance between the diallel hybrids and experimental checks in these materials. Variation among hybrids due to experimental checks was highly significant ($P<0.001$) for grain yield, anthesis-silking interval and stalk lodging and significant ($P<0.05$) for ear rots suggesting differences in performance for these traits. Variation among diallel hybrids was significant ($P<0.05$) for ears per plant and stalk lodging and highly significant ($P<0.001$) for grain yield, anthesis date and root lodging. Significant diallel hybrid source of variation indicates presence of significant variation among GCA effects within the diallel hybrids. Partition of diallel hybrids into genetic components revealed highly significant ($P<0.001$) GCA mean squares for all traits at Kakamega (Table 7). Specific combining ability mean squares were only significant for grain yield ($p<0.05$). This implied that additive gene action was more important than non additive gene action for the traits studied, except for grain yield where both were important. Specific combining ability mean squares were consistently smaller that GCA means squares.

There were highly significant differences ($P<0.01$) among hybrids for all hybrids for all traits except for root lodging and ear rots at Kiboko-1 (Table 8) suggesting sources of variation between the diallel hybrids and the experimental checks fo r grain yield, anthesis date, anthesis-silking interval, ears per plant, stalk lodging and ear aspect existed. The contrast between the diallel hybrids and the experimental checks was highly significant ($P<0.01$) for grain yield, anthesis date, anthesis-silking interval and ear aspect and this meant that there were differences in performance between the diallel hybrids and the experimental checks for these traits. Variation among hybrids due to diallel hybrids was significant ($P<0.05$) for grain yield and ear aspect and highly significant ($P<0.01$) for anthesis date and root lodging. In addition variation due to experimental checks was highly significant ($P<0.01$) for anthesis date and ear aspect and significant ($P<0.05$) for stalk lodging only. Significant differences among experimental checks implied differences in performance between the checks. Significant differences among diallel hybrids suggested existence of significant variation among GCA effects within the diallel hybrids. Genetic variation among diallel hybrids revealed highly significant ($P<0.01$) GCA mean squares for grain yield, anthesis date, anthesis-silking interval, ears per plant, stalk lodging, and ear aspect and significant ($P<0.05$) for only ear rots at Kiboko-1 (Table 8). This meant that additive gene action was presence in these traits except for root lodging. Specific combing ability was significant ($P<0.05$) for only anthesis date and ears per plant suggesting the presence of non additive gene action for these traits. Specific combining ability mean squares were consistently smaller that GCA means squares for all the traits.

No significant differences were observed among hybrids for all traits studied except for anthesis date, anthesis-silking interval and root lodging at Kiboko-2 (Table 9). The significant differences observed among hybrids showed that there was variation between the diallel hybrids and the experimental checks in these materials. The single degree of freedom contrast (diallel hybrids vs Experimental checks) was highly significant ($P<0.01$) for grain yield, anthesis date and root lodging and significant ($P<0.05$ for ears per plant, meaning that there were differences in performance between the diallel hybrids and the experimental checks for these traits. Partitioning of hybrid source of variation into sources due to diallel hybrids and experimental checks revealed highly significant differences (P<0.01) among experimental checks for only anthesis date and for root lodging. The non significant differences observed for grain yield and other agronomic traits implied consistency in performance among the checks. Highly significant differences (P<0.001) due to diallel hybrids was observed for only anthesis-silking interval. Non significant differences suggested no variation among GCA effects within the diallel parents. Combining ability analysis for the diallel hybrids revealed highly significant (P<0.01) GCA mean squares for anthesis date and ear rots and significant (P<0.05) for ears per plant. Specific combining ability mean squares were not significant for all traits. Thus additive effects were more important for anthesis date, ear rots and ears per plant whereas both additive and non additive effects were less important for the other traits.

Variance due to hybrids was not significant for all traits studied at Kiboko-3 (Table 10) except for anthesis date suggesting that there was no useful variation between diallel hybrids and experimental checks for grain yield and other agronomic traits except for anthesis date. No significant differences were observed for the contrast between the diallel hybrids and the experimental checks suggesting that the diallel hybrids and experimental checks were equal in performance for all traits. Perhaps the severe drought stress experienced reduced the variability to non significant levels. Variation among experimental checks was highly significant (P<0.001) for anthesis date only. The same observation was recorded for the diallel hybrids. This showed that the performance of the checks was consistent for all traits studied except for anthesis date where inconsistency in

Table 10: Analysis of variance and means for grain yield and other agronomic traits of 110 F_1 QPM hybrids at Kiboko-3 in 2006 †

Source of variation	df	Mean squares						
		GY	AD	EPP	RL	SL	ER	EA
		tons/ha	*d*	*#*	*%*	*%*	*%*	*score 1-5*
Rep	1	4.84**	7.11	0.57*	1005.37**	289.34	1104.74**	0.50
Hybrids	109	0.69	14.58***	0.10	126.55	240.99	113.13	2.30
Diallel hybrids	90	0.70	7.93***	0.10	124.12	224.82	120.97	2.21
GCA	13	0.87	36.64***	0.14	183.35	576.06***	110.98	4.97**
SCA	77	0.67	3.09*	0.09	114.13	165.52	119.44	1.74
Exp checks	18	0.65	15.96***	0.08	137.51	334.77	70.13	2.84
Diallel vs Exp checks	1	0.32	-	0.10	146.92	8.73	171.09	1.40
Error	109	0.69	1.89	0.10	136.35	181.40	129.09	1.93

*, **, ***, Significant at $p< 0.05$, 0.01 and 0.001 respectively

† AD, anthesis date; EA, ear aspect; EPP, ears per plant; ER, ear rots; GCA, general combining ability; GY, grain yield; RL, root lodging; SCA, specific combining ability; SL, stalk lodging

NB: No values for ASI (asthesis-silking interval) most plots did not reach silking date due to severe drought.

performance was observed. Thus useful variation for anthesis date under drought condition for the checks can be obtained from these materials. Significant variation for anthesis date among the diallel hybrids suggested the existence of variation for anthesis date among GCA effects within the diallel parents for anthesis date. Genetic variation among the diallel hybrids revealed highly significant ($P<0.01$) GCA mean squares for anthesis date, stalk lodging and ear aspect at Kiboko-3 (Table 10) implying that additive effects were important for these traits in these materials. Anthesis date was the only trait that showed significant ($P<0.05$) SCA mean squares thus in addition to additive effects, non additive effects were also important for this trait. Both additive and non additive effects were less important for the other traits

Across environment analysis of variance among F_1 hybrids

Analysis of variance across environments was computed for those environments which showed significant mean squares differences among hybrids for grain yield since our main interest was mainly on grain yield. Variation due to environment and hybrids was highly significant ($P<0.001$) for all traits across environments (Table 11). Significant differences observed among the hybrids indicated that differences in performance between the diallel hybrids and the experimental checks across environments, was influenced by the environment in which they were grown. The single degree of freedom contrast for diallel hybrids vs experimental checks was highly significant ($P<0.001$) for grain yield, anthesis date, anthesis-silking interval and ears per plant suggesting dissimilarity in performance between diallel and experimental checks in these materials across environments. Variation within and between QPM cultivars for grain yield and other agronomic traits has been reported elsewhere by several workers. Pixley and Bjarnason (2002) reported significant variation for grain yield between QPM single-crosses. Vasal *et al. (*1993a) and Vasal *et al.* (1993b) observed significant variation among QPM hybrids for grain yield and silking date. 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). Partition of hybrids variation into sources due to diallel hybrids and experimental checks revealed highly significant differences ($P<0.001$) between diallel hybrids for all traits. In addition variance among the experimental checks was highly significant ($P<0.01$) for grain yield, stalk lodging, ear rots and ear aspect and

Table 11: A combined analysis of variance and means for grain yield and agronomic traits of 110 F_1 QPM hybrids across environments in 2006†

Source of variation	df	Mean squares							
		GY	AD	ASI	EPP	RL	SL	ER	EA
		tons/ha	*d*	*d*	*#*	*%*	*%*	*%*	*Score1-5*
Env	2	913.00***	2207.77***	1585.33***	3.64***	6159.53***	3427.26***	23476.86***	12.60***
Rep(Env)	3	6.72***	22.11***	20.13	0.02	328.07***	3.00	1745.59***	8.75***
Hybrids	109	2.82***	27.05***	13.47***	0.05***	70.43***	410.03***	235.93***	0.60***
Diallel Hybrids	90	2.02***	17.01***	12.10***	0.05***	65.56***	460.64***	31.47***	0.56***
GCA	13	10.23***	84.96***	43.10***	0.21***	152.42***	1276.88***	811.711***	2.28***
SCA	77	0.62	4.17**	6.12	0.02	48.35	290.79	140.90	0.27
Exp checks	18	2.75***	10.32	9.54	0.04	97.66*	164.44**	271.21**	0.82**
Diallel hybrids vs Exp checks	1	75.37***	1232.06***	206.78***	0.66***	18.88	276.47	11.72	0.40
Hybrids*Env	218	0.98***	5.01**	5.93	0.04***	61.84***	243.84*	160.82*	0.37***
Diallel Hybrids*Env	180	0.77**	2.67	5.42	0.03**	59.09***	263.88	152.67	0.31*
GCA*Env	26	2.28***	4.16*	11.91*	0.09***	94.81***	487.54**	318.610***	0.55***
SCA*Env	154	0.51	2.29	4.32	0.02	50.97**	213.68	121.35	0.27
Exp checks*Env	36	1.62**	13.7	8.57	0.03	70.23	126.48***	185.38*	0.54*
Diallel vs Exp checks*Env	2	8.58***	58.31***	5.60	1.01***	158.29*	552.65	440.14*	2.87***
Error	327	0.57	3.46	7.54	0.02	38.56	193.52	129.83	0.25
Means for hybrids		3.26	67.62	2.62	0.90	3.78	6.04	11.74	2.33
Means for diallel hybrids		3.10	67.00	2.88	0.89	3.70	6.33	11.80	2.34
Means for Exp checks		4.00	70.61	1.39	0.97	4.15	4.62	11.44	2.28

*, **, ***, Significant at $p < 0.05$, 0.01 and 0.001 respectively

† AD, anthesis date; ASI, anthesis-silking interval; EA, ear aspect; EPP, ears per plant; ER, ear rots; GY, grain yield; RL, root lodging; SL, stalk lodging.

significant ($P<0.05$) for only root lodging. Significant differences experimental checks indicated that performance of the experimental checks was not consistent across environments. Significant diallel hybrids source of variation indicated presence of significant variation among GCA effects within diallel hybrids. Partition of diallel hybrids into genetic components revealed highly significant differences ($P<0.001$) among GCA mean squares across environments for all traits whereas SCA was highly significant ($P<0.01$) for anthesis date only. Thus additive genetic variance was more important than non additive genetic variance in these materials for all traits studied, except for anthesis date, where both were important.

Highly significant ($P<0.01$) genotype x environment source of variance was detected for grain yield, anthesis date, ears per plant, root lodging and ear aspect and significant ($P<0.05$) for stalk lodging and ear aspect meaning that the diallel and experimental checks responded differently over environments for these traits. Significant genotype x environment has been reported from CIMMYT QPM trials conducted in Eastern and Southern Africa among advanced QPM single crosses for grain yield, ears per plant and root and stalk lodging and among tropical hybrids for grain yield ear rots and stalk lodging (CIMMYT, 2003). The interaction between the contrast and environment (Diallel vs experimental checks x Env) was highly significant ($P<0.001$) for grain yield, anthesis date, ears per plant and ear aspect and significant ($P<0.05$) for only root lodging and ear rots, suggesting the differences in performance observed between diallel and experimental checks for these traits, was influenced by the environment in which they were grown. Within the hybrids, variation due to experimental checks x environment was highly significant ($P<0.01$) for grain yield and stalk lodging and significant (P<0.05) for ear rots and ear aspect implying that the experimental checks did not perform consistently across environments for these traits. Diallel hybrids x environment effects were highly significant (P<0.01) for grain yield, ears per plant and root lodging and significant (P<0.05) for ear aspect implying that the environment influenced the performance of the diallel hybrids for these traits. GCA x environment was highly significant (P<0.01) for grain yield, ears per plant, root lodging, stalk lodging, ear rots and ear aspect and significant (P<0.05) for anthesis date and anthesis-silking interval suggesting that the GCA effects associated with parents were not consistent in these materials over environments. The larger value of GCA mean squares compared to the GCA x environment mean squares observed for all the traits suggested that the interaction effects were of minor importance in these materials. SCA x environment was not significant for all traits except for root lodging indicating that the hybrid combinations performed the same across environments except for root lodging where performance was not consistent.

General and specific combining ability effects

The estimates of GCA effects for grain yield varied significantly among lines and between environments. Lines 1 and 4 showed consistently positive GCA effects for grain yield at all environments (Table 12). The exception was at Kiboko-3 where Line 1 had negative but small GCA effects (-0.07 tons/ha). Significant positive GCA effects meant good alleles for grain yield and thus these two lines contributed good alleles for grain yield to their progenies which is desirable and the lines were parents to the highest yielding cross 1x4 (Table 5). Across environments Line 4 had the highest positive highly

Table 12: General combining ability effects (GCA) of fourteen early QPM inbred lines for grain yield (tons/ha) per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
1	0.11	0.19*	0.10	0.58**	-0.07	0.13
2	-0.01	0.32***	-0.05	-0.39	-0.10	0.08
3	-0.72**	-0.16*	-0.01	0.04	-0.02	-0.30
4	1.52***	1.30***	0.43***	0.17	0.10	1.08***
5	-0.48*	0.10	0.00	-0.06	-0.07	-0.13
6	0.93***	0.07	-0.05	-0.49*	0.03	0.32
7	0.08	-0.23**	0.29*	0.34	0.21	0.04
8	0.51*	-0.19*	0.07	-0.10	0.14	0.13
9	-0.80***	-0.45***	-0.26*	-0.03	0.26	-0.50*
10	-0.20	-0.24**	-0.33**	-0.08	-0.07	-0.26
11	-0.24	0.13	-0.06	0.17	0.07	-0.06
12	-0.29	-0.29***	-0.02	-0.19	-0.52**	-0.20
13	-0.35	-0.33***	-0.09	-0.17	0.15	-0.26
14	-0.04	-0.22**	-0.02	0.21	-0.10	-0.09

*, **, ***, Significant at $p < 0.05$, 0.01 and 0.001 respectively

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across Embu, Kakamega and Kiboko-1

Table 13: General combining ability effects (GCA) of fourteen early QPM inbred lines for anthesis date (d) per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
1	1.57***	1.39***	1.95***	0.15	1.83***	1.63***
2	0.27	-0.36	0.74**	1.40	0.45	0.22
3	-0.06	0.14	-0.01	-0.10	-0.09	0.02
4	2.11***	1.60***	1.91***	0.65	1.87***	1.87***
5	-2.23***	-1.40***	1.67	-0.43	-1.17***	-1.77***
6	0.19	0.18	0.12	-1.02	-0.13	0.16
7	-0.85**	-1.11**	-1.17***	1.15	-0.92**	-1.05**
8	2.40***	1.18**	1.41***	1.69	1.79***	1.66***
9	-0.68*	-1.16**	-1.05***	-1.89*	-1.63***	-0.96*
10	0.15	-0.53	-0.63*	-0.10	-0.30	-0.34
11	-0.06	22.00	0.54*	0.32	0.66*	0.23
12	-2.06***	-0.45	-1.92***	-1.06	-1.96***	-1.48***
13	-1.10***	-0.28	-0.05	-0.52	0.16	-0.48
14	0.36	0.60	0.17	-0.23	-0.55	0.26

*, **, ***, Significant at $p < 0.05$, 0.01 and 0.001 respectively

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across Embu, Kakamega and Kiboko-1

Table 14: General combining ability effects (GCA) of fourteen early QPM inbred lines for anthesis-silking interval (d) per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	Across‡
1	-1.04***	-2.01*	-0.96*	-1.83***	-1.33***
2	0.83**	0.24	0.33	0.33	0.47
3	-0.33	0.20	-0.34	0.46	-0.16
4	-0.33	-2.76***	-0.09	0.88*	-1.06**
5	-0.16	-1.17	-0.09	-0.46	-0.78
6	-0.25	-0.46	-0.26	-0.38	-0.32
7	-0.16	0.20	-1.46***	-1.67***	-0.48
8	-0.58*	0.33	-0.01	0.08	-0.09
9	-0.42	0.91	-0.55	-0.79*	-0.01
10	0.88**	2.70***	1.74***	2.42***	1.77***
11	0.08	0.08	-0.38	-0.63	-0.07
12	1.21***	1.45	0.91*	0.33	1.19**
13	0.00	1.04	0.58	1.54***	0.54
14	0.29	-0.76	0.58	-0.29	0.04

*, **, ***, Significant at p< 0.05, 0.01 and 0.001 respectively

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across Embu, Kakamega and Kiboko-1

Table 15: General combining ability effects (GCA) of fourteen early QPM inbred lines for ears per plant (EPP) per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
1	0.05***	0.17***	0.01	0.06*	-0.02	0.08**
2	0.03	0.13*	0.01	-0.09**	0.00	0.05*
3	0.00	-0.11*	-0.03*	0.00	0.01	-0.50
4	0.02	0.21***	0.05***	0.05	-0.02	0.09***
5	0.01	0.17***	0.02	0.01	0.02	0.07
6	0.02	-0.03	0.01	-0.01	-0.02	0.00
7	0.00	-0.11*	0.06***	0.06*	0.15*	-0.02
8	-0.01	-0.06	-0.01	-0.03	-0.01	-0.03
9	-0.03*	-0.15**	-0.02	0.02	0.09	-0.07***
10	-0.02	-0.05	-0.05***	-0.05	-0.03	-0.40
11	0.00	0.04	-0.01	0.01	0.03	0.01
12	0.00	-0.09*	0.00	0.00	-0.20**	-0.03
13	-0.05**	-0.14**	-0.04**	-0.06*	0.01	-0.07**
14	0.00	0.03	0.02	0.02	-0.01	0.02

*, **, ***, Significant at p< 0.05, 0.01 and 0.001 respectively

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across Embu, Kakamega and Kiboko-1

significant GCA effects for grain yield mainly contributed by highly significant positive GCA effects at Embu (1.52 tons/ha), Kakamega (1.30 tons/ha) and Kiboko-1 (0.43 tons/ha). This line was parent to twelve more crosses among the selected top performing hybrids (Table 5). This also supported our earlier observation that indeed, Line 4 had good general combining ability. Estimates of SCA effects for grain yield were not significant. SCA effects were highest and positive for the crosses 8x11 (0.56 tons/ha), 9x14 (0.54 tons/ha) and 4x6 (0.53 tons/ha) and highest and negative for the cross 6x10 (-0.62 tons/ha) (Appendix G).

Estimates of GCA effects for anthesis date differed significantly between lines (Table 13). Line 9 showed consistently significant negative GCA effects for anthesis date at each environment. Lines 5, 7 and 12 showed consistently negative GCA effects at all environments except at kiboko-1 and Kiboko-2 where Lines 5 and 7 showed positive GCA effects respectively. Across environments Line 5 had the highest highly significant negative GCA effect of -1.77 d followed by Line 12 (-1.48 d) and Line 7 (-1.05 d). Line 9 had negative significant GCA effects. Significant GCA effects implied that the lines had good alleles for earliness. Crosses made up of these parents were the earliest in maturity across environment: 9x12 (63 d) and 5x7 (64 d) (Appendix A). GCA effects for anthesis-silking interval were negative and consistent at all environments for Lines 1, 4 and 6 (Table 14). Across environments Line 1 had the highest negative highly significant GCA estimate of -1.33 d followed by Line 4 (-1.06 d). Significant negative GCA effects suggested shorter anthesis-silking interval hence these lines contributed alleles for shorter anthesis-silking interval to their progenies and were parents to the cross (1x4) that had the shortest anthesis-silking interval (Table 5) across environments. No significant estimates of SCA effects for anthesis date and anthesis-silking interval were observed. For anthesis date, SCA effects were highest and negative for crosses 9x12 (-2.05 d) and 5x7 (-2.01 d) and highest and positive for crosses 2x9 and 6x12 (1.42 d). For anthesis-silking interval, SCA effects were highest and negative for crosses 9x12 (-2.05 d) and 5x7 (-2.01 d) and highest and positive for crosses 2x9 and 6x12 (1.42 d) (Appendix G). Significant GCA effects were observed for ears per plant among lines and between environments (Table 15). Line 5 showed consistently positive GCA effects at each environment that were highly significant at Kakamega only. Lines 1 and 4 showed consistently positive GCA effects at all environments except at Kiboko-3 where both showed negative but small GCA effects of -0.02 EPP. Across environments Lines 1 and 4 had the highest highly significant GCA effect of 0.09 EPP and 0.08 EPP respectively. In addition Line 2 also showed significant GCA effects across environments. Positive significant GCA effects suggested increased number of ears per plant and thus these lines had good alleles for increased ears per plant showing the potential to increase the number of ears per plant in their progenies. These lines were parents to the crosses that showed increased ears per plant. These were 1x2, 1x13, and 4x14 (Appendix A). SCA effects were not significant and were highest and positive for the cross 3x12 (8.79%) and highest and negative for the cross 9x12 (-0.63%) (Appendix G).

