GENETIC ANALYSIS OF RESISTANCE TO FUSARIUM EAR ROT (*FUSARIUM VERTICILLIOIDES*) IN TROPICAL MAIZE (*ZEA MAYS* L.)

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DECLARATION AND APPROVAL

Declaration

I declare that the work presented in this thesis is original, except as acknowledged in the text. The material has not been submitted, or being considered for submission, either in whole or in part, for an award of degree at this or any other University.

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DEDICATION

To my parents Mr. and Mrs. Mengich. My siblings Ms. Ursila Mengich, Ms. Consolata Mengich, Ms. Janet Mengich, Mr. Collins Mengich , Mr. Elphas Mengich and Ms. Caroline Mengich .

ABSTRACT

Fusarium ear rot of maize is caused by *Fusarium verticillioides (=F. moniliforme)* and *F. proliferatum,* with *F. verticillioides* being the most widespread in Kenya. Fusarium ear rot causes yield loss in maize production and leads to contamination of maize grain with fumonisins that are harmful to both humans and livestock. Breeding for Fusarium ear rot resistance is the most economically feasible method for control of Fusarium ear rot. Knowledge of the inheritance of resistance to Fusarium ear rot infection is important in developing a breeding program for the disease. The objectives of this study were to estimate combining abilities and mode of gene action of maize inbred lines for resistance to Fusarium ear rot and evaluate the performance of single cross hybrids between mid-altitude adapted and lowland tropical inbred lines. Sixteen (16) maize inbred lines from the International Maize and Wheat Improvement Center (CIMMYT) breeding programs in Kenya and Mexico were crossed in a North Carolina design II (NCII) mating scheme to form 60 F_1hybrids that were evaluated in trials laid out as alpha-lattice with two replications and two row plots at four locations (Kiboko, Kibos, Alupe, and Kakamega) in Kenya in 2014. The trials at Kibos, Alupe, and Kakamega were artificially inoculated with an isolate of *F. verticillioides* commonly found in Western Kenya region, and three other trials were planted at the same locations but were not inoculated. Data were collected on grain yield (GY) and agronomic traits, Fusarium ear rot incidence (FSI) and severity (FSE). Analysis of variance and combining ability analysis of the data collected were carried out using SAS. Results indicated significant differences ($P < 0.001$) between hybrids for GY and FSI across both artificially inoculated and non-inoculated experiments. Inbred lines with the best desirable GCA effects for FSI under artificial inoculation were CKL05024 (-6.29), CML538 (-5.66), CKL05019 (-5.15), and CKL05003 (-5.14). Inbred lines CKL05024, CKL05003, and CKL05019 that also had desirable GCA effects for FSI under natural disease infestation are therefore potentially suitable for use in pedigree breeding to develop Fusarium ear rot resistant germplasm. Inbred lines CL-RCW37 (-10.79***), CKL05003 (-12.74***), CML247 (-4.82) and P502c2-185-3-4-2-3-B-2-B*6 (-3.56) had the best desirable GCA effects for FSE across artificially inoculated trials. Inbred lines CKL05003, (CKL05003/CML444//CKL05003) DH5-B, CL-RCW37 and P502c2-185-3-4-2-3-B-2-B*6 had desirable GCA effects for both FSI and FSE in artificially inoculated trials. Hybrids CML442/CL-RCW37 (-12.83) and CKL05003/ (LaPostaSeqC7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B (-10.39) had the best desirable SCA effects for FSI across artificially inoculated trials. Hybrids CKL05003/CML247 (-17.53*), CKL05024/P502c2-185-3-4-2-3-B-2-B*6 (-17.03*), and CKL05003/CML264 (-15.43*) had the best SCA effects for FSE across artificially inoculated trials. These hybrids can be tested further in multiple environments to confirm low FSI and FSE, and quantify fumonisin content before they can be used as parents to develop three-way cross hybrids for the mid altitude ecology of Kenya.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CAN	Calcium Ammonium Nitrate
CIMMYT	International Maize and Wheat Improvement Center
CML	CIMMYT Maize Line
DAP	Di-Ammonium Phosphate
DTMA	Drought Tolerant Maize for Africa
FAO	Food and Agriculture Organization
GCA	General Combining Ability
GLS	Gray Leaf Spot
MLN	Maize Lethal Necrosis
MOA	Ministry of Agriculture
MSV	Maize Streak Virus
PDA	Potato Dextrose Agar
QTL	Quantitative Trait Loci
SCA	Specific Combining Ability
SNA	Sucrose Nutrient Agar

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CHAPTER ONE

INTRODUCTION

1.1 Importance of maize

Maize (*Zea mays* L.) combined with rice and wheat benefits about 4.5 billion people residing in 94 developing countries around the world and gathers for no less than 30% of the food calorie requirement (FAOSTAT, 2010; CIMMYT, 2010). Of this population, 120-140 million poor farmers (living on ≤2 USD per day), 900 million poor consumers and almost a third of the entire undernourished children depend on maize as food or feed with 90% of them living in sub-Saharan Africa, tropical and sub-tropical Latin America and Asia (Hyman *et al*., 2008; CIMMYT, 2010). In Kenya, maize is staple food crop and cultivated in over 40% of the total area (FAOSTAT, 2015). The production in 2011-2015 (average) stood at 3.53 million tons and a forecast of 3.3million tons in 2016 against an annual demand of 3.6 million tons (FAOSTAT, 2015).

Introduced by Portuguese in 15th century, maize has become Kenyan staple, against which food security is measured. Maize is grown for both income generating as well as nutritive value which is given as 10% protein, 3% sugar 4.8% oil, 9.5% fiber, and 1.7% ash (Nuss and Tanumihardjo, 2010). Other uses include animal feed, industrial raw material (corn oil), domestic fuel especially in rural areas, and also as organic manure. The production constraints include both biotic and abiotic factors. Among the abiotic stresses, drought is the principle factor causing approximately 17% yield losses in tropics and can be higher when it occurs during or after flowering (Edmeades, 2008). Another significant abiotic constraint causing low yields is poor soil fertility, especially low soil nitrogen (Bänziger and Diallo, 2004). Sub–Saharan Africa has a high disparity in nitrogen fertilizer use as compared to other continents. Despite Africa utilizing 13% of the total cultivated land, the common fertilizer rate (P and K included) is 9 kg/ha which is below 250 kg/ha in North America & Western Europe, 73 kg/ha in Latin America and 100 kg/ha in South Asia (Molden, 2007). Many farmers are unable to use the recommended fertilizer rates during planting as a result of high fertilizer cost and majority of African farmers included among the most impoverished globally.

Foliar diseases mainly gray leaf spot (*Cercospora zeae-maydis*), common leaf rust (*Puccinia sorghi*), maize streak virus (MSV), Northern corn leaf blight (*Exserohilum turcicum*), and more recently maize lethal necrosis (MLN) are among the most important biotic constraints affecting maize production. MLN has become one of the most important factors reducing maize production in Kenya and causes devastating effect when it attacks the crop growth and may result in yield losses of 100% (Wangai *et al*., 2012).

Other biotic constraints of significance in maize production alongside foliar diseases in Kenya are cob rots. There are several types of cob rots caused by different causal organisms. The three most important and prevalent cob rots are Aspergillus ear rot caused by *Aspergillus flavus*, diplodia ear rot caused by *Stenocarpella maydis* (Berk.) Sutton and Fusarium ear rot caused by *Fusarium verticillioides* (synonym, *F. moniliforme*). Among these ear rots, Fusarium ear rots are prevalent in areas with high rainfall. *Fusarium verticillioides* (Sacc.) Nirenberg, a hemibiotrophic fungus induces widespread and destructive ear rot disease in maize and as a result causes direct yield loss and contamination of grains with mycotoxins (Alakonya *et al*., 2008). Alakonya *et al*. (2008) observed fusarium ear rot severity of 71% in studies conducted in western Kenya as well as 100% fumonisin contamination when both clean and rotten maize ears were tested. Considered the most studied mycotoxin, fumonisin B1 is a secondary metabolite which is the most prevalent and toxic (Julian *et al*., 1995; Desjardins *et al*., 2002; VanEgmond *et al.,* 2007). Fumonisin production depends on prevailing environmental condition and is correlated with the *Fusarium* species biomass. Miller (2001) noted that fumonisin production is favoured by a temperature range of 15-25 ^{o}C, high oxygen tension and low PH. Haschek *et al*., (1992) reported that hogs and rats suffered pulmonary edema and liver cancer when fed with pure cultures of *F. verticillioides.* In humans, fumonisins have been associated with esophageal cancer and neural tube birth defects (Rheeder *et al*., 1992; Stack, 1998).