Estimates of GCA effects for root lodging (Table 16) were consistently highly significant and positive for Line 7 over environments contributing to a highly significant positive GCA effect of 3.93% across environments. This meant susceptibility to root lodging for this line which is undesirable. For stalk lodging (Table 17), GCA effects differed among lines and across environments. Line 6 and 10 showed consistently negati-

Table 16: General combining ability effects (GCA) of fourteen early QPM inbred lines for root lodging (%) per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
1	-0.61	-0.17	-0.01	-0.26	0.98	-0.26
2	0.00	1.27	0.21	-0.03	-0.07	0.49
3	0.79	0.11	0.00	0.19	-2.52	0.30
4	-0.21	-2.93	-0.41	-0.26	1.73	-1.18
5	-0.19	0.49	-0.21	0.40	-3.40	0.03
6	-0.40	-3.13	-0.41	-0.26	-1.60	-1.31
7	1.04**	9.96***	0.81**	0.65**	-1.02	3.93***
8	-0.61	-0.36	-0.21	0.41	5.58*	-0.39
9	1.00**	4.26*	0.00	-0.26	0.45	1.75
10	-0.21	-4.93*	0.00	-0.01	0.47	-1.71
11	-0.21	-2.65	0.00	-0.26	4.64*	-0.95
12	0.02	3.91	0.20	-0.03	-2.53	1.38
13	-0.21	-2.43	0.20	-0.03	0.95	-0.81
14	-0.21	-3.41	-0.20	-0.26	-3.67	-1.27

*, **, ***, Significant at p< 0.05, 0.01 and 0.001 respectively

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across Embu, Kakamega and Kiboko-1

Table 17: General combining ability effects (GCA) of fourteen early QPM inbred lines for stalk lodging (%) per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
1	0.10	6.85	0.56	-0.03	2.43	2.50
2	-0.08	-3.75	-2.74	-0.03	2.02	-2.18
3	1.32	2.51	-0.80	0.18*	2.51	1.02
4	-1.49	-7.85	0.42	-0.03	-6.07*	-2.97
5	-0.30	2.68	-1.24	0.19*	-3.85	0.38
6	-0.90	-8.92	-1.83	-0.03	-6.50*	-3.88*
7	3.72***	1.00	3.63*	-0.03	10.93***	2.78
8	-1.09	-5.62	-0.47	-0.03	-2.52	-2.39
9	1.31	24.72***	9.63***	-0.03	7.35**	11.89***
10	-1.27	-9.47	-3.05	-0.03	-0.01	-4.60*
11	-0.25	-4.56	-3.41*	-0.03	-0.99	-2.74
12	-0.89	12.67***	4.83**	-0.03	1.00	5.53**
13	-0.30	-3.81	-5.23**	-0.03	-3.10	-3.11
14	0.10	-6.50	-0.30	-0.03	-3.21	-2.23

*, **, ***, Significant at p< 0.05, 0.01 and 0.001 respectively

†EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across Embu, Kakamega and Kiboko-1

Table 18: General combining ability effects (GCA) of fourteen early QPM inbred lines for ear rots (%) per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
1	1.29	-1.83	0.17	-0.73	0.41	-0.16
2	-7.73***	-6.39	-0.06	-1.31	-2.36	-4.97**
3	-0.88	7.07*	0.00	-0.60	0.86	2.02
4	-3.58	-9.55**	-0.28	-1.98	-0.68	-4.51*
5	-0.78	-4.55	0.84*	-2.40	4.38	-1.53
6	-1.96	-1.73	0.19	7.00***	-1.77	-1.20
7	-6.49**	-2.25	0.14	-1.73	2.67	-2.91
8	1.90	-1.75	-0.47	-0.33	-2.98	-0.15
9	0.10	0.85	-0.68	-1.45	2.97	-0.05
10	6.40**	9.48**	-0.23	0.66	-0.31	5.18**
11	2.49	-1.37	1.09**	0.19	1.48	0.70
12	6.10**	2.01	-0.24	-0.33	0.26	2.86
13	4.72*	14.92***	0.20	0.27	-1.55	6.95***
14	-1.59	-4.91	0.04	0.57	-3.39	-2.22

*, **, ***, Significant at $p < 0.05$, 0.01 and 0.001 respectively

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across; Embu, Kakamega and Kiboko-1

Table 19: General combining ability effects (GCA) of fourteen early QPM inbred lines for ear aspect per environment and across environments†

Inbred	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
1	0.17	0.22*	0.24*	-0.20	-0.54	0.21**
2	-0.18	-0.23**	-0.09	-0.03	0.21	-0.17*
3	0.15	0.03	-0.19	-0.15	0.07	-0.02
4	-0.56***	-0.40***	-0.15	0.10	-0.16	-0.37***
5	0.32**	0.02	-0.09	-0.01	0.42	0.08
6	-0.22*	-0.11	-0.01	0.24	0.07	-0.11
7	-0.26**	0.14	-0.28**	-0.15	0.13	-0.13
8	-0.16	0.14	-0.28**	0.01	-0.37	-0.10
9	0.09	0.03	-0.03	0.10	-0.26	0.03
10	0.44***	0.10	0.47***	0.14	0.36	0.34***
11	0.09	0.02	0.20	0.03	-0.26	0.10
12	0.19*	0.12	0.04	-0.05	1.05***	0.11
13	0.09	0.06	0.14	0.07	-0.79**	0.10
14	-0.16	-0.07	0.01	-0.09	0.07	0.07

*, **, ***, Significant at $p < 0.05$, 0.01 and 0.001 respectively

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡ Across Embu, Kakamega and Kiboko-1

ve GCA effects over environments contributing to significant negative GCA effects across environments. Significant negative GCA effects for stalk lodging meant good alleles for stalk lodging. Line 9 showed consistently positive GCA effects for stalk lodging except at Kiboko-2 where the effects were negative but small (-0.03). Across environments this inbred showed the highest highly significant positive GCA effects of 11.89% indicating bad alleles for stalk lodging.

Estimates of GCA effects for ear rots differed among lines and across environments except for Kiboko-3 where the GCA effects were not significant among lines (Table 18). Lines 2 and 4 showed negative and consistent GCA effects over environments. Inbred Line 2 had the highest highly significant negative GCA effect of -4.97% and line 4 (-4.51%) had negative and significant GCA effects for ear rot across environments. Significant negative GCA effects for ear rots meant resistance to ear rots diseases was present. Therefore these lines mostly showed good alleles for reduced ear rots incidence which is desirable in QPM breeding and were parents to the crosses that showed reduced ear rots incidence; 2x4, 4x7 and 4x14 (Appendix A). Lines 10 and 13 displayed highly significant positive GCA for ear rots indicating contribution of bad alleles for ear rots susceptibility to their progenies which is undesirable. No significant estimate for SCA effects were observed for this trait. SCA effects were highest and positive for the cross 10x13 (10.31%) and highest and negative for the cross 7x13 (-9.34%) (Appendix G). Lines 2 and 4 showed consistently negative GCA effects for ear aspect at all environments and across environments except at Kiboko-3 and Kiboko-2 where they showed positive GCA effects (Table 19). Significant negative GCA effects for ear aspect suggested good ear aspect thus these lines contributed alleles for good ear aspect to their progenies. The cross 2x4 had the best ear aspect mean of 1.45 EA (Table 5). Other crosses with good ear aspect across environments included 3x4, 4x6, 4x7 and 4x11 (Appendix A). Estimates of SCA effects were not significant for ear aspect and were highest and positive for the cross 1x10 (0.52%) and highest and negative for the cross 1x7 (-0.89%) (Appendix G).

GCA and SCA variance components

The relative importance of GCA and SCA variance was expressed as the ratio between the additive and total genetic variance. The ratio varied with traits but it generally accounted for over 75% of the total genetic variance for each trait across environments (Table 20). Additive genetic variance for grain yield was highest at Kakamega accounting for 95% and lowest at Kiboko-3 drought condition accounting for 56% of the total genetic variance implying that under drought stress additive gene effects were as important as non additive gene effects for grain yield (Table 20, Fig 1). Across environments additive genetic variance for grain yield accounted for 94% of the total genetic variance. In this study additive gene effect for grain yield was the most important contributor to the heritable variance in these materials across environments. This indicated that the effect of GCA was superior in the grain yield of crosses and the differences in grain yield mainly resulted from the differences of the effect of GCA effects. Similar results have been reported by several authors (Xingming *et al.,* 2004; Nigussie and Zelleke, 2001; Vasal *et al.,* 1993a; Vasal *et al.,* 1993b). With predominance of GCA over SCA variance for grain yield in these materials, promising hybrids can be identified and selected mainly based on the prediction from GCA effects. Additive

Table 20: Ratio of additive genetic variance to total genetic variance σ^2 for grain yield and agronomic traits per environment and across environments†

Trait	EMB	KAK	KIB-1	KIB -2	KIB -3	Across‡
Grain yield	0.91	0.95	0.67	0.68	0.56	0.94
Anthesis date	0.94	0.86	0.94	0.57	0.92	0.96
ASI	0.83	0.84	0.80	0.87	*	0.86
Ears per plant	0.50	0.42	0.75	0.71	0.61	0.91
Root lodging	0.66	0.72	0.57	0.60	0.62	0.76
Stalk lodging	0.66	0.78	0.83	0.50	0.76	0.81
Ear rots	0.83	0.78	0.65	0.78	0.48	0.85
Ear aspect.	0.87	0.74	0.76	0.45	0.74	0.89

† EMB, Embu; KAK, Kakamega; KIB, Kiboko;

‡, Across Embu, Kakamega and Kiboko-1

*, No value for ASI (anthesis-silking interval) most of the plants did not reach silking date.

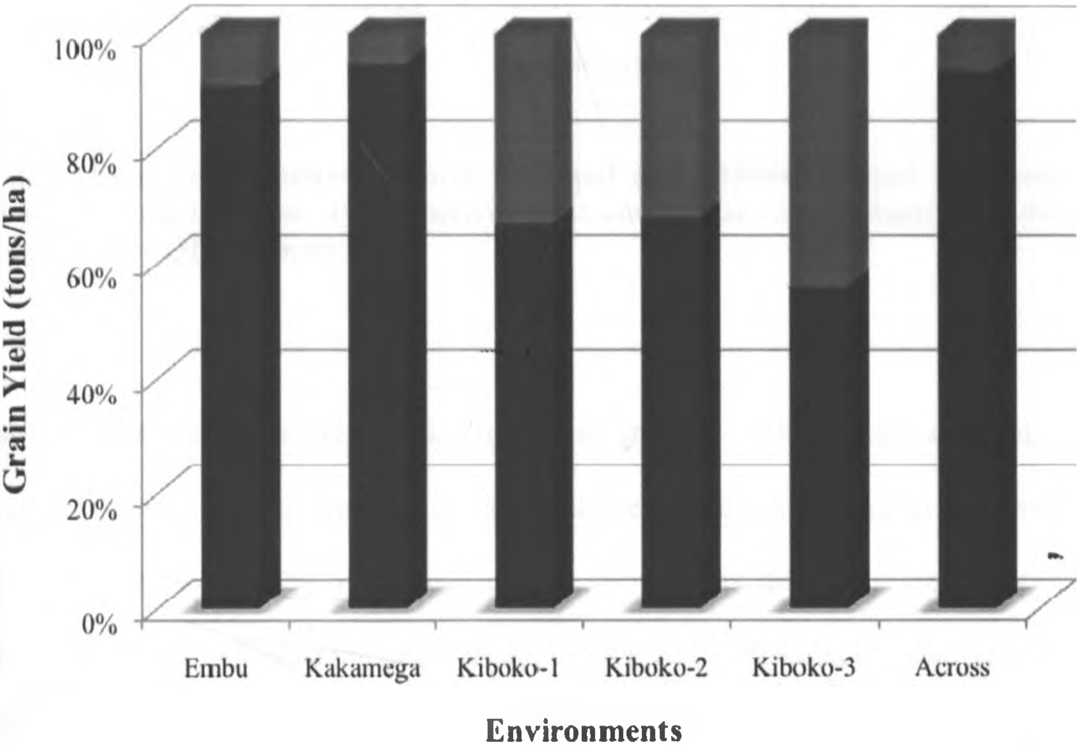

Fig. 1: Percentage of additive (lower bar) and non additive (Upper bar) genetic variance for grain yield (tons/ha) per environment and across environments in a diallel among 14 early QPM inbred lines

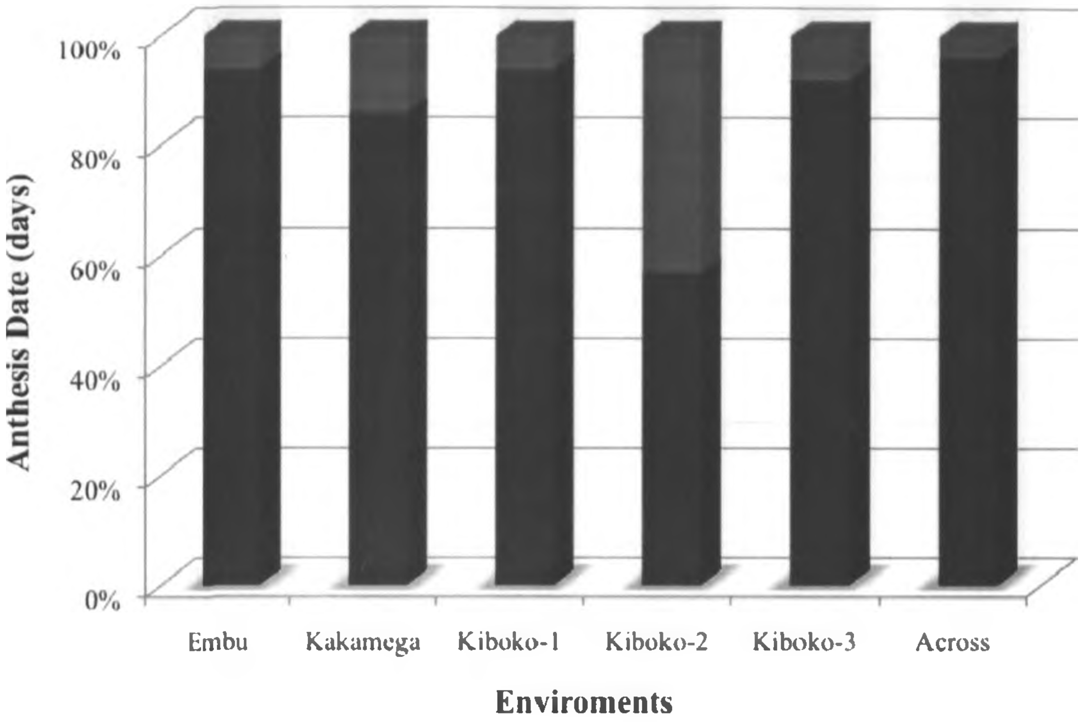

Fig. 2: Percentage of additive (Lower bar) and non additive (Upper bar) genetic variance for anthesis date (d) per environment and across environments in a diallel among 14 early QPM inbred lines

variance for anthesis date (Table 20, Fig 2) and anthesis- silking interval (Table 20) accounted for over 80% of the total variance at each environment except at Kiboko-2 where it accounted for 57% of the total genetic variance. In this environment, additive effects appeared to be just as important as dominance and interaction effects. Across env ironments, additive genetic variance for anthesis date and anthesis-silking interval accounted for 96% and 86% of the total variance respectively. This implied that additive gene effects were more important than non additive gene effects for these two traits in these materials. Differences observed for anthesis date and anthesis-silking interval

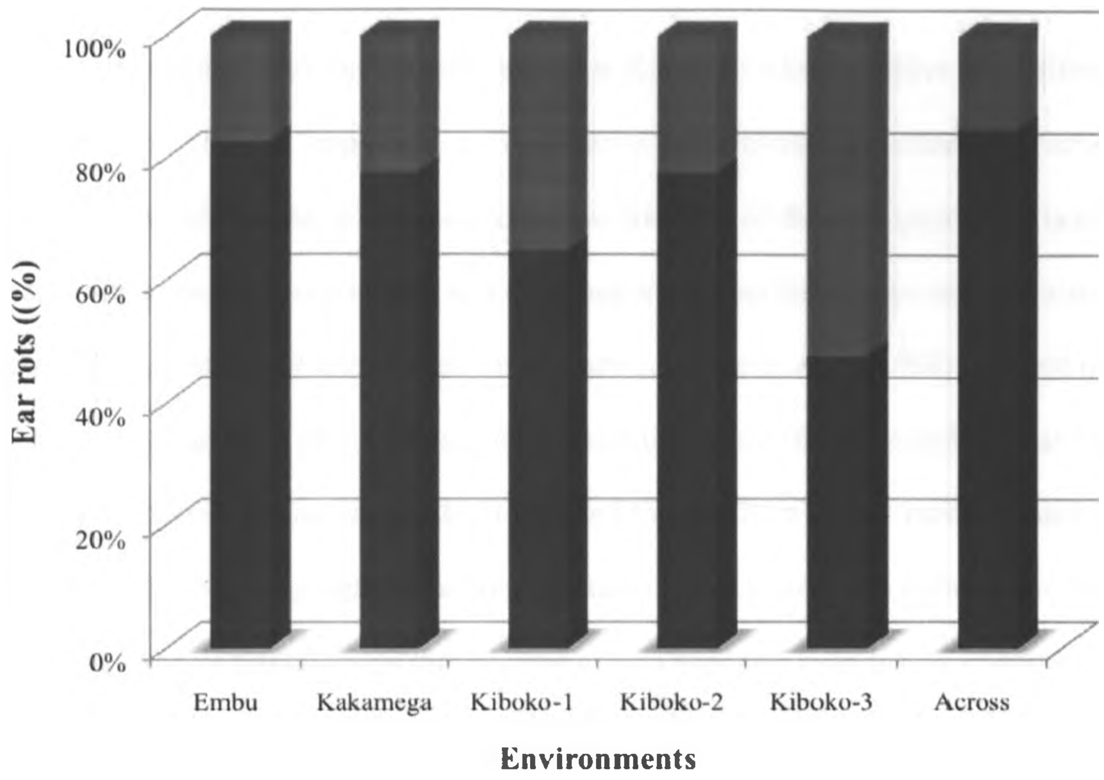

Fig. 3: Percentage of additive (Lower bar) and non additive (Upper bar) genetic variance for ear rots (%) per environment and across environments in a diallel among 14 early QPM inbred lines

across environments were mainly due to differences of the effect of GCA effects thus promising early maturing hybrids with shorter anthesis-silking interval can be identified and selected mainly based on the prediction from GCA effects. Nigussie and Zelleke (2001) reported that, similar to these results, additive gene effects were more important than non additive gene effects for anthesis date among eight elite maize populations. The magnitude of additive genetic variance for ear rots accounted for over 65% of the total variance at each environment except at Kiboko-3 where ear rot accounted for 48% of the total genetic variance (Table 20, Fig 3). This implied that additive gene effects for ear rots were important at each environment except at Kiboko-3 where additive gene effects appeared to be just as important as dominance and interaction effects. Across environments additive genetic variance accounted for 85% of the total genetic variance. This suggested that additive variance was more important than dominance and interaction effects in this set of inbred lines across environments. Dorrance *et al.* (1998) reported the predominance of additive gene effects over non additive gene effects for diplodia ear rots resistance in maize. Naidoo *et al.* (2002) reported that additive effects predominated in ear rots inheritance among eight inbred lines tentatively associated with reduced ear rots. Menkir and Ayodele (2005) found that additive effects appeared to be just as important as dominance and interaction effects among 24 inbred lines evaluated in five environments in Nigeria. The predominance of additive effects over dominance and interaction effects for ear rots suggested that promising lines can be identified and selected mainly based on the prediction of GCA effects. Additive genetic variance for ears per plant accounted for 50% and 42% of the total genetic variance at Embu and Kakamega respectively. At Kiboko, additive genetic variance accounted for over 60% of the total genetic variance (Table 20). This implied that additive genetic variance was as important as non additive genetic variance for ears per plant at Embu and Kakamega whereas at Kiboko environments additive genetic variance predominated. Across environments additive genetic variance appeared to be more important than non-additive genetic variance for ears per plant (Table 20). A similar trend was observed for root lodging, stalk lodging and ear aspect (Table 20). These findings agree with those of several other workers. Bhatnagar *et al.* (2004) reported similar results with additive effects being more important than non additive effects for root lodging and stalk lodging among seven white

QPM inbred lines and stalk lodging among nine yellow QPM inbred lines evaluated in five southern U.S environments. Vacaro *et al.* (2002) found that additive effects were more important for ears per plant, root lodging and stalk lodging among twelve maize pools and populations evaluated at two environments in Brazil. Menkir and Ayodele (2005) found a higher contribution of additive variance for ear aspect. The large proportion of additive genetic variance observed in these traits suggests that selection which takes advantage of additive variation can be effective in these materials.

Prediction of three-way and four-way crosses and general combing ability for grain yield

Means for grain yield of the highest performing twenty and lowest performing five single-crosses and predicted three-way and double-cross hybrids are presented in (Table 21). Grain yield for the highest performing single-cross hybrid and highest performing predicted three-way cross hybrid was almost the same with a difference of 60 kg/ha. The highest performing double-cross hybrid was out-yielded by the highest performing single cross by 13%. The mean grain yield did not differ for the single-crosses, three-way and double-cross hybrids. Failure for the single-crosses to yield more than the three-way or double-cross suggested lack of heterosis among the single-crosses. Pixley and Bjarnason (2002) in a study to assess grain yield stability for QPM hybrids among eighteen single-crosses, eighteen three-way and eighteen double crosses formed from same inbred lines reported that the single-crosses, three-way and double-cross hybrids did not differ in mean grain yield and suggested lack of heterosis among the lines that constituted the hybrids. In tropical maize, Saleh *et al.* (2002) did not find

Table 21: Mean grain yield of the highest performing twenty and lowest performing five diallel single-crosses and predicted grain yield of the highest twenty and lowest five three-way and double-cross hybrids in 2006

Single crosses		Three-way cross		Double crosses	
Cross	**tons/ha**	**Cross**	**tons/ha**	**Cross**	**tons/ha**
(i) Highest twenty hybrids					
1x4	4.72	1/6x4	4.66	1/6X4/8	4.11
4x6	4.61	1/8x4	4.60	1/6X4/14	4.09
4x8	4.48	6/8x4	4.54	1/6X4/7	4.06
4x11	4.17	1/11x4	4.44	1/8X4/14	4.04
3x4	4.03	6/11x4	4.39	1/8X2/4	4.04
2x4	4.02	1/3x4	4.37	1/11X2/4	4.03
4x7	3.95	1/2x4	4.37	1/11X4/8	4.03
4x12	3.94	1/7x4	4.33	1/6X3/4	4.01
4x9	3.81	1/12x4	4.33	1/6X2/4	4.01
4x14	3.73	8/11x4	4.32	1/8X4/11	4.01
7x10	3.70	3/6x4	4.32	1/4X6/8	3.99
4x13	3.68	2/6x4	4.32	1/8X4/6	3.98
1x14	3.66	6/7x4	4.28	1/6X4/5	3.98
1x2	3.66	6/12x4	4.27	4/8X6/11	3.97
1x7	3.63	1/9x4	4.27	1/6X4/13	3.97
1x8	3.63	3/8x4	4.25	1/12X4/7	3.96
4x5	3.62	2/8x4	4.25	4/5X6/8	3.96
8x11	3.59	1/14x4	4.23	1/3X4/7	3.96
2x11	3.59	7/8x4	4.22	1/6X4/12	3.96
7x12	3.56	6/9x4	4.21	1/7X4/10	3.95
(ii) Lowest five hybrids					
12x13	2.56	2/5x12	2.49	3/9x5/12	2.60
5x12	2.50	3/9x13	2.48	3/9x12/13	2.60
2x12	2.47	8/13x9	2.48	5/13x9/12	2.55
5x9	2.35	9/12x5	2.43	5/8x9/12	2.53
9x13	2.33	5/13x9	2.34	3/9x5x13	2.49
Mean	**3.24**		**3.24**		**3.24**

Differences in average performance between single-crosses, three-way and double-crosses. The lowest performing single-cross hybrid was 9x13 (2.33 tons/ha) and the second lowest was 5x9 (2.35 tons/ha). Parents of these crosses constituted the lowest predicted three-way hybrid 5/13x9 (2.34 tons/ha) and the lowest predicted double-cross hybrid 3/9x5x13 (2.49 tons/ha).

All the selected predicted three-way cross hybrids had their grain yield above 4 tons/ha compared to 30% and 50% of selected single-cross and the predicted double-cross hybrids respectively. This suggested more yield stability for the three-way cross than the single and the double-crosses. Three-way crosses may be advantageous in terms of cost of production of hybrid seed compared to the single-crosses especially in the semi arid areas of Kenya where farmers do not buy hybrid seed. The highest performing single-cross hybrid was 1x4 (4.72 tons/ha) followed by 4x6 (4.61 tons/ha). The highest performing three-way-cross hybrid was 1/6x4 (4.66 tons/ha) followed by 1/8x4 (4.60 tons/ha). The highest performing double-cross hybrid was 1/6x4/8 (4.11 tons/ha). All these superior crosses had Line 4 as a common parent. In addition, the inbred line was parent to twelve single-crosses among the selected, dominant male parent to all the highest performing predicted three-way hybrids and common parent to all the highest performing double-cross hybrids. This confirmed our earlier observations that Line 4 was indeed superior and good in general combining ability for grain yield over the other parents, contributing good alleles for grain yield to its progenies. Line 1, though not significant across environments, was parent to 25% of the single-crosses, 45% of the three-way hybrids and 90% of the double-cross hybrids thus contributing good alleles for grain yield to its progenies. The hypothesis that superior single-crosses confer superior double-crosses and three-way crosses was acceptable for these materials.

Phenotypic Correlations

Results of phenotypic correlations between yield and yield components at Embu, Kakamega, Kiboko-1, Kiboko-2 and Kiboko-3 and across the environments are presented in Table 22.

Significant positive association between grain yield and number of ears per plant was observed at each environment with Kiboko-3 drought condition recording a very strong correlation (0.94***). This shows that under drought condition, grain yield becomes more associated with ears per plant confirming previous data where ears per plant has been reported to be an important secondary trait when selecting for drought tolerance and high yield potential in maize. For instance, Bolaños and Edmeades (1997), working with inbred progenies adapted to the lowland tropics reported that grain yield was more correlated to ears per plant under drought stress (0.77) than under well watered conditions (0.49). San Vicente *et al.* (1997) reported similar results of a strong phenotypic correlation between grain yield and ears per plant (0.65) for late tropically adapted inbred lines. The consistent association observed over environments contributed to a strong positive and significant correlation (0.67***) across environments. This signified the importance of increased ears per plant for higher grain yields in this set of inbred lines. Significant positive correlations were observed between grain yield and anthesis date at Embu and Kakamega whereas at Kiboko-2 and Kiboko-3, high and negative significant correlations were observed. The positive association observed at Embu and Kakamega is a characteristic of the moist mid-altitude ecology whereby grain yield potential is proportional to crop maturity. The negative association observed at Kiboko is a characteristic of the dry mid-altitude ecology where increased grain yield is associated with reduced anthesis date or earliness as a result of the component of drought escape found in the early maturing cultivars. However, extremely small (-0.09**) and negative significant association across the environments was observed. A consistent

Table 22: Phenotypic correlations between grain yield and agronomic traits at each environment and across environments†

Locality		GY	AD	ASI	RL	SL	EPP	ER
Embu	AD	0.27***						
	ASI	-0.17*	-0.58***					
	RL	-0.22**	0.06	0.07				
	SL	-0.08	-0.02	0.03	0.23***			
	EPP	0.34***	-0.07	-0.03	-2.50***	-0.11		
	ER	-0.40***	0.05	0.01	0.09	-0.13	-0.16*	
	EA	-0.65***	-0.20**	0.13	0.17*	0.01	-0.20**	0.60***
Kakamega	AD	0.22**						
	ASI	-0.33***	-0.43***					
	RL	-0.14*	-0.02	0.03				
	SL	-0.19**	-0.2**	0.18**	0.11			
	EPP	0.53***	0.24***	-0.34***	0.01	-0.19**		
	ER	-0.37***	-0.01	0.21**	0.16*	0.02	-0.43***	
	EA	-0.29***	-0.15*	0.09	-0.02	0.11	-0.13	0.03
Kiboko-1	AD	0.05						
	ASI	-0.39**	-0.29***					
	RL	-0.03	0.02	-0.08				
	SL	0.09	-0.25***	-0.14*	0.07			
	EPP	0.51***	0.01	-0.19**	-0.04	0.13		
	ER	-0.02	-0.03	0.00	-0.01	-0.03	-0.08	
	EA	-0.39***	0.14*	-0.05***	0.04	-0.22***	-0.33***	0.15*
Kiboko-2	AD	-0.17**						
	ASI	-0.49***	0.04					
	RL	-0.05	0.06	0.04				
	SL	-0.07	-0.01	-0.01	0.24***			
	EPP	0.65***	-0.24***	-0.46***	-0.04	-0.10		
	ER	0.04	-0.15*	-0.02	0.14	0.04	0.03	
	EA	-0.63***	0.13	0.39***	0.03	-0.01	-0.04***	0.07
Kiboko-3	AD	-0.23***						
	ASI	-						
	RL	0.20**	0.27***	-				
	SL	0.10	-0.23***	-	-0.13			
	EPP	0.94***	-0.27***	-	0.16*	0.15*		
	ER	-0.19**	-0.06	-	0.02	-0.08	-0.15*	
	EA	-0.31***	0.03	-	-0.13	-0.10	-0.25***	0.24***
Across	AD	-0.09**		-				
	ASI	-0.55***	0.05	-				
	RL	-0.30***	0.19***	0.18***				
	SL	-0.25***	-0.12***	0.14***	0.13***			
	EPP	0.67***	-0.15***	-0.48***	-0.13***	-0.16***		
	ER	-0.15***	0.17***	0.09**	0.24***	-0.01	-0.14***	
	EA	-0.41***	0.06***	0.33***	0.01	0.01	-0.33***	0.09**

*, **, ***, Significant at p< 0.05, 0.01 and 0.001 respectively

† AD, anthesis date; ASI, anthesis-silking interval; EA, ear aspect. EPP, ears per plant; ER, ear rots; GY, grain yield; RL, root lodging; SL, stalk lodging

negative significant correlation between grain yield and anthesis-silking interval was observed at each environment contributing to strong and negative (-0.55***) association across the environments. This indicated that increased grain yield was associated with shorter anthesis-silking interval showing the importance of anthesis-silking interval for increased grain yield in this set of inbred lines. Edmeades *et al.* (1997) and Bolaños and Edmeades (1997) also reported a strong correlation between grain yield and anthesis-silking interval (-0.53). Moderate to high and negative significant correlations between grain yield and ear aspect were observed at each environments. The consistent negative correlations observed at each environment contributed to high negative significant correlation (-0.41***) detected across the environments suggesting that better ear aspect was associated with increased grain yield. Similar results were reported by San Vicente *et al.* (1997). The association between grain yield and root lodging and between grain yield and stalk lodging was low and inconsistent over environments. Across environments, a moderate significant correlation was observed for root lodging (-0.30***) and stalk lodging (-0.25***) indicating the importance of reduced root and stalk lodging for increased grain yield in these materials. Inconsistent correlation between grain yield and ear rots was observed over environments contributing to the low and negative significant correlation (-0.15***) across the environments suggesting that reduced ear rots was associated with increased grain yield but this association was of low magnitude. Anthesis-silking interval was associated negatively with ears per plant (-0.48***) and positively with ear aspect (0.33***). In other words an increase in grain yield was associated with a reduction in anthesis-silking interval and barrenness, and better ear aspect in this set of inbred lines. Similar results were reported by, San Vicente et al.

(1997) and Edmeades *et al*. (1997).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to determine combining ability for grain yield and other agronomic traits among fourteen early drought tolerant QPM inbred lines crossed in a diallel cross. The F_1 hybrids were evaluated in five environments and the following conclusions and recommendations were made:

(i) Conclusions

Mean performance for the hybrids indicated that the diallel hybrids had lower grain yields and were earlier in maturity compared to the experimental checks across optimum environments. Under drought conditions the diallel hybrids performed better in terms of grain yield than the checks confirming that progress in screening for drought tolerance among the diallel parents had been made. The best hybrids were crosses between the diallel parents and parents of the reference check suggesting presence of heterosis which should be investigated further for breeding purposes. Entries 3 and 72 had higher grain yields than the reference check across optimum environments and under drought stress. The same entries had reduced anthesis date and shorter silking-interval compared to the reference check. These entries should be tested further for potential release as three-way and/or double-cross hybrids in the mid-altitude ecology of Kenya. Analysis of variance across optimum environments revealed that, differences in performance for grain yield and other agronomic traits between the diallel hybrids and the experimental checks was mainly contributed by the environment in which they were grown. For diallel hybrids, SCA effects across environments were not significant for all traits except for anthesis date. Significant GCA and GCA x environment interaction were observed for all traits across optimum environments. Inbred Line 4 had superior GCA effects for grain yield. It was indeed a parent to twelve single-crosses among the selected, dominant male parent to all the highest performing predicted three-way hybrids and common parent to all the highest performing double-cross hybrids confirming its superior GCA effects. The same inbred had good GCA for shorter anthesis-silking interval, good alleles for increased number of ears per plant, resistance to ear rots and good ear aspect. Inbred Lines 5, 12, 7 and 9 had good alleles for reduced anthesis date across optimum environments and under drought stress. Line 6 and 10 had good alleles for root lodging and stalk lodging. Additive gene action appeared to be more important than non additive gene action for grain yield and the other agronomic traits cross optimum environments in this set of inbred lines. Some increase in grain yield and improvement of the other agronomic traits should be expected through recurrent selection strategy, which increases the frequency of favorable alleles with additive effects provided that the environment variations are held to the minimum. Average grain yield for the single-crosses, predicted three-way and double-crosses was found to be the same suggesting lack of heterosis. However grain yield for the predicted three-way crosses seemed to be more stable than for the single-crosses and the predicted double-crosses. More effort should be directed towards the three-way crosses for they have more advantages in terms of cost of production of hybrid seed compared to the single-crosses especially in the semi arid areas of Kenya where farmers do not readily buy hybrid seed. Grain yield correlated negatively with anthesis-silking interval and ear aspect and positively with ears per plant. Anthesis-silking interval was associated negatively with ears per plant and positively with ear aspect. In other words, an increase in grain yield was associated with a reduction in anthesis-silking interval and barrenness, and better ear aspect in this set of inbred lines. Under drought conditions, a very strong positive correlation between grain yield and ears per plant was observed and this showed that as water is withdrawn grain yield becomes more associated with ears per plant thus in this set of materials ears per plant was an important secondary trait when selecting for tolerance and high grain yield potential.

(ii) Recommendations for future use

Data obtained from this study leads to the following recommendations.

1) Entries 3 and 72 should be tested further for potential release as parents in three-way and/or double-cross hybrids in the mid-altitude ecology.
2) Heterosis identified between the diallel parents and parents of the reference check (CM144xCML159) should be investigated further for use in breeding programs.
3) Parent 4 could be used in breeding programs for generating suitable single-crosses and synthetics that have a combination of high grain yield, shorter anthesis-silking interval, increased number of ears per plant, low incidences of ear rots and good ear aspect.
4) More effort should be directed towards three-way crosses than single-crosses to exploit the advantages of low cost of production of hybrid seed found in the three-way crosses.
5) Gains for grain yield in these materials may be achieved through indirect selection for shorter anthesis-silking interval and reduced bareness.
6) Since no normal checks were included in the evaluation, it will be necessary to

evaluate the best hybrids again to compare them with the normal local checks before any decisions are made on the hybrids to be released.

REFERENCES

Allard, R.W. 1960. Principles of plant breeding – Wiley New York and London.

Anonymous. 1988. National research council. Quality Protein Maize p 18-56. National academy press Washington DC.

Anonymous. 2004. Strategy for Revitalizing Agriculture 2004-2014. Published by the Ministry of Agriculture and the Ministry of Livestock and Fisheries Development. Republic of Kenya

ASARECA. 1997. Development of long term strategic plan for Regional Agricultural Research in eastern and central African region, ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa) Entebbe, Uganda, September 1997.

Baker, R.L. 1978. Issues in diallel analysis. Crop Sci. 18:533-536.

Banziger, M and A.O. Diallo.2004. Progress in Developing Drought and N stress tolerant maize cultivars for Eastern and Southern Africa pp 189-193. In D.K Friesen and A.F.E Palmer(eds). Integrated Approaches to higher maize productivity in the New Millennium. Proceedings of the 7th Eastern and Southern Africa regional maize conference, 5-11 February 2002.CIMMYT/KARI, Nairobi, Kenya.

Banziger, M., G.O. Edmeades, D. Beck, and M. Bellon. 2000. Breeding drought and nitrogen stress tolerance maize: From theory to practice. Mexico, D.F.: CIMMYT.

Betrán, F.J., J.M. Ribaut, D. Beck and D. Gonzalez de león. 2003. Genetic diversity, specific combining ability and heterosis in tropical maize under stress and non-stress environments. Crop Sci. 43:797-806.

Betrån, F.J., M. Banziger, and D.L. Beck. 1997. Relationship between line and topcross performance under selection for drought tolerance p383-386. In D.K Friesen and A.F.E Palmer (eds). Integrated Approaches to higher maize productivity in the New Millennium. Proceedings of the 7th Eastern and Southern Africa regional maize conference, 5-11 February 2002.CIMMYT/KARI, Nairobi, Kenya.

Bhatnagar, S., F.J. Betrån, and LW. Rooney. 2004. Combining abilities of protein maize inbreds. Crop Sci. 44:1997-2005.

Bias, C., S.A. Henderson, J.G. White, and L. Sitch. 1997. Variation in grain yield among early flowering varieties in Mozambique p274-279. In D.K Friesen and A.F.E Palmer (eds). Integrated Approaches to higher maize productivity in the New Millennium. Proceedings of the 7th Eastern and Southern Africa regional maize conference, 5-11 February 2002.CIMMYT/KARI, Nairobi, Kenya.

Bjarnason, M., and S.K. Vasal. 1992. Breeding of Quality Protein Maize. In Janick J. (ed) Plant breeding reviews 9:181-216.

Bolaños, J. and G.O. Edmeades. 1997. The importance of the anthesis silking interval in breeding for drought in tropical maize. In G.O. Edmeades, M. Banziger, H.R. Mickelson and C.D Peña-Valdinia (eds.). Developing drought and low N-tolerant Maize. Proceedings of a symposium, March 25-29, 1996, CIMMYT, El Batån, Mexico. Mexico, D.F.: CIMMYT.

Bressani, R. 1991. Protein quality of high lysine maize for humans, Cereal Foods World. 36:806-811.

CIMMYT. 1999. The improvement and promotion of quality protein maize in selected developing countries. Progress report. International maize testing program, CIMMYT, EL Batan, Mexico, D.F., Mexico.

CIMMYT. 2003. The development and promotion of Quality Protein Maize in sub Saharan Africa. Progress report. International maize testing program, CIMMYT, EL Batan, Mexico, D.F., Mexico.

Crow, J.F., and J. Kermicle. 2002. Oliver Nelson and Quality Protein Maize. Genetics. 160:819-821.

Dass, S., N.N. Singh, Y.P. Dang and A.K. Dhawan. 1997. Morpho-physiological basis for breeding drought and low-N tolerant maize genotypes in India p107-111. In G.O. Edmeades, M. Banziger, H.R. Mickelson and C.D Peña-Valdinia (eds.). Developing drought and low N-tolerant Maize. Proceedings of a symposium, March 25-29, 1996, CIMMYT, El Batán, Mexico. Mexico, D.F.: CIMMYT.

Diallo. A.O., J. Kikafunda, L. Wolde, O. Odongo, Z.O. Mduruma, W.S. Chivasti, D.K. Friesen and M. Banziger. 2004 p206-212. Drought and Low nitrogen tolerant hybrids for the mid-altitude ecology of Eastern Africa. In D.K Friesen and A.F.E Palmer (eds). Integrated Approaches to higher maize productivity in the New Millennium. Proceedings of the 7th Eastern and Southern Africa regional maize conference, 5-11 February 2002: CIMMYT/KARI, Nairobi, Kenya.

Diallo, A.O., A. Adam, R.K. Akanvou and P.Y.K. Sallah. 1997. Response of S4 maize lines evaluated under stress and nonstress environments p 280-285. In G.O. Edmeades, M. Banziger, H.R. Mickelson and C.D Peña-Valdinia (eds.). Developing drought and low N-tolerant Maize. Proceedings of a symposium, March 25-29, 1996, CIMMYT, El Batán, Mexico. Mexico, D.F.: CIMMYT.

Dorrance, A.E., K. H. Hinkelmann and H. L. Warren. 1998. Diallel analysis of Diplodia ear rots resistance in Maize. Plant Dis. 82:699-703.

Edmeades, G.O., J. Bolaños, S.C Chapman. 1997. Value of secondary traits in selecting for drought tolerance in tropical maize p 222-233. In G.O. Edmeades, M. Banziger, H.R. Mickelson and C.D Peña-Valdinia (eds.). Developing drought and low N-tolerant Maize. Proceedings of a symposium, March 25-29, 1996, CIMMYT, El Batán, Mexico. Mexico, D.F.: CIMMYT.

Egesel, C.D., J.C. Wong, R.J. Lambert, and T.R. Rocheford. 2003. Combining ability of maize inbreds for Carotenoids and Topopherols. Crop Sci. 43: 818-823.

Falconer, D.S. 1989. Introduction to quantitative genetics 3rd (ed) Longman, London, England.

FAOSTAT. 2003. Statistical Database of the Food and Agriculture of the United Nations. http//ww.fao.org.

Fehr. W. 1993. Principles of cultivar development. Macmillan London.

Glover, M.A., D.B. Willmot, L.L. Darrah, B.E. Hibbard and X. Zhu. 2005. Diallel analyses of agronomic traits using Chinese and U.S Maize Germplasm. Crop Sci. 45:1096-1102.

Griffing, B. 1956. Concepts of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9: 463-493.

Hallauer, A.R., and J.B. Miranda. 1988. Quantitative genetics in maize breeding. Iowa State University press. Ames, IA.

Hayman, B.I. 1954. The theory and analysis of diallel crosses. Genetics. 39:789-809.

Huang S, W.R. Adams, Q. Zhou, K.P. Malloy, D.A. Voyles J. Anthony, A.L. Kriz and M. H. Luethy. 2004. Improving nutritional quality of maize protein by expressing sense and antisense zein genes. J. Agric Food Chem. 52:1958-1964.

Krivanek, A.F., H.D. Groote, N.S. Gunaratha, A.O. Diallo and D. Friesen. 2007. Breeding and disseminating quality protein maize (QPM) for Africa. Afr. J. Biotechnology. 6:312-324.

Lynch, P.J., B. Hunter, and L.W. Kannenberg. 1973. Relative importance of single cross, three way cross and double cross corn hybrids recommended in Ontario, 1968-72. Can. J. Plant Sci. 53:805-810.

Manda, T.H.E., and C. Mwambula. 1999. Screening and selection of tropical maize genotypes for drought tolerance using primary and secondary traits p32-34. In CIMMYT and EARO. Maize production technology for the future: challenges and opportunities: proceedings of the sixth eastern and southern Africa regional maize conference, September 21-25, 1998, Addis Ababa, Ethiopia: CIMMYT and EARO.

Menkir, A., and M. Ayodele. 2005. Genetic analysis of gray leaf spot of midaltitude maize Inbred lines. Crop Sci 45:163-170.

Morris M.L. 1998. Maize seed industries in developing countries. CIMMYT.

Naidoo, G.A., M. Forbes, C. Paul, D.G. White, and T.R. Rocheford. 2002. Resistance to Aspergillus ear rots and aflatoxin accumulation in Maize F1 hybrids. Crop Sci. 42:360-364.

Nigussie, N., and H. Zelleke. 2001. Heterosis and combining ability in a diallel among eight elite populations. Afr. Crop Sci. 9: 471-479.