Ears infected with *Fusarium* exhibit cottony mycelium on a few individual or a group of kernels. The mycelia appear pale pink, lavender or white and can be portrayed by white steaks originating from one point on the pericarp (starburst), which is a sign of late infection (Bacon *et al.,* 1992; Munkvold and Desjardins (1997). Generally, the fungus attacks the ears close to the tips and infection is attributed to injury from ear borers and spread to the rest of the ear with extreme infection shown by mycelium growth all over the ear. The routes of infection of *F. verticillioides* are silk channel and ear injury (Drepper and Renfro, 1990), infected seeds, roots, and infection occurs mostly where hot and dry weather conditions prevails during flowering (Alakonya *et al*., 2008). Ears that mature when open and in an upright position have also been reported to have more rot than those which are fully covered husks and facing down wards at maturity (Shurtleff, 1980). Several control measures for Fusarium ear rot have been suggested. These include management of vectors such as thrips and ear borers to reduce spread of the pathogen, effective disposal of infected crop debris to avoid creation of inoculums in the preceding seasons and crop rotation with non-cereals (Martin and Johnson, 1982). The use of chemicals to control vectors is often not cost-effective to smallholder farmers and is harmful to the environment. Therefore, deployment of ear rot resistant varieties remains the best, environmentally friendly and effective long term option for the management of the disease. No substantive efforts to control the disease have been made in Kenya, yet it is of significant concern to the farmers (Alakonya *et al*., 2008).

1.2 Problem statement

It is estimated that Fusarium ear rot can cause yield losses of up to 40% in farmers' fields (Alakonya *et al*., 2008). The disease resistance is under polygenic control and is largely influenced by genotype, environment, and severity of infection (Bolduan *et al*., 2010; Zila *et al*., 2013). Previous studies done in USA mapped three genomic regions responsible for Fusarium ear rot resistance on chromosome 3 and two other QTLs on chromosome 6 (Xiang-Ming Wang, 2008). Most cultivated tropical maize varieties have low resistance level and information on the sources of resistance and type of gene action is lacking for tropical maize germplasm. (Zila *et a*l., 2013). Knowledge of the genetics of resistance to Fusarium ear rot is critical in developing Fusarium ear rot breeding program.

1.3 Justification of the study

The development of improved stress varieties combining tolerance to the major abiotic stresses and resistance to ear rots is the best and long term environmentally sustainable option to address the problem facing maize production and associated health risks for the maize consumers. The best viable and environmentally sustainable option is to breed for host resistance to the disease. Combining abilities of lines to fusarium ear rot will be useful in development of fusarium ear rot tolerant hybrids.

Knowledge of the genetic basis of inheritance of resistance to Fusarium ear rot in tropical maize is important in formulating proper breeding strategies. The tolerant varieties will improve farm level productivity by reducing losses due to fusarium ear rot. Seed growers and companies will also reduce seed losses during seed production

1.4 GENERAL OBJECTIVE

To contribute to increased productivity of hybrid maize through management of Fusarium ear rot in Kenya.

1.4.1 Specific objectives

1. To determine the mode of gene action for resistance to Fusarium ear rot in tropical maize inbred lines under artificial inoculation with Fusarium ear rot, and
2. To determine the performance of single cross hybrids between mid-altitudes adapted and lowland tropical inbred lines.
3. Estimate general combining ability (GCA) effects of maize inbred lines and specific combining ability (SCA) effects of hybrids for Fusarium ear rot resistance.

1.5 Research hypotheses

1. Mode of gene action for resistance to *Fusarium* ear rot differ at different environments.
2. Grain yield and ear rot performance of F1 hybrids differ at different environments.
3. Genetic combining ability (GCA and SCA) differ among the half-sib crosses and among maize inbred lines.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Fusarium verticillioides was first described and associated with animal diseases in 1904 (Sheldon, 1904). The pathogen is endemic in most regions of the world including the United States (Munkvold and Desjardins, 1997), Europe (Logrieco *et al*., 2002; Covarelli *et al*., 2012), Brazil (Orsi *et al*., 2000), Argentina (Torres *et al*., 2003) and in many parts of Africa (Flett, 1994 ; Kedera *et al*., 1999; Gamanya and Sibanda, 2001; Fandohan *et al*., 2003). Fusarium colonizes maize worldwide and its distribution largely depends on the climatic patterns in the affected areas. *Fusarium verticillioides* belongs to the hemibiotriphic genus of well-known maize pathogens (Mohammadian *et al*., 2011). Hemibiotrophs has a typical two phases of life cycle (Biotrophic and necrotrophic). During bio trophic phase it depends on the host cells to obtain nutrients by using hyphae. In necrotrophic phase the fungi kill the host cells and obtain nutrient from dead cells. Usually in *Fusarium*, bio trophic phase is asymptomatic while necrotrophic phase is manifested by visible disease symptoms.