Njoroge, K., B. Wafula, and J.K. Ransom. 1997. Characterization of drought stress in the major maize production zones of Kenya p35-38. In G.O. Edmeades, M. Banziger, H.R. Mickelson and C.D Peña-Valdinia (eds.). Developing drought and low N-tolerant Maize. Proceedings of a symposium, March 25-29, 1996, CIMMYT, El Batán, Mexico. Mexico, D.F.: CIMMYT.

Patterson, H.D., and E.R. Williams. 1976. A new class of resolvable incomplete block designs. Biometrika. 63:83-89.

Pixley, K.V., and M.S. Bjarnason. 2002. Stability of grain yield, endosperm modification and protein quality of hybrid and open pollinated quality protein Maize (QPM) cultivars. Crop. Sci. 42:1882-1890.

Prasanna, B.M., Vasal S.K., B. Kassahum, and N.N sigh. 2001. Quality Protein Maize Current science: 1308-1318.

Rossouw, J.D., J.B.J. van Rensburg, and C.S van Denventer. 2002. Breeding for resistance to ear rot of maize caused by Stenocarpella maydis (Berk) Sutton. 2. Inheritance of resistance. S. Afr. Tydskr. Plant Grond 19:188-194.

Saleh, G.B., D. Abdullah, and A.R. Anuar. 2002. Performance, heterosis and heritability in selected tropical maize single, double and three way cross hybrids. J. Agric. Sci. 138:21-28.

San Vicente, F.M., S.K. Vasal, S.D. Mclean, M. Banziger, S.K Ramanujam, and M. Barandiaran 1997. Performance of promising late yellow inbred lines under stress conditions p301-303. In G.O. Edmeades, M. Banziger, H.R. Mickelson and C.D Peña-Valdinia (eds.). Developing drought and low N-tolerant Maize. Proceedings of a symposium, March 25-29, 1996, CIMMYT, El Batán, Mexico. Mexico, D.F.: CIMMYT.

SAS Institute 2003.SAS Proprietary Software. SAS Institute Inc. Cary NC

Simmonds, N.W. 1989. Principles of crop improvement. Inc., New Yolk. ELBS English language book society. Longman.

Singh, B. D. 1995. Plant breeding hybrid and synthetic varieties. Kalyani publishers. New Delhi, India.

Smith, O.S., K. Hoard, F. Shaw, and R. Shaw. 1999. Prediction of single cross Performance p 353-360. In J.G. Moors and S. Pandey (eds). The genetics and exploitation of heterosis in crops. Madison, Wisconsin, USA.

Srinivasan, G., M. Banziger, G.O. Edmeades, J.E. Lothrop and J.L. Torres. 1997. Identification of drought tolerance in elite tropical highland maize germplasm p 309-312. In G.O. Edmeades, M. Banziger, H.R. Mickelson and C.D Peña-Valdinia (eds.). Developing drought and low N-tolerant Maize. Proceedings of a symposium, March 25-29, 1996, CIMMYT, El Batán, Mexico. Mexico, D.F.: CIMMYT.

Sprague, G.F, and L.M. Tatum. 1942. General versus specific combining ability of corn. J. Am Soc. Agron. 34: 923-932.

Springfield, G.H. 1950. Heterozygosis and hybrid vigor in maize. Agron. J. 42:145-152

Vacaro, E. J.F.B. Neto, D.G. Pegorato, C.N. Nuss and L.D.H Conceição. 2002. Combining ability of twelve maize populations. Pasq. Agropec.bras. Brasilia 37:67-72.

Vasal, S.K. 2000. The quality protein maize story. Food Nutr. Bull. 21:445-450.

Vasal, S.K. 2002. Quality Protein Maize: Overcoming the hurdles. J. Crop production. 6:193-227.

Vasal, S.K., G. Srinivasan, S. Pandey, F. González, C. J. Crossa and D.L. Beck. 1993a. Heterosis and combining ability of CIMMYT's Quality Protein Maize Germplasm: 1. Lowland tropical. Crop Sci. 33:46-51.

Vasal, S.K., G. Srinivasan, F. González C, D.L. Beck and J. Crossa. 1993b. Heterosis and combining ability of CIMMYT's Quality Protein Maize Germplasm: II. Subtropical. Crop Sci. 33:51-57.

Weatherspoon, J.H. 1970. Comparative yields of single, three-way and double-crosses of Maize. Crop Sci.10:157-159.

Xingming, F., T. Jing, H. Bihua, and L. Feng. 2004. Analyses of combining ability and heterotic groups of yellow grain quality protein maize inbreds p143-147. In D.K Friesen and A.F.E Palmer (eds). Integrated Approaches to higher maize productivity in the New Millennium. Proceedings of the 7th Eastern and Southern Africa regional maize conference, 5-11 February 2002: CIMMYT/KARI, Nairobi, Kenya..

Zhang, Y., and M.S. Kang. 1997. DIALLEL-SAS Program for Griffing's diallel analyses. Agron. J. 89:76-182.

APPENDIX A

Mean grain yield and agronomic traits for 110 QPM hybrids across three environments in 2006

Cross	Entry	Grain yield					Agronomic traits						
		Across	Embu	Kak	Kib-1	Kib-2	AD	ASI	RL	SL	EPP	ER	EA
		tons/ha					*d*	*d*	*%*	*%*	*#*	*%*	*Sc 1-5*
Diallel Hybrids													
1x2	1	3.66	5.04	1.92	4.35	3.32	69.39	1.79	1.78	7.93	0.84	14.26	2.45
1x3	2	3.24	5.09	1.43	3.97	2.48	68.40	2.51	9.86	18.51	0.71	18.73	2.49
1x4	3	4.72	7.50	2.67	4.81	3.89	70.54	0.53	5.76	8.24	0.80	14.60	1.88
1x5	4	3.15	4.68	1.04	3.71	3.16	68.03	1.47	5.59	7.25	0.83	15.91	2.60
1x6	5	3.23	5.00	1.03	3.75	3.15	69.19	1.78	5.22	8.23	0.79	14.21	2.40
1x7	6	3.63	6.18	0.89	4.58	2.88	67.24	3.42	13.65	15.88	0.77	11.74	2.42
1x8	7	3.63	5.41	0.79	4.78	3.54	70.32	2.65	6.90	7.01	0.70	23.65	2.23
1x9	8	3.06	4.51	0.59	4.41	2.71	66.75	1.77	8.70	42.00	0.70	11.35	2.74
1x10	9	3.43	4.96	1.68	4.64	2.45	67.97	3.62	5.68	13.96	0.79	20.42	3.38
1x11	10	3.24	5.35	1.40	3.96	2.25	69.99	2.24	11.64	2.83	0.78	15.08	2.54
1x12	11	3.56	5.62	1.38	3.56	3.67	67.87	5.09	6.33	7.81	0.76	18.17	2.36
1x13	12	3.29	5.16	0.60	4.19	3.21	64.97	3.71	6.58	8.15	0.83	29.88	2.59
1x14	13	3.66	5.90	1.10	5.26	2.39	68.54	2.80	11.05	9.04	0.76	12.16	2.72
2x3	15	2.92	4.17	0.87	3.36	3.28	67.28	4.98	2.47	13.39	0.76	15.80	2.22
2x4	16	4.02	6.86	2.91	3.22	3.11	68.88	4.14	5.85	3.97	0.79	0.58	1.45
2x5	17	3.38	5.32	1.93	3.54	2.74	66.32	4.49	4.50	9.09	0.78	9.42	2.35
2x6	18	3.05	5.38	1.39	2.88	2.57	67.76	2.98	2.43	4.44	0.80	9.94	2.21
2x7	19	3.15	4.86	1.02	4.35	2.36	67.39	2.61	16.38	13.82	0.80	11.68	2.39
2x8	20	3.32	5.99	1.08	3.34	2.87	69.67	3.28	8.88	4.49	0.73	10.00	2.10
2x9	21	3.10	4.86	0.68	3.79	3.05	67.89	3.34	6.48	16.07	0.67	11.96	2.05
2x10	22	2.96	5.28	1.08	2.65	2.84	67.49	7.11	2.87	9.17	0.67	13.48	2.31
2x11	23	3.59	5.74	1.87	3.59	3.16	67.03	3.58	2.94	5.89	0.78	9.91	1.70
2x12	24	2.47	4.03	0.81	2.57	2.48	66.01	5.13	8.55	10.46	0.61	8.18	2.58
2x13	25	3.22	5.51	1.54	3.11	2.70	66.17	5.66	4.51	6.05	0.67	11.62	2.29
2x14	26	3.23	6.08	0.95	3.30	2.61	67.27	4.77	4.00	8.96	0.68	13.56	2.32
3x4	29	4.03	6.47	2.52	3.97	3.16	69.09	4.01	5.79	8.05	0.71	13.25	1.67
3x5	30	2.63	3.93	0.80	3.05	2.72	65.61	3.18	5.65	13.97	0.67	24.83	2.67
3x6	31	3.48	6.11	0.98	3.57	3.26	67.89	3.29	2.11	5.24	0.67	13.91	2.10
3x7	32	3.45	4.31	0.49	5.40	3.59	66.27	1.34	12.57	16.78	0.71	13.58	2.38
3x8	33	3.22	5.16	0.70	3.68	3.33	67.96	2.99	3.87	16.65	0.62	20.98	2.29
3x9	34	3.48	4.26	1.32	5.46	2.87	65.07	4.58	2.86	17.21	0.77	9.73	2.26
3x10	35	2.97	4.63	0.53	3.72	2.99	66.38	5.72	5.16	19.36	0.62	32.20	2.56
3x11	36	3.05	4.30	1.01	3.72	3.18	67.33	4.86	7.41	9.18	0.72	12.35	2.48
3x12	37	2.76	3.59	0.51	4.00	2.93	65.52	3.99	14.80	30.07	0.68	35.04	2.52
3x13	38	2.64	3.38	0.50	3.89	2.77	66.65	6.29	9.13	3.06	0.60	37.03	2.60
3x14	39	3.05	4.64	0.60	3.85	3.12	66.91	3.68	4.62	3.83	0.67	18.05	2.01
4x5	42	3.62	6.41	1.96	3.65	2.45	68.47	5.31	4.67	2.63	0.76	11.62	2.13
4x6	43	4.61	8.48	3.48	3.58	2.90	69.05	3.76	8.71	1.50	0.76	9.60	1.94
4x7	44	3.95	5.89	2.17	3.67	4.08	69.01	2.80	8.12	5.83	0.81	6.82	1.92
4x8	45	4.48	8.09	2.07	4.07	3.68	70.37	5.80	15.48	5.03	0.80	14.69	1.88
4x9	46	3.81	6.76	1.05	4.47	2.98	67.00	2.37	4.94	10.49	0.72	9.01	2.09

APPENDIX A Cont:

Cross	**Entry**	**Grain Yield**					**Agronomic traits**						
		Across	**EMB**	**KAK**	**KIB-1**	**KIB-2**	**AD**	**ASI**	**RL**	**SL**	**EPP**	**ER**	**EA**
		tons/ha					**d**	**d**	**%**	**%**	**#**	**%**	**Sc-1-5**
4x10	47	3.48	6.31	1.53	2.67	3.41	68.39	8.49	2.14	1.84	0.75	20.49	2.68
4x11	48	4.17	5.43	3.09	4.20	3.97	69.23	1.60	4.62	2.84	0.81	11.61	1.80
4x12	49	3.94	7.14	2.03	2.77	3.83	66.63	4.85	6.90	9.91	0.75	11.54	2.08
4x13	50	3.68	7.01	2.27	2.16	3.27	69.68	6.48	13.78	1.66	0.71	14.82	2.26
4x14	51	3.73	6.47	2.12	3.38	2.96	69.60	5.86	6.46	3.99	0.83	7.73	2.18
5x6	54	3.44	6.02	1.23	3.40	3.11	66.06	2.61	4.21	1.84	0.73	19.45	2.39
5x7	55	3.35	4.43	1.37	4.55	3.04	64.09	2.00	7.76	12.67	0.84	8.83	2.28
5x8	56	3.32	5.64	1.01	3.95	2.68	66.99	3.84	7.04	8.75	0.73	16.41	2.28
5x9	57	2.35	4.03	0.62	2.10	2.65	64.90	3.90	10.56	18.51	0.72	17.31	2.36
5x10	58	3.08	4.53	1.03	3.46	3.30	65.38	5.19	2.19	7.79	0.73	10.95	2.43
5x11	59	3.06	4.32	1.25	3.96	2.73	66.25	3.70	3.40	9.06	0.79	13.59	2.69
5x12	60	2.50	3.53	0.63	3.30	2.57	64.58	4.98	6.07	8.04	0.72	18.36	2.64
5x13	61	3.00	3.88	1.64	3.26	3.21	65.09	3.58	3.98	7.30	0.78	17.06	2.51
5x14	62	2.90	5.14	0.93	2.82	2.72	65.00	3.83	2.43	6.79	0.76	16.00	2.30
6x7	64	3.28	5.68	0.99	3.42	3.03	65.94	2.52	15.71	8.13	0.76	22.44	2.30
6x8	65	3.49	6.79	1.00	3.56	2.64	68.67	2.81	6.63	10.48	0.71	9.48	2.02
6x9	66	3.34	6.29	0.61	3.44	3.01	63.56	3.13	9.43	7.84	0.67	13.66	2.30
6x10	67	2.60	4.63	0.76	3.06	1.95	66.77	7.17	1.82	6.05	0.67	31.19	2.99
6x11	68	2.99	5.40	1.02	2.60	2.93	66.79	2.63	8.03	6.63	0.72	14.60	2.17
6x12	69	2.94	5.70	1.20	2.37	2.48	65.95	4.85	10.36	5.71	0.69	12.33	2.42
6x13	70	3.25	7.07	0.50	2.63	2.80	67.10	6.97	4.41	6.12	0.60	25.51	2.08
6x14	71	3.39	6.03	0.92	3.67	2.94	67.34	3.31	4.45	6.50	0.70	13.19	2.16
7x8	74	2.97	5.33	0.71	3.20	2.65	68.32	3.00	8.55	13.31	0.66	16.18	2.38
7x9	75	3.30	5.45	0.41	4.45	2.87	66.37	1.20	15.44	21.51	0.71	23.23	1.74
7x10	76	3.70	6.08	0.95	3.93	3.83	66.73	2.90	7.25	19.50	0.72	14.68	2.20
7x11	77	2.96	4.70	0.60	3.31	3.24	65.87	2.03	7.45	27.39	0.72	15.95	2.64
7x12	78	3.56	5.57	0.71	4.61	3.37	64.86	2.59	10.76	16.61	0.73	11.83	2.31
7x13	79	3.38	4.79	0.49	4.73	3.53	66.21	1.73	7.37	15.40	0.67	9.87	2.06
7x14	80	3.08	3.76	0.60	4.76	3.20	66.52	2.97	8.62	15.61	0.70	11.34	2.32
8x9	83	2.63	4.64	0.62	3.11	2.16	67.58	3.27	3.87	7.63	0.66	13.35	2.27
8x10	84	2.74	4.66	0.62	3.59	2.09	69.26	7.64	7.89	8.43	0.62	28.73	2.85
8x11	85	3.59	7.09	1.43	2.59	3.25	69.91	3.99	10.96	3.31	0.75	12.13	2.28
8x12	86	2.66	4.28	0.42	2.86	3.07	66.25	3.47	7.58	10.67	0.64	35.40	2.37
8x13	87	3.14	5.82	0.42	3.40	2.92	68.60	5.55	10.23	7.23	0.60	18.11	2.20
8x14	88	3.32	5.71	1.02	3.50	3.04	68.68	4.71	4.84	6.76	0.68	13.08	2.16
9x10	91	2.87	4.80	0.59	3.36	2.73	65.96	4.28	5.47	9.50	0.64	16.22	2.59
9x11	92	2.70	3.41	0.59	3.94	2.85	67.68	2.99	6.02	11.99	0.65	30.87	2.78
9x12	93	2.66	4.20	0.20	3.52	2.72	62.90	3.23	2.26	58.44	0.64	22.85	2.36
9x13	94	2.33	4.68	0.41	2.19	2.05	67.11	5.33	12.81	19.41	0.55	28.02	2.53
9x14	95	3.16	4.50	1.17	4.17	2.82	65.91	3.52	7.23	17.12	0.81	9.28	2.34
10x11	96	2.70	4.48	0.95	3.35	2.00	67.37	4.75	4.57	7.40	0.65	23.16	2.85
10x12	97	2.75	4.63	0.51	3.77	2.08	65.65	7.25	6.71	9.59	0.63	34.51	2.53
11x12	101	3.17	5.80	1.36	3.03	2.48	65.43	5.14	4.46	7.41	0.70	15.41	2.56
10x14	99	3.13	4.96	0.63	4.12	2.79	65.65	5.57	4.77	6.69	0.75	11.44	2.53
10x13	98	3.12	5.83	0.50	3.91	2.22	66.88	5.89	6.83	5.12	0.52	63.99	2.72
11x13	102	2.81	4.96	0.53	3.14	2.60	68.66	4.94	12.84	4.42	0.62	29.28	2.42

APPENDIX A Cont:

Cross	**Entry**	**Grain Yield**					**Agronomic traits**						
		Across	**EMB**	**KAK**	**KIB-1**	**KIB-2**	**AD**	**ASI**	**RL**	**SL**	**EPP**	**ER**	**EA**
				tons/ha			**d**	**d**	**%**	**%**	**#**	**%**	**Sc-1-5**
11x14	103	3.20	5.21	0.63	3.83	3.14	66.61	3.11	9.79	8.32	0.69	26.26	2.40
12x13	105	3.01	5.45	0.41	2.79	3.39	66.34	5.40	6.82	3.42	0.68	31.38	2.67
12x14	106	2.56	3.47	0.51	3.34	2.91	66.47	5.18	6.06	2.51	0.71	25.10	2.37
13x14	107	3.08	4.37	0.39	4.26	3.29	67.33	3.63	9.05	5.69	0.68	16.85	2.31
Experimental checks													
1xB	14	4.27	4.67	1.95	6.43	4.05	71.64	1.63	6.03	14.08	0.79	26.77	2.81
2xA	27	5.03	6.53	4.99	4.71	3.89	73.02	1.68	1.72	5.19	0.84	9.09	1.30
2xB	28	3.58	4.69	3.19	3.33	3.12	70.57	3.33	4.90	5.49	0.68	16.04	2.28
3xA	40	3.24	5.79	0.90	3.52	2.76	68.94	4.88	1.17	14.24	0.78	17.88	2.21
3xB	41	3.92	5.01	1.53	5.05	4.08	70.03	2.85	8.76	16.70	0.78	10.37	1.82
4xA	52	5.22	6.81	5.35	5.11	3.61	74.26	0.35	2.24	3.57	0.86	6.61	1.93
4xB	53	5.04	7.16	4.12	4.72	4.17	71.26	5.98	5.73	4.17	0.77	9.89	2.45
5xB	63	3.98	5.54	2.14	5.03	3.23	68.51	3.90	6.50	5.22	0.82	20.13	2.30
6xA	72	4.60	8.13	2.96	4.23	3.07	67.48	2.06	2.07	8.74	0.81	9.21	2.07
6xB	73	4.72	6.77	2.85	5.25	4.00	69.92	2.12	4.66	5.19	0.79	12.06	2.17
7xA	81	4.39	6.75	2.97	4.29	3.55	71.42	2.23	3.82	12.35	0.88	15.00	2.34
7xB	82	3.53	3.34	2.23	4.19	4.36	69.42	2.40	20.04	30.78	0.86	11.47	2.45
8xA	89	3.90	5.33	2.95	4.07	3.27	74.50	1.53	17.05	1.05	0.74	14.97	2.05
8xB	90	4.37	7.05	1.54	5.43	3.44	71.26	4.04	5.46	0.86	0.74	21.73	2.26
10xB	100	3.64	6.01	1.13	4.91	2.50	69.60	3.36	12.04	10.25	0.69	47.80	3.04
11xB	104	3.71	5.55	1.80	4.73	2.78	71.57	2.03	3.60	7.19	0.78	15.96	2.57
13xA	108	3.50	6.10	1.38	4.08	2.46	73.17	4.17	5.96	1.93	0.70	20.20	2.22
13xB	109	3.72	6.11	1.57	3.71	3.51	69.83	4.73	17.90	4.18	0.75	19.32	2.47
AxB	110	4.40	5.76	3.37	5.06	3.41	73.55	2.52	9.16	4.28	0.76	11.91	2.20
Mean		**3.39**	**5.40**	**1.35**	**3.81**	**3.02**	**67.84**	**3.77**	**7.11**	**9.96**	**0.73**	**17.28**	**2.33**
LSD (0.05)		**0.66**	**1.64**	**0.92**	**1.59**	**1.00**	**1.62**	**2.60**	**7.81**	**13.39**	**0.12**	**18.55**	**0.52**
Min		**2.33**	**3.34**	**0.20**	**2.10**	**1.95**	**62.90**	**0.35**	**1.17**	**0.86**	**0.52**	**0.58**	**1.30**
Max		**5.22**	**8.48**	**5.35**	**6.43**	**4.36**	**74.50**	**8.49**	**20.04**	**58.44**	**0.88**	**63.99**	**3.38**

APPENDIX B

Mean grain yield and agronomic traits for 110 QPM hybrids at Embu in 2006

Cross	Entry	GY *t/ha*	AD *d*	ASI *d*	RL *%*	SL *%*	EPP *#*	ER *%*	EA *Sc 1-5*
Diallel hybrids									
1x2	1	5.04	68.50	-1.50	-0.17	0.00	1.09	8.85	1.97
1x3	2	5.09	65.50	0.00	-0.23	0.00	1.07	5.00	2.56
1x4	3	7.50	71.00	-3.50	-0.11	0.00	1.03	13.07	1.61
1x5	4	4.68	67.50	-2.50	-0.24	2.40	1.01	19.42	2.47
1x6	5	5.00	68.00	-1.50	0.33	0.00	1.12	11.14	2.31
1x7	6	6.18	66.50	0.50	0.00	9.50	0.98	6.94	1.90
1x8	7	5.41	70.50	-1.50	-0.23	2.40	0.98	24.14	2.05
1x9	8	4.51	67.00	-1.00	-0.23	7.15	1.01	8.92	2.45
1x10	9	4.96	69.00	-0.50	0.24	0.00	1.04	21.40	3.32
1x11	10	5.35	68.50	-0.50	0.53	0.00	1.21	14.74	1.75
1x12	11	5.62	66.50	1.50	-0.07	0.00	1.01	14.66	2.00
1x13	12	5.16	65.50	-0.50	-0.86	0.00	0.98	16.45	2.49
1x14	13	5.90	68.50	-2.00	-0.01	0.00	0.97	12.60	2.30
2x3	15	4.17	68.00	1.00	0.45	0.00	1.00	13.04	2.47
2x4	16	6.86	65.00	4.50	0.30	0.00	1.08	-6.75	0.93
2x5	17	5.32	64.00	0.00	0.07	4.75	1.09	6.90	2.41
2x6	18	5.38	68.50	0.00	-0.11	0.00	1.05	5.19	1.96
2x7	19	4.86	66.50	0.50	4.94	2.40	0.95	8.40	2.07
2x8	20	5.99	69.00	-1.50	0.41	0.00	1.02	1.81	1.97
2x9	21	4.86	68.50	0.00	1.81	7.40	0.98	3.67	1.98
2x10	22	5.28	67.50	2.00	-0.06	0.00	1.00	5.93	2.14
2x11	23	5.74	66.00	0.00	0.25	2.40	1.07	3.99	1.50
2x12	24	4.03	64.00	3.50	0.05	0.00	0.95	4.23	2.40
2x13	25	5.51	63.50	1.00	-0.24	0.00	0.93	8.21	1.66
2x14	26	6.08	68.00	0.00	0.11	2.40	1.05	9.18	1.60
3x4	29	6.47	68.00	-1.50	0.06	0.00	1.09	9.52	1.27
3x5	30	3.93	64.00	0.50	0.25	2.40	0.92	13.42	2.65
3x6	31	6.11	68.00	-2.00	0.45	0.00	1.03	12.70	1.63
3x7	32	4.31	65.00	-1.00	3.10	7.50	0.99	7.97	2.14
3x8	33	5.16	68.50	0.00	-0.14	0.00	0.96	18.12	2.25
3x9	34	4.26	66.00	-0.50	9.27	21.45	1.05	10.80	2.37
3x10	35	4.63	66.50	1.50	4.64	0.00	0.91	21.98	2.69
3x11	36	4.30	66.50	-0.50	-0.29	2.40	0.85	6.95	2.21
3x12	37	3.59	64.50	-0.50	0.51	0.00	1.00	18.28	2.40
3x13	38	3.38	66.00	-1.50	0.11	2.40	0.93	14.71	2.94
3x14	39	4.64	66.50	0.00	-0.19	0.00	0.99	6.32	1.63
4x5	42	6.41	67.00	0.00	-0.01	2.40	1.03	14.19	1.96
4x6	43	8.48	68.50	-1.00	-0.05	0.00	1.05	7.12	1.27
4x7	44	5.89	69.00	-1.50	2.27	0.00	1.07	4.80	1.56
4x8	45	8.09	72.00	-2.00	-0.05	0.00	1.03	12.44	1.20

APPENDIX B Cont:

Cross	**Entry**	**GY** *t/ha*	**AD** *d*	**ASI** *d*	**RL** *%*	**SL** *%*	**EPP** *#*	**ER** *%*	**EA** *Sc 1-5*
4x9	46	6.76	65.50	-0.50	0.18	0.00	0.95	-2.81	1.02
4x10	47	6.31	69.50	1.00	-0.46	0.00	1.00	16.62	1.80
4x11	48	5.43	69.00	-0.50	2.51	0.00	0.99	9.32	1.77
4x12	49	7.14	66.00	0.50	0.00	0.00	1.00	14.08	1.93
4x13	50	7.01	68.00	-0.50	0.00	0.00	1.07	17.37	1.78
4x14	51	6.47	70.50	0.50	-0.01	0.00	1.00	7.21	1.88
5x6	54	6.02	66.00	-1.50	-0.22	0.00	1.05	12.52	2.46
5x7	55	4.43	63.00	0.50	2.08	4.75	1.08	8.32	2.13
5x8	56	5.64	64.00	-0.50	-0.29	0.00	1.01	20.81	1.79
5x9	57	4.03	63.50	0.50	0.12	0.00	0.97	5.84	2.58
5x10	58	4.53	64.00	0.00	0.05	0.00	0.98	11.30	2.69
5x11	59	4.32	64.50	0.00	2.28	0.00	1.04	9.50	2.80
5x12	60	3.53	63.00	0.50	0.05	0.00	0.95	14.29	2.90
5x13	61	3.88	63.00	0.00	-0.11	0.00	0.91	18.37	2.61
5x14	62	5.14	63.50	0.00	-0.58	0.00	1.02	16.90	2.08
6x7	64	5.68	65.50	0.00	0.42	0.00	1.05	12.19	1.59
6x8	65	6.79	68.00	0.50	0.06	0.00	1.02	6.95	1.74
6x9	66	6.29	65.50	-0.50	-0.13	0.00	1.06	4.00	2.15
6x10	67	4.63	66.50	2.00	0.06	0.00	0.95	31.31	2.99
6x11	68	5.40	64.50	0.50	0.13	4.75	1.00	14.07	1.99
6x12	69	5.70	65.50	0.50	2.57	4.75	1.03	10.54	1.60
6x13	70	7.07	64.00	-0.50	-0.11	0.00	1.03	12.58	1.27
6x14	71	6.03	67.50	0.00	0.19	0.00	1.00	11.31	2.23
7x8	74	5.33	70.00	-0.50	0.01	2.40	0.93	13.87	2.02
7x9	75	5.45	65.00	-1.00	-2.70	0.00	1.00	4.97	1.53
7x10	76	6.08	64.50	0.00	-0.76	0.00	1.01	7.96	2.08
7x11	77	4.70	64.00	1.00	0.04	5.00	0.97	12.89	2.21
7x12	78	5.57	64.50	0.00	2.60	2.40	0.97	7.65	1.75
7x13	79	4.79	64.00	-1.00	0.00	11.90	0.94	1.99	1.99
7x14	80	3.76	66.00	0.00	2.85	19.05	0.94	5.35	2.05
8x9	83	4.64	68.00	-2.00	0.24	0.00	0.90	12.06	1.35
8x10	84	4.66	70.50	-0.50	0.39	0.00	1.02	20.65	2.97
8x11	85	7.09	69.00	-0.50	0.16	0.00	1.05	12.88	1.72
8x12	86	4.28	66.00	0.50	0.19	0.00	1.02	33.75	2.90
8x13	87	5.82	68.00	0.00	0.05	2.40	0.98	10.42	1.80
8x14	88	5.71	69.00	0.50	0.06	0.00	1.00	11.61	1.70
9x10	91	4.80	66.00	0.00	-0.34	0.00	0.93	25.16	2.13
9x11	92	3.41	67.00	-1.00	-0.06	0.00	0.83	21.57	2.61
9x12	93	4.20	63.00	0.00	2.46	0.00	1.00	30.22	2.69
9x13	94	4.68	65.50	0.00	2.35	0.00	0.89	13.91	2.04
9x14	95	4.50	65.00	0.50	0.51	0.00	1.03	4.86	2.05
10x11	96	4.48	66.50	0.50	-0.07	2.65	0.95	23.69	2.46
10x12	97	4.63	64.00	3.00	0.12	2.40	0.95	33.75	2.40

APPENDIX B Cont:

Cross	**Entry**	**GY** ***t/ha***	**AD** ***d***	**ASI** ***d***	**RL** ***%***	**SL** ***%***	**EPP** ***#***	**ER** ***%***	**EA** ***Sc 1-5***
10x13	98	5.83	65.50	0.00	-0.12	0.00	1.00	15.21	2.38
10x14	99	4.96	65.50	1.00	-0.69	0.00	0.97	7.80	2.33
11x12	101	5.80	63.50	0.50	-0.58	0.00	1.05	11.29	2.27
11x13	102	4.96	67.50	0.50	-0.06	0.00	0.82	27.93	2.39
11x14	103	5.21	66.50	0.50	0.01	0.00	1.05	19.35	1.91
12x13	105	5.45	63.50	2.00	-0.30	0.00	1.03	31.21	2.06
12x14	106	3.47	65.00	2.00	-0.06	0.00	0.97	30.09	2.66
13x14	107	4.37	66.50	0.00	2.21	0.00	0.96	19.11	2.05
Experimental checks									
1xB	14	4.67	73.50	0.50	10.23	0.00	0.75	34.94	2.54
2xA	27	6.53	73.00	-0.50	-0.07	2.40	1.09	12.75	1.47
2xB	28	4.69	70.50	0.50	0.07	0.00	0.84	10.95	2.15
3xA	40	5.79	71.50	-3.50	0.86	0.00	0.95	10.42	1.79
3xB	41	5.01	69.50	2.00	0.13	0.00	0.95	6.65	1.57
4xA	52	6.81	76.00	-4.50	-0.51	4.75	1.07	6.75	1.27
4xB	53	7.16	73.50	-1.00	0.05	0.00	0.95	8.08	1.80
5xB	63	5.54	68.50	-1.00	7.75	0.00	1.05	23.34	2.22
6xA	72	8.13	74.00	-5.00	-0.13	0.00	0.95	5.66	1.22
6xB	73	6.77	70.00	-1.50	-0.12	0.00	1.00	4.54	1.75
7xA	81	6.75	71.50	-3.00	0.12	4.75	1.10	22.37	1.93
7xB	82	3.34	69.00	3.00	37.17	19.05	0.87	12.24	2.83
8xA	89	5.33	76.00	-4.50	0.48	0.00	0.97	23.92	1.97
8xB	90	7.05	72.00	-0.50	-0.23	0.00	0.97	24.35	1.87
10xB	100	6.01	67.00	0.00	7.28	2.40	0.95	24.08	2.94
11xB	104	5.55	70.50	-2.00	0.00	16.70	0.93	17.65	2.07
13xA	108	6.10	69.50	-1.50	0.17	0.00	0.97	18.20	1.86
13xB	109	6.11	69.50	0.50	-0.12	7.15	0.87	17.98	1.81
AxB	110	5.76	64.00	-0.50	2.44	2.40	0.93	12.31	2.00
Mean		**5.40**	**67.23**	**-0.24**	**1.05**	**1.83**	**0.99**	**13.38**	**2.07**
LSD (0.05)		**1.64**	**4.63**	**4.75**	**6.59**	**11.52**	**0.15**	**17.83**	**0.79**
Min		**3.34**	**63.00**	**-5.00**	**-0.86**	**0.00**	**0.75**	**-6.75**	**0.93**
Max		**8.48**	**76.00**	**4.50**	**37.17**	**21.45**	**1.21**	**34.94**	**3.32**

APPENDIX C

Mean grain yield and agronomic traits for 110 QPM hybrids at Kakamega in 2006

Cross	Entry	GY *t/ha*	AD *d*	ASI *d*	RL *%*	SL *%*	EPP *#*	ER *%*	EA *Sc 1-5*
Diallel hybrids									
1x2	1	1.92	70.50	3.50	2.98	15.36	1.03	19.66	2.78
1x3	2	1.43	72.00	5.00	23.47	33.91	0.74	32.45	2.56
1x4	3	2.67	74.00	0.00	8.03	3.45	0.96	16.13	2.00
1x5	4	1.04	71.00	3.00	7.42	15.50	0.98	12.41	2.51
1x6	5	1.03	72.50	3.00	10.89	13.30	0.83	17.28	2.52
1x7	6	0.89	70.00	5.50	12.49	20.93	0.75	16.55	3.04
1x8	7	0.79	74.00	4.50	4.11	9.83	0.58	23.15	2.79
1x9	8	0.59	69.50	5.00	15.33	88.50	0.58	13.77	2.87
1x10	9	1.68	69.50	6.00	0.27	0.67	1.04	19.45	2.99
1x11	10	1.40	72.50	4.50	7.48	0.05	0.81	15.41	2.95
1x12	11	1.38	76.00	-2.00	4.14	0.64	0.87	21.68	2.92
1x13	12	0.60	71.00	5.00	15.05	15.89	1.11	43.31	2.91
1x14	13	1.10	72.00	3.50	14.68	5.56	0.85	11.72	3.08
2x3	15	0.87	69.50	6.00	4.13	10.77	0.92	18.57	2.54
2x4	16	2.91	72.00	5.00	16.19	0.11	1.00	7.92	1.44
2x5	17	1.93	69.00	6.50	7.89	15.51	0.88	11.95	2.08
2x6	18	1.39	70.50	3.50	4.72	2.16	0.85	14.70	2.14
2x7	19	1.02	68.50	5.50	39.40	3.89	0.92	14.96	2.55
2x8	20	1.08	74.00	3.00	20.73	0.05	0.97	18.19	2.52
2x9	21	0.68	70.50	6.50	10.42	20.68	0.54	20.25	1.98
2x10	22	1.08	70.00	12.00	7.03	0.02	0.77	21.03	2.91
2x11	23	1.87	70.00	4.00	5.76	11.78	0.85	15.83	1.85
2x12	24	0.81	70.00	6.50	16.77	7.60	0.62	12.13	2.59
2x13	25	1.54	68.00	6.00	5.86	3.21	0.77	15.02	2.57
2x14	26	0.95	71.00	5.50	8.22	3.20	0.64	17.95	2.93
3x4	29	2.52	71.00	2.50	0.03	3.95	0.67	16.99	1.55
3x5	30	0.80	70.00	7.00	15.91	13.30	0.64	36.25	2.98
3x6	31	0.98	74.00	1.50	-0.71	6.66	0.59	15.11	2.52
3x7	32	0.49	69.50	9.00	19.98	3.97	0.40	19.18	3.09
3x8	33	0.70	72.50	4.50	-1.98	9.43	0.38	23.84	2.87
3x9	34	1.32	67.50	6.50	1.02	18.01	0.79	8.66	2.04
3x10	35	0.53	70.00	7.50	3.81	7.13	0.49	42.42	2.54
3x11	36	1.01	71.00	4.50	6.65	7.06	0.88	17.75	3.03
3x12	37	0.51	71.50	5.50	43.12	53.47	0.57	51.81	2.95
3x13	38	0.50	71.00	8.00	11.50	-0.03	0.39	59.36	2.58
3x14	39	0.60	70.00	5.50	10.19	2.93	0.46	29.78	2.48
4x5	42	1.96	72.00	2.00	3.78	2.84	1.03	9.05	1.96
4x6	43	3.48	71.50	2.50	-2.27	2.55	0.98	12.08	2.06
4x7	44	2.17	72.50	1.00	11.33	8.68	0.80	8.83	2.54
4x8	45	2.07	72.50	4.50	12.47	-0.09	1.10	16.94	2.54

APPENDIX C Cont:

Cross	**Entry**	**GY** *t/ha*	**AD** *d*	**ASI** *d*	**RL** *%*	**SL** *%*	**EPP** *#*	**ER** *%*	**EA** *Sc 1-5*
4x9	46	1.05	70.50	2.50	12.08	11.38	0.73	20.84	3.03
4x10	47	1.53	72.50	7.50	0.34	0.00	0.73	24.36	3.10
4x11	48	3.09	72.50	1.50	7.27	2.81	0.92	13.91	2.06
4x12	49	2.03	71.00	5.00	7.84	6.91	0.90	9.00	2.50
4x13	50	2.27	72.00	2.50	9.60	0.06	0.84	12.28	2.48
4x14	51	2.12	73.00	1.00	11.11	3.35	1.13	8.26	1.98
5x6	54	1.23	70.50	3.00	7.96	-0.15	0.65	26.37	2.87
5x7	55	1.37	63.50	5.50	13.18	25.68	0.82	9.33	2.98
5x8	56	1.01	70.00	4.00	21.37	19.81	0.97	12.00	3.07
5x9	57	0.62	69.50	4.50	28.97	40.55	0.75	28.78	2.52
5x10	58	1.03	67.50	6.00	4.29	3.82	0.82	10.60	2.53
5x11	59	1.25	70.00	3.00	-0.29	14.38	0.96	17.68	2.43
5x12	60	0.63	70.00	5.50	18.43	17.76	0.71	22.44	2.43
5x13	61	1.64	68.50	3.50	0.59	4.19	0.96	15.75	2.98
5x14	62	0.93	69.50	3.00	3.51	-0.52	1.05	15.10	2.60
6x7	64	0.99	69.50	6.00	13.60	7.66	0.74	32.68	2.98
6x8	65	1.00	71.00	6.00	13.13	0.11	0.63	12.01	2.00
6x9	66	0.61	69.00	8.00	5.35	0.60	0.40	23.33	2.99
6x10	67	0.76	70.50	6.50	1.96	0.08	0.80	31.06	2.50
6x11	68	1.02	71.00	4.50	13.04	-0.01	0.69	15.14	2.00
6x12	69	1.20	69.00	11.00	19.10	0.02	0.69	14.13	2.87
6x13	70	0.50	70.50	5.50	3.72	-0.19	0.34	38.44	2.57
6x14	71	0.92	70.50	4.00	8.53	0.08	0.65	15.06	2.54
7x8	74	0.71	72.00	6.50	9.83	7.17	0.59	18.49	2.89
7x9	75	0.41	70.00	6.50	49.63	3.17	0.30	41.49	1.83
7x10	76	0.95	70.00	7.00	10.21	-0.09	0.62	21.40	2.46
7x11	77	0.60	69.50	3.00	14.22	7.34	0.42	19.01	3.00
7x12	78	0.71	68.00	3.50	16.43	31.80	0.59	16.01	3.08
7x13	79	0.49	70.00	5.50	15.11	19.05	0.43	17.75	2.52
7x14	80	0.60	71.50	8.50	18.43	12.51	0.57	17.33	2.50
8x9	83	0.62	70.50	8.00	6.63	15.81	0.53	14.64	2.95
8x10	84	0.62	70.50	2.50	4.97	-0.52	0.51	36.81	2.60
8x11	85	1.43	72.50	4.50	9.44	-0.18	0.81	11.39	3.02
8x12	86	0.42	69.50	11.00	11.69	4.05	0.39	37.04	2.60
8x13	87	0.42	70.50	11.00	2.87	6.53	0.31	25.80	3.09
8x14	88	1.02	72.50	4.50	5.57	-0.20	0.68	14.56	2.52
9x10	91	0.59	69.50	8.50	2.17	5.08	0.62	7.29	3.07
9x11	92	0.59	70.50	8.00	14.96	25.31	0.49	40.17	3.02
9x12	93	0.20	65.50	9.00	-0.57	159.50	0.25	15.48	2.73
9x13	94	0.41	70.50	5.00	36.36	37.38	0.37	42.12	2.65
9x14	95	1.17	71.00	3.50	1.03	11.22	1.09	13.70	2.47
10x11	96	0.95	70.50	11.50	4.88	0.08	0.72	22.63	2.56
10x12	97	0.51	70.00	12.00	15.65	7.77	0.57	35.27	2.52

APPENDIX C Cont:

Cross	**Entry**	**GY** ***t/ha***	**AD** ***d***	**ASI** ***d***	**RL** ***%***	**SL** ***%***	**EPP** ***#***	**ER** ***%***	**EA** ***Sc 1-5***
10x13	98	0.50	71.00	9.00	5.32	2.98	0.21	112.78	3.04
10x14	99	0.63	70.00	7.00	6.51	-0.02	0.71	15.07	2.56
11x12	101	1.36	70.00	7.50	15.76	0.09	0.82	19.52	2.94
11x13	102	0.53	70.00	10.50	4.38	-0.01	0.73	30.62	2.48
11x14	103	0.63	70.50	4.50	-0.11	16.14	0.52	33.16	2.56
12x13	105	0.41	70.00	7.00	13.15	-0.02	0.59	31.56	2.52
12x14	106	0.51	72.00	6.50	3.03	3.57	0.65	20.11	2.54
13x14	107	0.39	71.50	4.50	-2.35	3.43	0.45	14.59	2.50
Experimental checks									
1xB	14	1.95	71.50	7.00	3.40	0.00	1.20	18.60	3.04
2xA	27	4.99	71.00	4.50	-1.28	0.10	1.00	5.43	1.39
2xB	28	3.19	74.00	3.00	2.57	3.94	0.70	21.14	1.44
3xA	40	0.90	74.50	5.50	0.89	0.57	1.13	25.33	2.53
3xB	41	1.53	73.00	4.00	8.28	16.65	0.92	14.09	1.66
4xA	52	5.35	72.50	3.00	8.27	0.12	0.94	6.47	2.48
4xB	53	4.12	72.00	3.00	8.15	7.15	0.89	11.70	1.83
5xB	63	2.14	72.00	1.50	12.02	3.63	1.04	16.92	2.02
6xA	72	2.96	73.50	0.50	1.62	0.00	0.93	12.76	2.33
6xB	73	2.85	72.50	3.00	10.01	0.08	0.90	19.58	1.44
7xA	81	2.97	73.00	1.00	15.07	3.40	1.30	7.64	2.98
7xB	82	2.23	74.00	0.00	12.64	42.90	1.31	10.69	1.89
8xA	89	2.95	74.00	4.50	5.09	0.01	1.00	6.02	2.44
8xB	90	1.54	72.50	7.50	7.82	-0.04	0.94	19.12	2.52
10xB	100	1.13	71.00	5.00	24.72	-0.42	0.81	71.53	2.66
11xB	104	1.80	74.00	3.00	-2.29	4.55	1.14	14.26	3.04
13xA	108	1.38	73.00	0.00	8.50	0.06	0.65	22.19	2.47
13xB	109	1.57	70.50	6.50	8.83	-0.02	1.04	20.65	2.04
AxB	110	3.37	72.00	3.50	19.07	0.02	1.07	11.51	2.41
Mean		**1.35**	**70.96**	**5.09**	**9.87**	**9.66**	**0.76**	**21.18**	**2.54**
LSD (0.05)		**0.92**	**3.51**	**7.12**	**18.91**	**43.08**	**0.47**	**32.54**	**0.91**
Min		**0.20**	**63.50**	**-2.00**	**-2.35**	**-0.52**	**0.21**	**5.43**	**1.39**
Max		**5.35**	**76.00**	**12.00**	**49.63**	**159.50**	**1.31**	**112.78**	**3.10**