2.2 Characterization of *Fusarium* species

In order to develop a sound breeding strategy against *Fusarium* pathogens, it is critical for a researcher to make correct characterization and diagnosis before field inoculation (Chungu *et al.,* 1996). To date, *Fusarium* identification relies heavily on morphology. It is classified in Phylum *Ascomycota,* class *Ascomycetes,* order *Hypocreales* and Fusarium species based on the shape of the asexual spores - banana shaped, (Moretti, 2009).

The sexual stage (Teleomorph) of *Fusarium* species is often classified in genus *Gibberella* and morphologically under section liseola with four anamorphs: *F. moniliformis, F. subglutinans, F. proliferatum and F. anthophilum* (Zila *et al*., 2013). However, Gerlach and Niremberg (1982) changed *F. moniliformis* to *F. verticilioides* (sacc.) Niremberg. Taxonomists have considered three distinguishing factors to group *Fusarium* species: presence and shape of microconidia, absence of chlamydospores, and shape of macroconidia (Moretti, 2009). According to Rodrigues and Menezes (2006), *F. verticillioides* has plenty of microconidia, which appear in chains on a monophialide. The microconidia are club-shaped, unicellular with oval shape. Macroconidia is fusoid with a thin wall when present, the basal cell is banana or foot-shaped. *Fusarium verticillioides* has no chlamydospores and when observed on PDA the colony appears pink or sometimes purple at the lower surface and white mycelium at the top (Rodriguez and Menezes, 2006).

2.3 Significance of Fusarium ear rot in maize

Fusarium verticillioides can cause between 50-80% damage to maize in farmers' fields and in storage and produces mycotoxins (Fandohan *et al*., 2003). Thus the fungus poses a serious food security and health concern as maize is recognized as the main food crop to nearly 90% of population in Kenya (Wambugu *et al*., 2012). Apart from direct yield losses, Fusarium ear rot lowers the grain quality and quantity and reduced marketability of the produce through discoloration. As a result, the income expectation from maize harvest is greatly lowered thus weakening the economic capabilities of the farmers. Alakonya *et al*., (2008) reported that ear rots caused significant losses of nearly 40% in farmers' field as observed from the local variety H622 in western Kenya.

Fumonisins are secondary metabolites produced by *Fusarium verticillioides* and are the most investigated mycotoxins because they are frequently isolated from maize grains and are detrimental to animal and human health (Gelderblom *et al*., 1988, Miller, 2001, Munkvold and Desjardins, 1997). Previous studies show that the quantity of fumonisin in maize grains is correlated with the extent of *Fusarium* fungal mass accumulated in the grain (Miller, 2001).

Leukoencephalomalacia disease was coined in 1902 after horses were fed with Fusarium ear rot maize grains and by 1970, fumonisins had been isolated in the laboratory for research purposes (Marasas *et al*., 1996). Rats and hogs developed pulmonary edema and liver cancer after being fed with fumonisin contaminated maize grains. More studies have implicated fumonisin with esophageal cancer in human body (Gelderblom *et al*., 1988; Wang *et al*., 1991; Munkvold and Desjardins, 1997). Low PH, Low oxygen in plant tissues and environmental temperature range of 15-25^{o}C favours production of fumonisins (Miller, 2001). Considering that millions of people in Africa depend on maize as food and feed, they may be consuming fumonisisns regardless of the health risk posed by the pathogens (Kedera *et al*., 1999; Gamanya & Sibanda, 2001). For instance in Kenya, Alakonya *et al*.(2008) found fumonisin levels exceeding 5000 µg / kg despite acceptable limit rated at 1000 µg /kg of maize grains.

In addition to mycotoxins, seed harvested from infected crop is vulnerable to both stalk and seedling blight thus a threat to seed growers or producers. Of greater concern is the fact that *F. verticillioides* can be isolated from symptomless grains meaning that harmful levels of mycotoxins can be consumed in maize meals (Desjardins and Plattner, 1998; Rheeder *et al*., 1992).