APPENDIX D

Mean grain yield and agronomic traits for 110 QPM hybrids at Kiboko-1 in 2006

Cross	Entry	GY *t/ha*	AD *d*	ASI *d*	RL *%*	SL *%*	EPP *#*	ER *%*	EA *Sc 1-5*
Diallel hybrids									
1x2	1	3.32	67.50	1.00	0.00	3.68	1.05	0.00	2.60
1x3	2	2.48	66.60	2.00	0.00	8.60	0.83	0.00	2.34
1x4	3	3.89	67.40	0.00	0.00	1.58	0.98	0.00	2.03
1x5	4	3.16	64.21	2.00	0.00	5.49	0.98	2.50	2.80
1x6	5	3.15	66.15	3.00	0.00	3.15	1.00	0.00	2.38
1x7	6	2.88	63.83	3.00	2.40	17.11	1.00	2.40	2.31
1x8	7	3.54	66.78	2.00	0.00	7.40	0.95	2.50	1.86
1x9	8	2.71	63.97	1.00	0.00	12.55	0.86	0.00	2.90
1x10	9	2.45	65.89	2.50	0.00	5.96	0.88	0.00	3.82
1x11	10	2.25	68.33	1.00	2.40	-3.16	0.88	2.80	2.93
1x12	11	3.67	62.68	5.50	0.00	14.84	1.05	0.00	2.15
1x13	12	3.21	63.87	4.00	0.00	1.66	0.95	0.00	2.37
1x14	13	2.39	67.05	3.50	0.00	7.81	0.98	0.00	2.79
2x3	15	3.28	65.05	3.00	2.50	8.17	0.95	0.00	1.66
2x4	16	3.11	66.41	3.00	0.00	0.79	1.05	0.00	1.97
2x5	17	2.74	63.65	4.50	0.00	2.59	0.95	0.00	2.56
2x6	18	2.57	64.93	3.00	0.00	3.34	0.95	0.00	2.53
2x7	19	2.36	64.80	2.50	2.50	19.12	0.95	0.00	2.57
2x8	20	2.87	67.31	1.50	2.40	2.20	0.81	0.00	1.81
2x9	21	3.05	63.83	3.00	0.00	1.32	1.03	0.00	2.18
2x10	22	2.84	63.28	7.00	0.00	-3.57	0.93	0.00	1.88
2x11	23	3.16	63.98	4.00	0.00	-2.45	0.98	0.00	1.74
2x12	24	2.48	62.15	3.00	0.00	7.64	0.90	0.00	2.76
2x13	25	2.70	63.11	6.00	0.00	2.70	0.88	0.00	2.65
2x14	26	2.61	64.21	4.50	0.00	4.52	0.93	0.00	2.44
3x4	29	3.16	67.20	2.00	0.00	7.83	0.89	0.00	2.20
3x5	30	2.72	62.74	2.00	0.00	6.47	0.83	2.65	2.39
3x6	31	3.26	63.67	2.00	0.00	-2.51	0.98	0.00	2.16
3x7	32	3.59	63.18	0.50	0.00	9.55	0.98	0.00	1.92
3x8	33	3.33	64.16	2.50	0.00	7.64	0.98	0.00	1.76
3x9	34	2.87	62.60	6.50	0.00	14.83	0.86	0.00	2.38
3x10	35	2.99	62.78	5.00	2.40	3.45	0.86	2.80	2.46
3x11	36	3.18	64.51	2.50	0.00	2.57	0.95	0.00	2.20
3x12	37	2.93	61.21	4.00	0.00	16.06	0.95	2.65	2.22
3x13	38	2.77	63.14	2.00	0.00	3.68	0.86	0.00	2.29
3x14	39	3.12	63.54	4.00	0.00	-0.64	0.95	0.00	1.91
4x5	42	2.45	64.60	5.00	0.00	1.96	0.95	0.00	2.49
4x6	43	2.90	67.80	2.50	0.00	5.67	0.93	0.00	2.50
4x7	44	4.08	64.25	3.50	0.00	-0.62	1.18	2.10	1.65
4x8	45	3.68	66.60	6.50	0.00	5.79	1.00	0.00	1.91

APPENDIX D Cont:

Cross	**Entry**	**GY** *t/ha*	**AD** *d*	**ASI** *d*	**RL** *%*	**SL** *%*	**EPP** *#*	**ER** *%*	**EA** *Sc 1-5*
4x9	46	2.98	63.90	2.00	0.00	12.79	0.98	0.00	2.23
4x10	47	3.41	63.87	7.00	0.00	2.80	0.95	2.65	3.15
4x12	49	3.83	62.55	2.50	0.00	21.38	0.98	0.00	1.82
4x13	50	3.27	65.58	2.00	0.00	-0.83	0.93	0.00	2.52
4x14	51	2.96	67.75	4.50	0.00	3.75	1.03	0.00	2.67
5x6	54	3.11	63.30	2.00	0.00	-0.89	0.95	2.50	1.83
5x7	55	3.04	60.76	2.00	0.00	10.63	0.98	0.00	1.72
5x8	56	2.68	63.06	4.00	0.00	0.29	0.93	0.00	2.00
5x9	57	2.65	60.39	3.00	0.00	26.28	1.03	0.00	1.98
5x10	58	3.30	62.12	2.50	0.00	2.55	1.00	0.00	2.07
5x11	59	2.73	62.31	2.50	0.00	5.35	0.90	7.90	2.82
5x12	60	2.57	62.01	4.50	2.40	4.59	0.93	0.00	2.59
5x13	61	3.21	61.83	2.50	0.00	3.49	1.03	0.00	1.95
5x14	62	2.72	62.45	4.50	0.00	3.17	0.95	2.65	2.21
6x7	64	3.03	62.47	2.00	0.00	8.85	0.95	2.65	2.32
6x8	65	2.64	65.72	2.50	0.00	13.34	0.90	0.00	2.31
6x9	66	3.01	62.33	2.00	0.00	11.35	1.00	0.00	1.76
6x10	67	1.95	62.42	6.00	0.00	1.87	0.83	0.00	3.48
6x11	68	2.93	62.99	2.00	0.00	2.56	0.93	0.00	2.51
6x12	69	2.48	63.61	4.50	0.00	7.71	1.00	0.00	2.80
6x13	70	2.80	64.44	5.00	0.00	4.07	0.93	2.80	2.41
6x14	71	2.94	63.70	2.50	0.00	9.05	0.93	2.50	1.72
7x8	74	2.65	64.03	2.00	0.00	10.01	0.90	0.00	2.23
7x9	75	2.87	62.89	0.50	0.00	26.89	1.00	0.00	1.85
7x10	76	3.83	62.61	1.00	0.00	11.94	1.03	0.00	2.05
7x11	77	3.24	62.93	2.00	2.50	6.80	0.98	2.65	2.70
7x12	78	3.37	61.92	1.50	2.40	9.18	0.95	0.00	2.09
7x13	79	3.53	62.09	2.00	4.75	4.85	0.95	0.00	1.68
7x14	80	3.20	62.21	2.00	0.00	7.52	0.98	0.00	2.40
8x9	83	2.16	66.57	2.00	0.00	4.15	0.92	0.00	2.50
8x10	84	2.09	65.12	5.50	0.00	3.44	0.91	0.00	2.96
8x11	85	3.25	66.36	2.50	0.00	4.29	1.03	0.00	2.10
8x12	86	3.07	63.08	3.50	0.00	11.60	0.95	0.00	1.61
8x13	87	2.92	64.36	4.00	0.00	6.15	0.93	0.00	1.71
8x14	88	3.04	64.96	3.50	0.00	5.93	0.93	0.00	2.25
9x10	91	2.73	63.09	1.50	2.50	1.43	0.85	0.00	2.58
9x11	92	2.85	63.19	3.00	0.00	7.18	0.98	0.00	2.70
9x12	93	2.72	59.35	2.50	0.00	41.63	0.91	0.00	1.65
9x13	94	2.05	63.18	5.00	0.00	0.23	0.74	0.00	2.90
9x14	95	2.82	62.57	3.50	2.40	27.66	0.93	0.00	2.50
10x11	96	2.00	64.57	5.00	0.00	2.89	0.84	0.00	3.54
10x12	97	2.08	61.75	7.50	0.00	2.31	0.79	0.00	2.67
10x13	98	2.22	63.56	6.00	0.00	2.11	0.74	0.00	2.74

APPENDIX D Cont:

Cross	**Entry**	**GY**	**AD**	**ASI**	**RL**	**SL**	**EPP**	**ER**	**EA**
		t/ha	*d*	*d*	*%*	*%*	*#*	*%*	*Sc 1-5*
10x14	99	2.79	60.91	6.50	0.00	6.31	0.98	0.00	2.69
11x12	101	2.48	61.71	5.00	0.00	4.80	0.90	2.65	2.47
11x13	102	2.60	65.44	4.50	0.00	6.65	0.88	5.25	2.38
11x14	103	3.14	63.00	3.00	0.00	3.97	0.93	0.00	2.74
12x13	105	3.39	62.91	4.00	2.50	5.27	1.00	0.00	3.42
12x14	106	2.91	62.26	5.00	0.00	5.49	1.00	0.00	1.92
13x14	107	3.29	64.82	2.00	0.00	4.55	0.95	2.50	2.38
Experimental checks									
1xB	14	4.05	69.17	1.00	0.00	2.89	1.00	0.00	2.86
2xA	27	3.89	69.73	1.50	0.00	4.09	1.13	0.00	1.03
2xB	28	3.12	67.06	2.50	0.00	1.39	0.85	7.15	3.24
3xA	40	2.76	64.04	4.00	0.00	26.77	0.95	0.00	2.30
3xB	41	4.08	68.98	0.50	0.00	2.53	0.95	0.00	2.23
4xA	52	3.61	72.02	-1.50	0.00	4.01	1.17	0.00	2.03
4xB	53	4.17	65.78	6.00	0.00	2.69	1.00	0.00	3.73
5xB	63	3.23	65.33	4.50	2.40	4.05	0.90	0.00	2.66
6xA	72	3.07	61.32	1.00	0.00	9.14	0.95	0.00	2.65
6xB	73	4.00	67.11	2.50	0.00	13.17	0.98	2.50	3.32
7xA	81	3.55	68.12	1.00	0.00	13.89	1.03	0.00	2.12
7xB	82	4.36	67.57	0.50	0.00	4.87	0.95	2.65	2.63
8xA	89	3.27	70.87	1.00	0.00	4.31	0.83	0.00	1.73
8xB	90	3.44	69.40	3.50	2.40	1.75	0.98	0.00	2.40
10xB	100	2.50	68.65	2.50	0.00	7.06	0.80	0.00	3.53
11xB	104	2.78	68.75	2.00	2.80	1.01	0.88	0.00	2.62
13xA	108	2.46	70.80	4.00	0.00	2.61	0.95	0.00	2.32
13xB	109	3.51	67.47	-0.50	2.95	6.13	0.97	0.00	3.55
AxB	110	3.41	73.18	0.00	0.00	6.38	0.95	0.00	2.20
Mean		**3.02**	**64.66**	**3.00**	**0.41**	**6.63**	**0.94**	**0.63**	**2.38**
LSD (0.05)		**1.00**	**2.31**	**3.98**	**2.95**	**13.87**	**0.15**	**3.93**	**0.98**
Min		**1.95**	**59.35**	**-1.50**	**0.00**	**-3.57**	**0.74**	**0.00**	**1.03**
Max		**4.36**	**73.18**	**7.50**	**4.75**	**41.63**	**1.18**	**7.90**	**3.82**

APPENDIX E

Mean grain yield and agronomic traits for 110 QPM hybrids at Kiboko-2 in 2006

Cross	Entry	GY *t/ha*	AD *d*	ASI *d*	RL *%*	SL *%*	EPP *#*	ER *%*	EA *Sc 1-5*
Diallel hybrids									
1x2	1	4.35	72.35	2.58	0.00	0.00	0.81	2.36	1.96
1x3	2	3.97	71.36	3.02	0.00	0.00	0.83	4.47	1.97
1x4	3	4.81	71.63	1.07	0.00	0.00	1.03	-1.49	1.91
1x5	4	3.71	70.83	0.94	0.00	0.00	0.92	-0.55	1.78
1x6	5	3.75	72.61	0.57	0.00	0.00	0.89	3.65	3.06
1x7	6	4.58	69.39	3.84	0.00	0.00	0.82	0.34	2.04
1x8	7	4.78	70.47	3.29	0.00	0.00	0.92	1.65	2.01
1x9	8	4.41	69.23	2.54	0.00	0.00	1.02	11.41	2.58
1x10	9	4.64	69.98	4.74	0.00	0.00	0.96	6.96	2.29
1x11	10	3.96	71.90	3.47	0.00	0.00	0.79	1.72	2.58
1x12	11	3.56	71.34	4.68	0.00	0.00	0.77	2.49	2.73
1x13	12	4.19	55.10	3.42	0.00	0.00	0.84	2.03	2.80
1x14	13	5.26	69.12	2.10	0.00	0.00	0.93	3.56	2.02
2x3	15	3.36	68.52	6.96	0.00	0.00	0.86	8.70	2.09
2x4	16	3.22	72.30	5.28	0.00	0.00	0.73	1.12	2.52
2x5	17	3.54	70.16	4.48	0.00	0.00	0.81	6.63	2.49
2x6	18	2.88	71.43	2.95	0.00	0.00	0.88	4.13	2.69
2x7	19	4.35	71.11	2.73	2.65	0.00	0.84	0.49	2.38
2x8	20	3.34	72.50	5.06	0.00	0.00	0.72	1.22	2.72
2x9	21	3.79	72.47	3.67	0.00	0.00	0.73	0.34	2.25
2x10	22	2.65	69.98	7.23	0.00	0.00	0.59	0.85	2.99
2x11	23	3.59	69.63	3.17	0.00	0.00	0.81	5.00	2.16
2x12	24	2.57	69.70	7.26	0.00	0.00	0.51	5.46	2.70
2x13	25	3.11	70.16	5.32	0.00	0.00	0.65	-0.02	3.17
2x14	26	3.30	69.42	5.04	0.00	0.00	0.68	3.56	1.90
3x4	29	3.97	71.79	6.01	0.00	0.00	0.83	-0.45	2.30
3x5	30	3.05	67.86	4.36	2.65	2.65	0.75	8.62	2.89
3x6	31	3.57	69.64	4.58	0.00	0.00	0.72	7.87	3.01
3x7	32	5.40	68.83	2.19	0.00	0.00	1.04	-0.35	2.40
3x8	33	3.68	70.08	3.48	2.65	0.00	0.71	0.28	2.49
3x9	34	5.46	66.63	2.66	0.00	0.00	0.97	1.19	2.82
3x10	35	3.72	68.58	6.43	0.00	0.00	0.79	3.42	2.10
3x11	36	3.72	71.04	7.22	0.00	0.00	0.85	5.40	3.16
3x12	37	4.00	68.42	3.99	0.00	0.00	0.86	-0.57	2.91
3x13	38	3.89	68.09	10.58	0.00	0.00	0.74	7.53	1.78
3x14	39	3.85	70.23	3.35	0.00	0.00	0.87	2.13	1.97
4x5	42	3.65	70.43	5.63	0.00	0.00	0.74	1.57	2.49
4x6	43	3.58	69.72	5.02	0.00	0.00	0.84	15.96	2.21
4x7	44	3.67	70.82	2.10	0.00	0.00	0.94	-0.01	2.56
4x8	45	4.07	72.54	5.11	0.00	0.00	0.82	4.25	2.81

APPENDIX E Cont:

Cross	**Entry**	**GY** ***t/ha***	**AD** ***d***	**ASI** ***d***	**RL** ***%***	**SL** ***%***	**EPP** ***#***	**ER** ***%***	**EA** ***Sc 1-5***
4x9	46	4.47	69.03	2.75	0.00	0.00	0.91	-1.04	2.77
4x10	47	2.67	70.73	9.99	0.00	0.00	0.97	0.50	3.59
4x11	48	4.20	71.90	2.69	0.00	0.00	0.89	3.50	2.36
4x12	49	2.77	69.06	7.20	0.00	0.00	0.76	-2.11	3.62
4x13	50	2.16	71.17	10.96	0.00	0.00	0.69	-2.59	2.98
4x14	51	3.38	71.12	7.22	0.00	0.00	0.89	6.13	2.46
5x6	54	3.40	68.99	3.21	0.00	0.00	0.87	8.66	2.68
5x7	55	4.55	70.47	2.00	5.25	0.00	0.97	12.30	2.29
5x8	56	3.95	71.29	3.68	0.00	0.00	0.74	2.80	2.49
5x9	57	2.10	68.69	4.81	0.00	0.00	0.61	-0.80	2.57
5x10	58	3.46	70.14	7.88	0.00	0.00	0.79	-0.70	2.84
5x11	59	3.96	68.98	4.89	0.00	0.00	0.83	3.25	2.18
5x12	60	3.30	67.92	5.47	0.00	0.00	0.89	4.72	2.92
5x13	61	3.26	69.66	4.65	0.00	0.00	0.85	0.87	2.81
5x14	62	2.82	68.20	3.15	0.00	0.00	0.62	2.99	2.93
6x7	64	3.42	69.15	3.04	0.00	0.00	0.83	-0.40	2.53
6x8	65	3.56	71.30	3.13	0.00	0.00	0.85	8.60	2.43
6x9	66	3.44	54.11	4.26	0.00	0.00	0.84	11.33	2.60
6x10	67	3.06	69.51	8.34	0.00	0.00	0.69	7.13	2.92
6x11	68	2.60	70.83	3.26	0.00	0.00	0.84	9.79	3.14
6x12	69	2.37	68.72	5.19	0.00	0.00	0.64	23.74	2.44
6x13	70	2.63	71.23	8.94	0.00	0.00	0.66	16.73	3.26
6x14	71	3.67	70.80	4.12	0.00	0.00	0.86	18.77	2.53
7x8	74	3.20	71.69	3.99	0.00	0.00	0.82	3.89	2.74
7x9	75	4.45	69.62	1.90	0.00	0.00	0.99	0.09	2.69
7x10	76	3.93	71.24	4.81	2.95	0.00	0.88	8.68	3.05
7x11	77	3.31	69.62	2.06	0.00	0.00	0.86	3.33	2.88
7x12	78	4.61	69.28	3.68	0.00	0.00	0.95	-0.04	1.67
7x13	79	4.73	70.27	1.46	0.00	0.00	0.87	5.41	1.56
7x14	80	4.76	70.32	3.94	0.00	0.00	0.88	-0.22	1.85
8x9	83	3.11	68.87	4.55	0.00	0.00	0.80	5.78	2.75
8x10	84	3.59	70.70	9.77	0.00	0.00	0.63	1.64	2.59
8x11	85	2.59	74.37	5.48	0.00	0.00	0.86	-0.26	2.93
8x12	86	2.86	69.88	3.44	2.65	0.00	0.82	5.44	2.76
8x13	87	3.40	73.41	7.09	2.65	0.00	0.70	8.35	3.09
8x14	88	3.50	70.18	5.93	0.00	0.00	0.75	3.91	2.36
9x10	91	3.36	69.13	7.05	0.00	0.00	0.70	3.06	2.45
9x11	92	3.94	71.53	2.97	0.00	0.00	0.89	0.59	2.51
9x12	93	3.52	66.77	3.96	0.00	0.00	0.95	-0.07	2.87
9x13	94	2.19	69.52	5.65	0.00	0.00	0.70	1.15	2.96
9x14	95	4.17	68.43	3.53	0.00	0.00	0.89	-1.10	2.23
10x11	96	3.35	69.99	4.50	0.00	0.00	0.64	11.77	3.45
10x12	97	3.77	69.31	7.01	0.00	0.00	0.77	0.15	2.46

APPENDIX E Cont:

Cross	**Entry**	**GY** *t/ha*	**AD** *d*	**ASI** *d*	**RL** *%*	**SL** *%*	**EPP** *#*	**ER** *%*	**EA** *Sc 1-5*
10x13	98	3.91	69.35	5.79	0.00	0.00	0.56	5.36	2.00
10x14	99	4.12	67.44	4.64	0.00	0.00	0.91	9.57	2.50
11x12	101	3.03	68.66	5.28	0.00	0.00	0.72	4.44	2.00
11x13	102	3.14	73.38	5.37	0.00	0.00	0.67	4.42	2.98
12x13	105	2.79	70.78	6.80	0.00	0.00	0.60	-0.82	2.97
12x14	106	3.34	69.43	5.37	0.00	0.00	0.89	-1.40	2.79
13x14	107	4.26	68.77	5.25	0.00	0.00	0.87	5.18	2.42
Experimental checks									
1xB	14	6.43	73.42	2.27	0.00	0.00	0.98	2.63	2.07
2xA	27	4.71	77.40	1.87	0.00	0.00	0.88	3.10	2.31
2xB	28	3.33	73.68	4.16	0.00	0.00	0.71	6.80	3.10
3xA	40	3.52	69.07	5.76	0.00	0.00	0.78	0.64	3.38
3xB	41	5.05	71.89	5.20	0.00	0.00	0.99	6.06	2.37
4xA	52	5.11	79.22	2.21	0.00	0.00	1.06	0.37	2.95
4xB	53	4.72	74.03	5.95	2.65	0.00	0.88	12.39	2.91
5xB	63	5.03	70.31	3.29	0.00	0.00	1.01	7.70	2.25
6xA	72	4.23	67.94	3.13	0.00	0.00	0.97	5.30	2.34
6xB	73	5.25	72.94	1.74	5.30	0.00	0.95	17.17	2.96
7xA	81	4.29	76.79	3.45	0.00	0.00	0.86	3.37	2.20
7xB	82	4.19	70.53	4.29	2.65	0.00	0.92	10.00	2.47
8xA	89	4.07	77.12	2.06	0.00	0.00	0.83	0.09	2.02
8xB	90	5.43	73.01	4.57	0.00	0.00	0.79	6.38	2.29
10xB	100	4.91	71.57	4.21	0.00	0.00	0.85	9.54	2.45
11xB	104	4.73	72.54	2.06	0.00	0.00	0.88	4.81	2.44
13xA	108	4.08	77.71	4.34	0.00	0.00	0.90	1.08	2.48
13xB	109	3.71	71.95	9.95	5.45	0.00	0.64	5.33	2.57
AxB	110	5.06	79.20	5.03	0.00	0.00	0.91	0.27	2.15
Mean	**Mean**	**3.81**	**70.47**	**4.54**	**0.34**	**0.02**	**0.82**	**4.16**	**2.55**
LSD (0.05)	**LSD (0.05)**	**1.59**	**6.60**	**3.34**	**2.45**	**0.71**	**0.22**	**12.47**	**1.04**
Min	**Min**	**2.10**	**54.11**	**0.57**	**0.00**	**0.00**	**0.51**	**-2.59**	**1.56**
Max	**Max**	**6.43**	**79.22**	**10.96**	**5.45**	**2.65**	**1.06**	**23.74**	**3.62**

APPENDIX F

Mean grain yield and agronomic traits for 110 QPM hybrids at Kiboko-3 in 2006

Cross	Entry	GY *t/ha*	AD *d*	ASI *d*	RL *%*	SL *%*	EPP *#*	ER *%*	EA *Sc 1-5*
Diallel hybrids									
1x2	1	0.99	68.39	2.57	0.97	10.88	0.53	3.10	2.87
1x3	2	1.40	68.84	6.39	12.41	26.13	0.58	3.78	2.38
1x4	3	1.57	68.65	-0.96	0.56	15.98	0.58	0.79	1.83
1x5	4	0.87	68.12	6.36	4.71	6.03	0.52	0.05	2.46
1x6	5	0.58	68.13	.	-4.07	11.57	0.26	-2.19	1.79
1x7	6	0.66	67.04	7.74	6.06	17.51	0.37	-0.23	3.78
1x8	7	0.92	70.37	3.91	28.32	5.43	0.46	0.27	2.35
1x9	8	1.47	65.07	0.97	0.07	47.19	0.65	24.74	3.05
1x10	9	0.80	67.38	1.04	23.46	32.78	0.36	-1.03	0.74
1x11	10	0.62	71.24	.	2.44	6.65	0.26	2.36	1.93
1x12	11	0.87	65.87	.	7.09	7.68	0.46	23.09	4.09
1x13	12	0.78	67.54	6.36	5.03	7.45	0.34	0.87	1.24
1x14	13	1.03	68.89	1.95	0.97	9.11	0.29	3.77	0.94
2x3	15	0.67	67.71	.	6.73	19.35	0.39	0.10	3.82
2x4	16	1.32	69.49	2.95	-2.24	9.65	0.54	-5.57	3.03
2x5	17	1.35	65.82	4.57	3.65	11.43	0.56	14.60	3.13
2x6	18	1.74	66.67	7.12	8.48	13.06	0.85	0.32	1.95
2x7	19	0.89	68.49	8.42	7.01	12.86	0.40	15.14	1.33
2x8	20	0.75	68.53	4.36	0.08	7.18	0.40	-0.66	3.49
2x9	21	1.00	66.41	.	10.27	18.77	0.44	-7.28	3.84
2x10	22	0.42	67.67	4.95	-0.93	23.26	0.31	1.50	3.27
2x11	23	1.57	66.00	9.63	38.12	9.12	0.71	4.08	2.86
2x12	24	0.54	64.08	11.74	1.95	22.37	0.44	-0.33	3.34
2x13	25	1.01	66.75	3.95	4.30	7.18	0.55	1.55	3.63
2x14	26	0.55	65.85	15.74	2.96	12.94	0.25	2.05	3.44
3x4	29	0.51	69.11	10.74	0.59	11.71	0.24	0.77	3.77
3x5	30	1.60	65.84	1.77	-0.18	6.88	0.61	9.20	2.21
3x6	31	1.46	66.04	3.35	2.89	2.75	0.67	0.05	3.92
3x7	32	0.89	66.96	7.42	5.65	28.49	0.54	12.98	3.17
3x8	33	1.13	68.07	0.04	-1.41	17.23	0.49	9.46	0.35
3x9	34	1.03	64.56	0.42	4.24	12.23	0.41	18.28	3.05
3x10	35	1.15	65.36	4.57	2.33	21.84	0.61	10.35	3.44
3x11	36	1.19	67.14	5.50	13.38	9.00	0.55	1.47	1.04
3x12	37	1.00	65.04	.	-0.05	17.08	0.50	-1.02	4.42
3x13	38	0.74	66.81	3.94	1.40	3.24	0.37	5.21	2.68
3x14	39	0.68	66.52	3.58	4.12	7.67	0.32	6.61	3.49
4x5	42	1.09	69.67	.	5.11	-6.15	0.57	-0.16	3.69
4x6	43	1.53	68.20	4.35	9.76	-2.92	0.52	8.94	1.99
4x7	44	1.16	68.71	.	4.07	5.40	0.53	25.00	3.50
4x8	45	1.03	70.14	5.08	14.74	5.40	0.37	11.77	1.86

APPENDIX F Cont:

Cross	**Entry**	**GY**	**AD**	**ASI**	**RL**	**SL**	**EPP**	**ER**	**EA**
		t/ha	***d***	***d***	***%***	***%***	***#***	***%***	***Sc 1-5***
4x9	46	0.80	66.89	21.42	0.13	8.83	0.28	4.04	1.05
4x10	47	0.74	67.52	3.97	2.38	1.80	0.36	-0.52	3.95
4x11	48	1.22	68.54	6.73	19.61	0.05	0.44	1.03	2.62
4x12	49	1.06	65.98	.	9.85	5.58	0.42	-1.36	3.20
4x13	50	0.62	71.17	2.97	26.71	5.62	0.35	4.39	1.33
4x14	51	0.89	67.91	6.20	-0.97	7.01	0.47	1.72	2.66
5x6	54	0.85	65.05	.	2.24	0.21	0.49	-1.47	4.67
5x7	55	1.11	63.66	7.18	-1.86	12.20	0.70	0.82	3.14
5x8	56	1.09	68.33	1.97	11.16	9.57	0.46	4.39	0.90
5x9	57	1.11	63.81	3.63	19.14	4.23	0.71	12.27	3.50
5x10	58	0.87	65.78	.	-0.30	5.77	0.41	17.93	4.07
5x11	59	0.59	66.09	6.95	-0.61	8.88	0.36	39.23	4.05
5x12	60	1.17	62.38	.	4.13	10.30	0.57	5.09	3.84
5x13	61	1.35	63.85	2.71	-3.28	7.99	0.62	0.87	2.05
5x14	62	0.78	63.12	11.85	1.92	15.49	0.49	5.94	4.64
6x7	64	1.59	64.01	5.97	0.24	7.38	0.60	19.93	2.45
6x8	65	0.52	69.79	.	3.50	7.99	0.17	-0.19	4.46
6x9	66	1.32	64.90	6.75	5.77	1.74	0.53	8.51	1.96
6x10	67	0.59	66.47	3.46	-4.78	1.03	0.28	4.12	3.39
6x11	68	1.21	65.42	4.97	-1.91	5.67	0.43	-6.42	3.68
6x12	69	0.37	65.72	.	3.15	6.92	0.20	0.35	2.26
6x13	70	1.24	66.80	3.50	13.68	6.65	0.54	1.47	1.36
6x14	71	0.92	66.44	6.36	0.74	8.22	0.45	-7.02	3.47
7x8	74	0.84	66.97	5.73	-2.32	9.68	0.46	3.10	3.80
7x9	75	1.01	65.99	2.21	-1.64	40.45	0.61	2.03	2.93
7x10	76	1.28	67.56	2.95	17.63	18.11	0.48	12.85	2.90
7x11	77	1.20	65.14	3.79	-2.56	55.86	0.68	5.09	2.63
7x12	78	1.31	63.29	14.12	4.14	11.56	0.57	0.92	2.86
7x13	79	1.34	65.98	2.27	4.45	18.89	0.57	4.12	2.09
7x14	80	1.53	64.35	5.14	11.72	15.74	0.79	-2.13	3.06
8x9	83	1.63	67.32	1.35	6.83	5.61	0.53	2.84	1.86
8x10	84	0.66	69.20	7.73	15.22	0.66	0.32	1.29	3.70
8x11	85	1.68	69.83	2.46	34.75	2.13	0.54	0.01	2.47
8x12	86	1.12	64.44	5.43	2.46	13.68	0.50	-1.48	3.67
8x13	87	0.87	68.52	6.36	8.72	5.68	0.32	0.87	1.09
8x14	88	0.55	68.46	.	3.96	15.83	0.24	0.78	2.06
9x10	91	1.29	63.96	5.54	6.67	27.28	0.51	2.66	2.80
9x11	92	0.95	67.11	5.50	1.77	11.03	0.46	10.57	1.13
9x12	93	0.79	61.61	7.12	2.04	25.96	0.37	12.75	3.91
9x13	94	1.01	67.66	2.97	9.96	10.49	0.38	1.10	0.82
9x14	95	1.22	65.86	5.46	5.12	21.38	0.52	2.36	2.51
10x11	96	0.47	67.74	9.34	-0.13	7.18	0.38	11.38	2.84
10x12	97	1.01	64.21	.	3.80	4.11	0.55	-0.26	4.25

APPENDIX F Cont:

Cross	Entry	GY *t/ha*	AD *d*	ASI *d*	RL *%*	SL *%*	EPP *#*	ER *%*	EA *Sc 1-5*
10x13	98	0.78	65.71	5.46	-1.68	5.78	0.31	0.22	3.44
10x14	99	1.00	64.80	6.50	1.86	7.28	0.47	3.94	2.84
11x12	101	0.88	63.98	8.42	-0.53	16.43	0.38	0.92	3.07
11x13	102	0.48	68.90	4.76	7.38	8.26	0.25	8.81	3.07
12x13	105	1.80	65.95	.	8.51	9.03	0.49	12.62	3.90
12x14	106	0.73	65.89	.	0.13	-1.85	0.33	2.07	4.24
13x14	107	0.83	65.30	.	-1.84	5.15	0.39	4.92	1.27
Experimental checks									
1xB	14	0.90	73.35	2.35	8.02	10.33	0.53	-1.15	4.18
2xA	27	0.60	75.48	.	13.15	7.17	0.30	18.73	4.33
2xB	28	1.15	71.08	.	3.24	13.27	0.55	-0.21	2.58
3xA	40	0.87	68.20	4.54	4.86	4.95	0.43	4.23	3.28
3xB	41	1.22	69.18	1.97	9.18	26.15	0.44	2.06	1.02
4xA	52	1.18	74.89	4.57	1.42	4.38	0.17	2.31	4.11
4xB	53	0.71	72.81	.	0.45	7.13	0.32	0.91	4.52
5xB	63	1.47	68.25	1.97	1.38	9.34	0.51	1.81	2.30
6xA	72	1.22	65.58	3.04	3.53	11.35	0.65	-0.37	0.61
6xB	73	0.83	69.47	.	2.01	2.98	0.34	4.92	2.10
7xA	81	1.07	71.32	1.97	3.96	31.13	0.44	7.17	3.33
7xB	82	1.41	68.79	5.73	4.55	47.95	0.59	1.38	1.82
8xA	89	0.63	.	.	8.53	-3.86	0.33	-3.08	2.26
8xB	90	1.08	71.91	4.74	16.84	2.01	0.44	-0.02	3.26
10xB	100	0.94	70.97	1.97	6.24	8.50	0.39	-0.01	3.71
11xB	104	0.69	74.05	.	4.57	5.53	0.33	-0.36	3.70
13xA	108	0.62	74.78	4.97	14.37	-4.92	0.36	-0.51	2.29
13xB	109	0.71	70.05	2.85	10.53	4.56	0.36	0.62	3.36
AxB	110	0.07	76.67	4.85	28.56	-0.35	0.10	1.68	3.73
Mean		**0.99**	**67.48**	**5.21**	**5.82**	**11.14**	**0.45**	**4.23**	**2.84**
LSD (0.05)		**0.96**	**1.97**	**6.73**	**21.22**	**22.14**	**0.34**	**20.40**	**2.57**
Min		**0.07**	**61.61**	**-0.96**	**-4.78**	**-6.15**	**0.10**	**-7.28**	**0.35**
Max		**1.80**	**76.67**	**21.42**	**38.12**	**55.86**	**0.85**	**39.23**	**4.67**

APPENDIX G

Specific combining ability effects for grain yield and agronomic traits across three environments in 2006

Cross	Entry	GY *t/ha*	AD *d*	ASI *d*	EPP *#*	RL *%*	SL *%*	ER *%*	EA *Sc 1-5*
1x2	1	0.31	-0.01	-1.01	0.03	-2.4	0.84	1.49	0.03
1x3	2	0.13	-0.48	0.95	-0.02	4.40	4.08	-1.39	-0.03
1x4	3	0.04	0.34	-1.65	0.00	0.53	-3.08	3.88	-0.27
1x5	4	-0.17	0.64	-0.23	-0.02	-0.14	-1.03	1.64	-0.05
1x6	5	-0.39	0.04	0.29	0.02	1.27	0.29	-1.03	-0.03
1x7	6	0.10	-0.91	1.94	-0.03	-2.40	4.06	-0.48	-0.89
1x8	7	-0.09	0.38	0.22	-0.07	-0.88	-0.79	5.25	-0.12
1x9	8	-0.46	-1.00	0.15	-0.08	-0.06	16.71	-2.02	0.25
1x10	9	0.14	-0.29	-0.65	0.08	-1.72	-2.60	-3.43	0.52
1x11	10	-0.09	0.81	0.20	0.03	0.70	-5.26	0.27	-0.07
1x12	11	0.46	1.35	-1.06	0.03	-3.53	-9.61	-3.16	-0.25
1x13	12	-0.05	-1.15	0.76	0.14	1.54	-0.44	1.50	0.02
1x14	13	0.08	0.28	0.09	-0.05	2.70	-3.12	-2.93	0.10
2x3	15	-0.07	0.27	0.15	0.07	-2.48	0.89	0.35	0.02
2x4	16	-0.30	-1.42	1.88	0.02	1.99	-1.18	0.87	-0.22
2x5	17	0.41	-0.11	0.80	-0.04	-2.14	3.00	1.41	0.08
2x6	18	-0.38	0.63	-0.85	-0.01	-1.13	1.44	-0.30	0.02
2x7	19	-0.44	0.50	-0.03	0.03	7.34	1.91	2.73	0.29
2x8	20	0.26	1.13	-2.26	0.02	4.63	-1.76	0.79	0.01
2x9	21	-0.23	1.42	-0.16	-0.02	-0.34	-5.82	3.68	-0.04
2x10	22	0.28	-0.04	1.88	0.03	-0.16	1.24	-3.84	-0.26
2x11	23	0.50	-0.77	-0.60	0.02	-1.21	3.30	-1.89	-0.53
2x12	24	-0.56	-0.23	-0.20	-0.09	-0.05	-4.74	-4.07	0.21
2x13	25	0.16	-1.73	0.45	0.00	-2.20	0.94	-5.96	0.06
2x14	26	0.06	0.36	-0.05	-0.06	-0.84	-0.07	4.46	0.31
3x4	29	0.06	-0.05	-0.66	-0.06	-2.82	-0.75	-1.71	-0.28
3x5	30	-0.06	0.09	0.92	-0.09	0.69	-1.69	4.78	0.27
3x6	31	0.49	1.32	-1.90	0.03	-2.69	-0.46	-3.58	0.21
3x7	32	0.01	-0.14	0.59	-0.01	-0.37	-3.07	-1.03	0.23
3x8	33	0.01	-0.18	-0.30	-0.04	-3.61	1.34	1.16	0.29
3x9	34	0.32	-0.55	1.47	0.14	-2.57	-1.38	-7.66	-0.10
3x10	35	-0.23	-0.18	0.17	-0.05	1.28	0.42	4.72	-0.07
3x11	36	0.06	0.09	-0.48	0.07	-1.86	-1.43	-6.87	0.00
3x12	37	-0.15	0.29	-0.91	0.04	8.79	9.64	6.50	0.07
3x13	38	-0.51	0.13	-0.42	-0.03	0.25	-3.45	3.50	0.17
3x14	39	0.05	-0.61	0.41	-0.06	1.00	-4.13	1.33	-0.25
4x5	42	-0.45	0.57	0.99	-0.01	-0.58	-0.29	0.80	-0.05
4x6	43	0.53	0.31	-0.16	-0.01	-1.21	2.98	-2.15	-0.02
4x7	44	-0.24	0.68	-0.34	0.06	-1.82	-1.56	0.13	0.00
4x8	45	0.12	-0.19	1.27	0.08	2.87	0.63	4.96	0.13

APPENDIX G Cont:

Cross	**Entry**	**GY** ***t/ha***	**AD** ***d***	**ASI** ***d***	**EPP** ***#***	**RL** ***%***	**SL** ***%***	**ER** ***%***	**EA** ***Sc 1-5***
4x9	46	0.00	-1.23	-0.46	-0.04	-0.94	-6.65	-0.32	0.16
4x10	47	-0.18	0.14	1.58	-0.05	-0.8	3.62	2.55	0.36
4x11	48	0.19	0.41	-1.24	-0.02	1.09	2.78	-0.92	-0.24
4x12	49	0.37	-1.05	-0.34	0.00	-1.60	0.55	-4.31	0.00
4x13	50	0.23	0.28	-1.02	0.03	1.33	-0.25	-3.42	0.27
4x14	51	-0.28	1.21	0.15	0.07	1.96	3.21	-0.35	0.18
5x6	54	0.22	1.11	-0.91	-0.05	-0.04	-2.84	5.18	0.11
5x7	55	0.08	-2.01	0.74	0.01	-1.61	3.79	-2.61	-0.04
5x8	56	-0.10	-1.22	0.19	0.06	3.49	3.14	1.03	-0.07
5x9	57	0.03	0.24	0.29	0.03	4.47	4.43	1.37	-0.12
5x10	58	0.26	-0.39	-1.34	0.02	0.06	1.31	-8.42	-0.34
5x11	59	0.00	0.21	-0.49	0.01	-1.98	1.63	-0.28	0.14
5x12	60	-0.43	1.42	-0.09	-0.04	1.59	-5.55	-0.94	0.21
5x13	61	0.23	-0.25	-0.94	0.07	-2.92	-1.42	-7.30	0.02
5x14	62	-0.04	-0.32	0.06	0.05	-1.17	-4.48	3.34	-0.10
6x7	64	-0.04	-0.44	0.59	0.06	-2.24	-0.20	7.98	0.16
6x8	65	0.21	-0.82	0.54	-0.01	2.64	6.29	-5.19	-0.30
6x9	66	0.39	-0.52	0.63	0.01	-2.11	-11.17	-0.26	0.00
6x10	67	-0.62	-0.15	0.51	0.02	-0.68	2.14	4.55	0.43
6x11	68	-0.20	-1.05	-0.15	-0.01	2.75	2.67	-1.84	-0.16
6x12	69	0.04	0.16	1.59	0.04	3.18	-4.83	-6.63	0.07
6x13	70	-0.14	-0.34	0.24	-0.05	-1.58	0.66	2.59	-0.16
6x14	71	-0.01	-0.50	-0.42	-0.04	1.81	3.03	0.41	0.01
7x8	74	-0.36	0.89	0.35	-0.03	-3.39	-1.16	-0.11	0.22
7x9	75	0.35	1.18	-0.38	-0.04	7.88	-11.24	7.39	-0.49
7x10	76	0.51	0.23	-0.51	0.05	-1.54	-1.34	-2.94	-0.30
7x11	77	-0.34	-0.68	-0.34	-0.08	-1.00	-0.66	1.98	0.36
7x12	78	0.24	0.36	-1.92	0.00	-1.44	-0.92	-3.41	-0.07
7x13	79	0.28	0.03	-0.77	-0.01	-0.10	5.18	-9.34	-0.30
7x14	80	-0.15	0.29	1.06	-0.02	0.69	5.21	-0.30	0.03
8x9	83	-0.47	0.81	-0.10	-0.03	-2.50	-9.21	-3.60	0.06
8x10	84	-0.26	0.52	-2.06	0.02	0.32	1.45	0.61	0.17
8x11	85	0.56	0.61	-0.55	0.07	0.21	-0.04	-3.67	0.07
8x12	86	-0.28	-1.01	1.02	-0.04	-1.35	-3.20	7.87	-0.11
8x13	87	0.28	-0.84	1.67	-0.03	-2.50	3.79	-7.00	-0.25
8x14	88	0.21	-0.08	0.01	0.01	0.06	-0.11	-2.10	0.00
9x10	91	0.31	0.64	-1.30	0.02	-2.02	-11.87	-6.48	-0.13
9x11	92	-0.48	0.41	0.55	-0.06	0.78	-3.85	9.92	0.36
9x12	93	0.13	-2.05	-0.21	-0.05	-6.03	44.09	-0.42	-0.09
9x13	94	-0.43	0.78	-0.06	-0.06	7.53	-2.43	1.64	0.11
9x14	95	0.54	-0.12	-0.40	0.18	-3.38	-1.62	-3.24	-0.05
10x11	96	-0.22	0.28	1.09	-0.02	1.23	2,69	-2.07	0.05
10x12	97	-0.24	0.16	1.66	-0.07	1.75	-3.11	3.35	-0.21