2.4 Factors that contribute to Fusarium ear rot infection

Past studies have revealed that both biotic and abiotic factors are associated with rise in the occurrence of Fusarium ear rots in the affected maize growing regions and these include: temperature, humidity, insect attack, differences in maize genotypes and other fungal infections (Miller, 2001). Temperatures of about 28 ^{o}C cause *F. verticillioides* to thrive and outgrow other *Fusarium* species and colonize maize plants. Fusarium ear rot is prominent in high humidity regions such as lowland tropics (Miller, 2001; Hung and Holland, 2012; Zila *et al*., 2013). Alakonya *et al*., (2008), also noted that warm and humid conditions were important in ear rot development. High temperatures trigger physiological stress thus weakening plant response to infection by the pathogens and increases insects' invasion as well as mycotoxin production (Miller, 2001).

Feeding by insects creates entry sites for fungal micro conidia or mycelia on the surface of the kernels. Sap suckers such as thrips and stalk borers are well known agents for increased *Fusarium* infection in maize fields while feeding on the immature kernels (Farah and Davis, 1991). Thrips are thought to escape harsh dry and hot weather conditions by hiding in developing ears. According to Farah and Davis (1991) it is not well understood whether thrips depend on kernels mainly for food or they also utilize the ears to reproduce, and in the process contaminate the ears with the fungus. Other insects associated with the spread of *Fusarium* species are caterpillars of cob borers and earworms (*Helicoverpa zea* Boddie) (Munkvold, 2003). High incidence of ear rots was observed on insect and birds damaged ears as compared to intact ears (Bakan *et al*., 2002; Clements *et al*., 2003).

Tight ear husks enable a plant to keep away vectors such as thrips and blocks invasion by birds that would further expose the ear to attack by the pathogens (Clements *et al*., 2003. Hoenisch & Davis (1994) noted that thin pericarp compromises resistance to Fusarium ear rots. Fungal penetration could also be minimized by selecting seed types with thicker pericarp layer and showing no silk-cut, a phenomenon commonly seen in humid and high temperature conditions during grain filling. Varieties which are prone to lodging experienced higher incidences of ear rots as well as genotypes with poor ear tip cover that allow for easy entry of vectors into the ear and possibly contaminate the cobs with conidia or the spores (Hoenisch and Davis, 1994). Maize genotypes with silk cut (kernel split across the embryo axis) and kernel pop (split from silk-scar moving outwards) have higher risk of infection by *F. verticillioides* (Stromberg *et al.*, 1999).

2.5 Symptoms of *F. verticillioides* infection

Fusarium verticillioides is an endophyte of maize with long-standing relationship with plants in the field (Snyder and Hansen, 1940; Munkvold and Desjardins, 1997, Fandohan *et al*., 2003). In some cases, the presence of the fungus goes unnoticed since it can cause symptomless infection and settle in plants parts including roots, stalk, leaves and kernels (Mungvold & Desjadins, 1997). No significant damage has been reported in this kind of association therefore revealing that some *Fusarium* species may not cause disease after all (Rheeder and Marasas, 2002). Ear infection is manifested by white to pink fungal mass (mycelia) starting from the tip and proceeding towards the base. The rots can be on individual or a group of kernels and spread over the cob. During severe infection, the husk leaves are held tightly to the cob by the fungal growth making it difficult to separate during harvesting (Farrar and Davis, 1991). *Fusarium verticillioides* is also recognized by “star burst” appearance on single grains, a characteristic streaks originating from the pericarp and spreading basi-petally outwards from the grain silk scar (Munkvold and Desjardins, 1997). This happens when the fungal infection occurs during the final stages of grain filling .As the fungi feeds on grain dry material it causes a decrease in density and overall grain weight (Presello *et al*., 2007).

In some cases infected maize grains germinate while still attached to the cob. Severe infection causes maize ears to wither and fungal mass lined between kernel rows (Farrar and Davis, 1991). Damage caused by birds and ear bores causes most of the infections seen near the ear tip (Bilgrami and Choudhary, 1998; Munkvold, 2003; Alakonya *et al*. 2008).

2.6 Epidemiology of *F. verticillioides* and infection routes

Nearly all epidemics of various diseases require an interaction of environment, pathogen and the host organism in order to occur**.** An ideal condition for Fusarium attack happens when hot spell during or after flowering accompanied by light showers or presence of moisture coincide ((Miller, 2001; Logrieco *et al*., 2002). Infected crop residue is the main source of inoculum for *Fusarium* species (Munkvold, 2003, Alakonya *et al*., 2008). Macro-conidia (asexually formed) and microconidia or ascospores (sexually formed) are developed from mycelium from the infected plant source and are blown by wind (Miller, 2001). Insects such as corn borers and thrips have been drawn in as vectors of spores of *F. verticillioides* from infected to healthy plants through plant injuries that create routes of entry of the pathogens into the ear (Munkvold, 2003, Alakonya *et al*., 2008). The mode of entry into ears is through the silk or styles to the kernels. *Fusarium verticillioides* may also infect a susceptible plant systemically and get into the ear through the peduncle.