APPENDIX G Cont:

Cross	**Entry**	**GY** ***t/ha***	**AD** ***d***	**ASI** ***d***	**EPP** ***#***	**RL** ***%***	**SL** ***%***	**ER** ***%***	**EA** ***Sc 1-5***
10x13	98	0.22	0.49	-1.19	-0.11	0.21	3.22	18.31	-0.11
10x14	99	0.03	-1.41	0.15	0.04	2.07	2.88	-6.90	-0.11
11x12	101	0.39	-0.58	0.34	0.06	1.41	-7.55	-3.99	0.02
12x13	105	0.35	0.63	-0.27	-0.10	-7.93	0.09	1.56	0.20
12x14	106	-0.35	-0.63	0.27	-0.09	0.10	7.93	-5.48	-0.20
13x14	107	-0.35	-0.63	0.27	-0.09	0.10	7.93	-5.48	-0.20

APPENDIX H

Predicted grain yield and other agronomic traits of the best one hundred three-way hybrids

TW	GY *t/ha*	AD *d*	ASI *d*	EPP *#*	RL *%*	SL *%*	ER *%*	EA *Sc 1-5*
1/6x4	4.66	69.79	2.15	0.78	7.23	4.87	12.10	1.91
1/8x4	4.60	70.45	3.17	0.80	10.62	6.63	14.65	1.88
6/8x4	4.54	69.71	4.78	0.78	12.10	3.27	12.15	1.91
1/11x4	4.44	69.89	1.06	0.81	5.19	5.54	13.11	1.84
6/11x4	4.39	69.14	2.68	0.79	6.67	2.17	10.61	1.87
1/3x4	4.37	69.82	2.27	0.76	5.77	8.15	13.93	1.78
1/2x4	4.37	69.71	2.34	0.80	5.80	6.10	7.59	1.66
1/7x4	4.33	69.78	1.67	0.81	6.94	7.04	10.71	1.90
1/12x4	4.33	68.58	2.69	0.78	6.33	9.07	13.07	1.98
8/11x4	4.32	69.80	3.70	0.81	10.05	3.94	13.15	1.84
3/6x4	4.32	69.07	3.88	0.74	7.25	4.78	11.43	1.81
2/6 x4	4.32	68.96	3.95	0.78	7.28	2.73	5.09	1.70
6/7 x4	4.28	69.03	3.28	0.79	8.41	3.67	8.21	1.93
6/12 x4	4.27	67.84	4.31	0.76	7.81	5.70	10.57	2.01
1/9 x4	4.27	68.77	1.45	0.76	5.35	9.37	11.81	1.99
3/8 x4	4.25	69.73	4.90	0.76	10.63	6.54	13.97	1.78
2/8 x4	4.25	69.62	4.97	0.80	10.67	4.50	7.64	1.66
1/14 x4	4.23	70.07	3.20	0.82	6.11	6.11	11.17	2.03
7/8 x4	4.22	69.69	4.30	0.81	11.80	5.43	10.75	1.90
6/9 x4	4.21	68.02	3.07	0.74	6.83	6.00	9.31	2.02
8/12 x4	4.21	68.50	5.33	0.78	11.19	7.47	13.11	1.98
1/13 x4	4.20	70.11	3.51	0.76	9.77	4.95	14.71	2.07
4/14x1	4.19	69.54	1.67	0.78	8.40	8.64	13.38	2.30
2/4x1	4.19	69.96	1.16	0.82	3.77	8.09	14.43	2.17
4/7x1	4.17	68.89	1.98	0.79	9.70	12.06	13.17	2.15
4/8x1	4.17	70.43	1.59	0.75	6.33	7.62	19.12	2.06
6/14x4	4.17	69.32	4.81	0.79	7.58	2.75	8.67	2.06
1/5x3	4.17	69.51	2.92	0.78	5.21	5.43	13.11	2.01
8/9x4	4.15	68.68	4.09	0.76	10.21	7.76	11.85	1.99
6/13x4	4.14	69.36	5.12	0.73	11.24	1.58	12.21	2.10
4/12x3	4.14	69.21	2.81	0.78	6.04	8.03	16.39	2.12
5/6x3	4.11	68.76	4.54	0.76	6.69	2.06	10.61	2.04
8/14x3	4.11	69.98	5.83	0.81	10.97	4.51	11.21	2.03
3/11x3	4.10	69.16	2.80	0.76	5.20	5.45	12.43	1.74
1/10x3	4.10	69.47	4.51	0.78	3.95	5.04	17.55	2.28
2/11x3	4.10	69.05	2.87	0.80	5.24	3.40	6.10	1.63
8/13x3	4.08	70.02	6.14	0.75	14.63	3.34	14.76	2.07
4/10x1	4.08	69.26	2.08	0.80	5.72	11.10	17.51	2.63
7/11x4	4.06	69.12	2.20	0.81	6.37	4.34	9.21	1.86
11/12x4	4.06	67.93	3.22	0.78	5.76	6.37	11.58	1.94

APPENDIX H Cont:

TW	GY *t/ha*	AD *d*	ASI *d*	EPP *#*	RL *%*	SL *%*	ER *%*	EA *Sc 1-5*
1/4x8	4.05	70.34	4.22	0.75	11.19	6.02	19.17	2.06
4/8x6	4.05	68.86	3.29	0.73	7.67	5.99	9.54	1.98
5/8x4	4.05	69.42	5.56	0.78	10.08	3.83	13.16	2.01
3/4x6	4.04	68.47	3.53	0.72	5.41	3.37	11.75	2.02
6/10x4	4.04	68.72	6.13	0.75	5.43	1.67	15.05	2.31
4/11x8	4.03	70.14	4.90	0.78	13.22	4.17	13.41	2.08
2/3x4	4.03	68.98	4.07	0.75	5.82	6.01	6.92	1.56
4/5x6	4.02	67.55	3.18	0.75	6.46	1.67	14.52	2.17
4/13x1	4.00	67.75	2.12	0.82	6.17	8.19	22.24	2.24
4/14x6	4.00	68.19	3.53	0.73	6.58	4.00	11.39	2.05
9/11x4	3.99	68.11	1.98	0.77	4.78	6.67	10.31	1.95
3/7x4	3.99	69.05	3.40	0.76	6.95	6.94	10.03	1.80
2/7x4	3.99	68.94	3.47	0.80	6.98	4.90	3.70	1.68
4/6x8	3.99	69.52	4.31	0.75	11.06	7.75	12.09	1.95
3/12x4	3.99	67.86	4.43	0.73	6.34	8.98	12.40	1.88
2/12x4	3.98	67.75	4.50	0.77	6.38	6.94	6.06	1.76
3/4x1	3.98	69.47	1.52	0.76	7.81	13.38	16.66	2.18
4/11x1	3.98	70.26	1.39	0.79	8.70	5.54	14.84	2.21
8/10x4	3.98	69.38	7.15	0.77	8.81	3.44	17.59	2.28
4/6x1	3.97	69.86	1.16	0.80	5.49	8.23	14.41	2.14
4/9x6	3.97	66.30	3.45	0.71	9.07	4.67	11.63	2.12
11/14x4	3.95	69.41	3.73	0.82	5.54	3.41	9.67	1.99
7/12x4	3.95	67.82	3.82	0.78	7.51	7.87	9.18	2.00
4/7x6	3.94	67.49	3.14	0.76	12.21	4.82	16.02	2.12
4/5x1	3.93	69.29	1.00	0.82	5.68	7.75	15.26	2.24
4/13x6	3.93	68.07	5.36	0.68	6.56	3.81	17.56	2.01
11/13x4	3.92	69.45	4.04	0.76	9.20	2.25	13.22	2.03
3/9x4	3.92	68.04	3.19	0.72	5.36	9.27	11.13	1.88
1/4x6	3.92	69.12	2.77	0.77	6.97	4.87	11.91	2.17
2/9x4	3.92	67.94	3.26	0.76	5.40	7.23	4.80	1.77
4/5x8	3.90	68.68	4.82	0.77	11.26	6.89	15.55	2.08
2/4x8	3.90	70.02	4.54	0.76	12.18	4.76	12.35	1.99
4/14x8	3.90	69.52	5.26	0.74	10.16	5.89	13.89	2.02
5/11x4	3.89	68.85	3.46	0.79	4.65	2.73	11.62	1.97
4/9x1	3.89	68.64	1.15	0.75	7.23	25.12	12.97	2.31
7/9x4	3.88	68.00	2.59	0.77	6.53	8.16	7.91	2.00
3/14x4	3.88	69.34	4.93	0.77	6.12	6.02	10.49	1.92
4/8x11	3.88	69.57	2.79	0.78	7.79	3.08	11.87	2.04
2/4x11	3.88	68.13	2.59	0.79	3.78	4.36	10.76	1.75
2/14x4	3.88	69.24	5.00	0.81	6.15	3.98	4.16	1.81
9/12x4	3.88	66.81	3.61	0.74	5.92	10.20	10.28	2.09
3/13x4	3.85	69.38	5.24	0.71	9.78	4.86	14.04	1.97
2/13x4	3.85	69.28	5.31	0.75	9.82	2.81	7.70	1.85

APPENDIX H Cont:

TW	**GY** *t/ha*	**AD** *d*	**ASI** *d*	**EPP** *#*	**RL** *%*	**SL** *%*	**ER** *%*	**EA** *Sc 1-5*
3/4x8	3.85	69.17	4.40	0.71	9.67	10.84	17.84	2.09
7/14x4	3.84	69.30	4.33	0.82	7.29	4.91	7.27	2.05
1/4x2	3.84	69.13	2.97	0.82	3.81	5.95	7.42	1.95
2/4x6	3.83	68.40	3.37	0.78	5.57	2.97	9.77	2.08
10/11x4	3.83	68.81	5.05	0.78	3.38	2.34	16.05	2.24
4/10x7	3.82	67.87	2.85	0.77	7.68	12.66	10.75	2.06
3/5x4	3.82	68.78	4.66	0.74	5.23	5.34	12.44	1.90
2/5x4	3.82	68.67	4.73	0.78	5.26	3.30	6.10	1.79
7/13x4	3.81	69.34	4.64	0.76	10.95	3.75	10.82	2.09
4/13x8	3.81	69.48	5.67	0.70	12.85	6.13	16.40	2.04
12/13x8	3.81	68.15	5.67	0.73	10.34	5.78	13.18	2.17
4/11x2	3.81	67.96	3.86	0.78	4.39	4.93	5.25	1.57
4/11x6	3.80	67.92	3.20	0.74	8.37	4.07	12.10	2.06
1/4x7	3.79	68.13	3.11	0.79	10.88	10.86	9.28	2.17
5/7x4	3.78	68.74	4.06	0.79	6.39	4.23	9.22	2.03
5/12x4	3.78	67.55	5.08	0.76	5.79	6.27	11.58	2.11
Mean	**3.24**	**67.17**	**3.94**	**0.71**	**7.07**	**10.33**	**17.41**	**2.34**

APPENDIX I

Predicted grain yield and other agronomic traits of the best one hundred double cross hybrids

DC	GY	AD	ASI	EPP	RL	SL	ER	EA
	t/ha	*d*	*d*	#	%	%	%	*Sc 1-5*
1/6x4/8	4.11	69.64	2.44	0.74	7.00	6.81	14.33	2.02
1/6x4/14	4.09	68.86	2.60	0.76	7.49	6.32	12.39	2.18
1/6x4/7	4.06	68.19	2.56	0.78	10.96	8.44	14.60	2.13
1/8x4/14	4.04	69.53	3.46	0.76	9.28	7.27	13.63	2.16
1/8x2/4	4.04	69.99	2.85	0.79	7.97	6.42	13.39	2.08
1/11x2/4	4.03	69.05	1.88	0.81	3.77	6.22	12.59	1.96
1/11x4/8	4.03	70.00	2.19	0.77	7.06	5.35	15.50	2.05
1/6x3/4	4.01	68.97	2.52	0.74	6.61	8.37	14.21	2.10
1/6x2/4	4.01	69.18	2.27	0.80	4.67	5.53	12.10	2.12
1/8x4/11	4.01	70.20	3.14	0.78	10.96	4.85	14.13	2.15
1/4x6/8	3.99	69.73	3.50	0.76	9.08	5.44	15.54	2.12
1/8x4/6	3.98	69.69	2.73	0.77	8.27	7.99	13.25	2.05
1/6x4/5	3.98	68.42	2.09	0.78	6.07	4.71	14.89	2.20
4/8x6/11	3.97	69.21	3.04	0.76	7.73	4.53	10.71	2.01
1/6x4/13	3.97	67.91	3.74	0.75	6.36	6.00	19.90	2.12
1/12x4/7	3.96	67.32	2.85	0.76	9.27	12.66	12.43	2.17
4/5x6/8	3.96	68.12	4.00	0.76	8.86	4.28	15.04	2.12
1/3x4/7	3.96	68.29	2.33	0.75	9.44	12.24	13.29	2.09
1/6x4/12	3.96	68.35	3.56	0.75	7.79	5.82	13.68	2.15
1/7x4/10	3.95	68.56	2.46	0.78	6.70	11.88	14.13	2.34
1/8x4/7	3.95	69.12	3.19	0.76	10.86	10.62	14.30	2.14
4/14x6/8	3.95	68.86	4.40	0.74	8.37	4.95	12.64	2.04
1/7x4/12	3.95	68.07	2.75	0.78	7.74	9.62	12.85	2.11
1/4x2/8	3.95	69.74	3.60	0.78	7.50	5.98	13.29	2.00
3/4x6/8	3.95	68.82	3.96	0.71	7.54	7.11	14.80	2.06
1/11x4/14	3.94	68.73	2.01	0.77	7.80	7.11	16.16	2.20
1/6x4/9	3.93	67.47	2.30	0.73	8.15	14.89	12.30	2.22
1/4x7/8	3.92	69.23	3.67	0.77	11.04	8.44	14.22	2.11
1/2x4/8	3.92	69.85	2.65	0.76	6.85	5.93	12.21	1.92
2/8x4/11	3.92	69.05	4.38	0.78	8.81	4.55	9.33	1.83
4/11x6/8	3.92	69.03	4.05	0.76	10.80	4.12	12.76	2.07
1/8x4/5	3.92	68.98	2.91	0.79	8.47	7.32	15.40	2.16
1/8x3/4	3.91	69.32	2.96	0.73	8.74	12.11	17.25	2.14
1/2x4/14	3.91	68.81	3.06	0.76	6.67	7.55	10.23	2.09
1/8x4/13	3.91	68.62	3.90	0.76	9.51	7.16	19.32	2.14
1/11x4/12	3.90	68.27	3.09	0.77	5.29	6.58	14.95	2.15
1/4x8/12	3.90	68.80	4.60	0.75	8.90	7.44	17.01	2.14
1/3x4/8	3.90	69.48	2.54	0.71	5.58	9.99	18.12	2.02
1/2x4/11	3.89	69.11	2.62	0.79	6.55	5.23	10.04	1.89
2/4x8/11	3.89	69.07	3.57	0.78	7.98	4.56	11.55	1.87

APPENDIX I Cont:

DC	GY	AD	ASI	EPP	RL	SL	ER	EA
	t/ha	*d*	*d*	*#*	*%*	*%*	*%*	*Sc 1-5*
1/6x4/11	3.89	69.09	2.29	0.76	8.54	4.80	13.47	2.13
1/10x4/7	3.88	68.23	3.84	0.76	7.20	11.37	15.38	2.30
1/4x2/6	3.88	69.12	2.87	0.79	5.39	5.41	9.66	2.06
1/4x8/11	3.88	69.98	3.07	0.77	9.66	4.43	16.26	2.12
1/2x4/7	3.88	68.51	2.68	0.79	10.41	10.48	9.65	2.03
1/4x8/14	3.88	69.71	4.28	0.77	9.97	6.27	14.56	2.25
3/4x6/7	3.87	68.05	2.80	0.74	7.88	7.34	10.98	2.09
3/8x4/6	3.87	69.00	3.98	0.72	7.50	7.20	12.83	1.92
1/11x4/7	3.87	68.22	1.90	0.78	7.87	13.59	13.48	2.19
4/13x6/8	3.87	68.78	5.52	0.69	9.71	4.97	16.98	2.03
1/7x2/4	3.87	69.08	1.93	0.81	8.01	8.96	11.84	2.16
1/3x4/14	3.87	68.77	2.75	0.74	6.80	7.29	14.52	2.07
1/3x4/6	3.86	69.18	2.40	0.74	4.72	7.44	13.99	2.02
2/4x6/8	3.86	69.21	3.95	0.77	8.88	3.87	11.06	2.03
1/9x4/7	3.86	67.79	1.88	0.75	9.95	14.03	14.65	2.03
2/6x4/5	3.86	67.58	3.75	0.76	5.82	4.10	9.76	2.03
3/6x4/9	3.86	66.69	3.87	0.73	6.70	8.65	11.56	2.05
2/6x4/8	3.86	69.06	3.50	0.75	7.52	5.11	7.42	1.88
1/4x6/7	3.86	68.62	2.94	0.78	8.92	7.86	10.59	2.17
2/4x6/11	3.86	68.27	2.98	0.79	4.67	3.67	10.27	1.91
1/7x4/14	3.85	68.65	2.28	0.77	8.39	9.68	11.23	2.21
1/8x4/12	3.85	68.76	3.72	0.75	8.79	7.94	20.71	2.12
1/13x4/7	3.85	68.42	3.04	0.74	10.14	10.30	12.76	2.15
1/14x4/8	3.85	69.78	3.44	0.75	5.99	6.50	14.77	2.11
4/7x6/12	3.85	66.62	3.43	0.75	10.52	9.04	13.85	2.16
1/4x6/12	3.85	69.54	3.74	0.73	9.51	9.65	17.58	2.07
3/4x6/9	3.84	67.25	3.50	0.73	4.65	8.61	10.56	2.10
4/14x6/11	3.84	68.05	2.94	0.74	6.89	4.79	15.16	2.08
1/5x2/4	3.84	68.68	3.03	0.79	4.18	6.97	12.48	2.20
1/8x4/10	3.84	69.53	4.40	0.75	8.70	8.91	19.61	2.50
3/6x4/7	3.84	67.59	2.91	0.74	10.70	8.61	14.72	2.07
1/7x3/4	3.84	68.55	1.80	0.76	9.08	12.34	13.43	2.17
1/6x4/10	3.84	68.58	3.77	0.76	5.49	7.44	18.95	2.55
1/9x4/14	3.84	68.00	2.31	0.77	7.24	11.22	11.26	2.26
3/6x4/8	3.84	68.69	3.39	0.70	6.25	9.17	13.33	1.98
4/5x6/7	3.84	67.05	2.79	0.79	7.20	5.46	11.17	2.13
1/7x4/13	3.84	67.68	2.19	0.78	6.96	9.40	15.29	2.11
1/14x2/4	3.84	69.20	3.24	0.79	4.50	7.28	12.54	2.21
1/4x6/12	3.83	68.18	3.87	0.77	6.79	6.86	13.38	2.20
4/7x6/8	3.83	68.42	3.77	0.75	12.11	6.99	15.73	2.13
1/3x2/4	3.83	69.07	2.83	0.78	3.95	9.40	14.48	2.06
3/4x6/11	3.83	68.37	3.38	0.74	5.71	4.69	11.87	2.08
1/5x4/7	3.83	67.58	2.82	0.79	7.96	9.86	11.70	2.18

APPENDIX I Cont:

DC	GY *t/ha*	AD *d*	ASI *d*	EPP *#*	RL *%*	SL *%*	ER *%*	EA *Sc 1-5*
4/5x6/11	3.82	67.65	2.91	0.77	5.24	3.81	13.56	2.21
1/9x2/4	3.82	68.70	2.01	0.76	4.74	10.68	12.46	2.12
1/5x4/8	3.82	69.08	3.08	0.75	6.09	6.66	16.57	2.13
1/3x4/9	3.82	67.86	2.72	0.75	5.78	18.87	12.23	2.14
1/2x4/5	3.82	68.44	2.66	0.80	5.43	7.14	10.13	2.07
1/7x4/8	3.82	69.55	2.24	0.74	7.33	8.60	15.31	2.10
1/13x2/4	3.82	68.94	3.62	0.75	6.46	5.97	13.82	2.22
1/4x2/7	3.82	68.63	3.04	0.80	7.35	8.40	8.35	2.06
2/6x4/14	3.81	68.13	3.99	0.73	5.75	5.23	9.23	1.97
1/4x6/11	3.81	69.36	2.34	0.78	7.55	3.85	12.63	2.17
1/9x3/4	3.81	67.75	2.50	0.75	5.85	13.61	13.02	2.18
1/2x4/13	3.81	67.64	3.51	0.77	5.68	6.60	14.17	2.05
1/4x6/14	3.81	69.09	3.55	0.78	7.86	5.69	10.93	2.31
2/6x4/11	3.80	67.94	3.53	0.76	6.38	4.50	8.67	1.81
2/8x4/5	3.80	68.14	4.57	0.78	8.22	6.71	10.28	1.99
4/6x7/8	3.80	68.50	3.48	0.77	11.48	7.37	13.36	2.03
4/13x6/7	3.80	67.84	3.81	0.71	7.15	7.21	12.95	2.00
Mean	**3.24**	**67.17**	**3.94**	**0.71**	**7.07**	**10.33**	**17.41**	**2.34**