Alternate hosts such as sorghum and rice also cause rapid infestation and spread of *F. verticillioides* (Miller, 2001).

2.7 Genetics of resistance to Fusarium ear rots

Maize being an open pollinated crop species has a wide genetic diversity. For this reason, the scope of work focused on inheritance of resistance to maize ear rots has been limited to specific ecological niches as the disease is established across the world (Namkan and Pataky, 1996). Studies done by Zhang *et al*., (2006) revealed that resistance to Fusarium ear rots is mainly quantitatively inherited or polygenic in nature.

Deng-Feng *et al*. (2009) also studied generation mean (F1, F2, BC1,BC2) derived from two inbred lines R15 and Ye 478 and reported that both additive and dominant gene action were involved in conferring maize resistance to *F. verticillioides.* The female inbred line R15 was the ear rot resistant line while Ye 478 was susceptible but had good agronomic traits. Therefore resistance gene from inbred line R15 was utilized to improve the line Ye 478. Xiang *et al*. (2010) also reported genomic regions influencing resistance to several ear rot pathogens (*Fusarium*, *Gibberella* and *Aspergilus)* in maize. These results demonstrated that additive and dominance gene action were important in conditioning resistance and the pericarp played a key role as the site of gene action by preventing insect damage and blocking access of the fungus in to the kernels (Namkan and Pataky, 1996). Other authors have found similar findings on the mechanism of Fusarium ear rot resistance (King and Scott, 1981; Robertson *et al*., 2006, Ding *et al.*, 2008)

The pericarp has been linked to the expression of resistance as it provides a barrier from the entry. Namkan and Pataky (1996) noted that genotypes with thinner pericarps were susceptible to *Fusarium* species as compared to genotypes with thicker pericarps.

2.8 Combining ability

Combining ability is the measure of performance of a progeny developed from a defined mating design (Sprague and Tatum, 1942, Hallauer and Miranda, 1988).

Combining ability gives an insight into the genetic background of a trait of interest. General combining ability (GCA) effects represent additive gene action while specific combining ability (SCA) effects represent dominant gene action (Kearsey and Pooni, 1996).

With a set of males and female lines crossed together, the difference from mean performance of a specific male and that of all the males indicates the general combining ability of this particular male and that applies to female lines as well. The means of crosses of individual male to a set of females forms half-sib family group GCA means.

For a case where there is no epistasis, a cross between i^{th} male and j^{th} female can be predicted using the model:

$$Y_{ij} = \text{Mean} + GCA_i + GCA_j$$

Deviations from the observed mean are attributed to dominance gene effects or epistasis (Kearsey and Pooni, 1996). A deviation arising from a particular cross is termed SCA and is obtained by the estimation of male x female cross component in North Carolina design II (Kearsey and Pooni, 1996).

Addititive gene action has been singled out as playing a major role for inheritance of a trait as it allows for recurrent selection to be done (Griffing, 1956; Beck and Crossa, 1991; Muraya *et al*., 2006). This is possible if GCA: GCA + SCA is more than one. For grain yield performance where heterosis is of importance, SCA effects can be used to identify inbred lines in different heterotic groups which show maximum heterosis when crossed to each other (Beck and Crossa, 1991, Crossa *et al*., 1990; Mhike *et al*., 2011). In development of hybrids where two or three lines are involved, SCA is desirable. Development of resistant hybrids can be achieved faster in case there is a strong association between inbred and hybrid performance as indicated by GCA and SCA effects.

2.9 North Carolina Design II

The North Carolina design II mating scheme was developed by Comstock and Robinson (1952). The mating design has been used to obtain genetic information from half-sib (HS) families (Kearsey and Pooni, 1996). In order to create the half-sib progeny, a set of male parents are selected and crossed to a set of female parents. From the analysis of the bi-parental progenies, phenotypic variance can be broken down into variation between males, females and male by female interaction. The information derived from the analysis can give an insight into underlying gene effects driving the observed phenotypic variation by partitioning additive and non-additive (dominance and epistasis) gene effects. Therefore the expected genetic components of males and female sources are equivalent to GCA in NC design II and the male by female interaction is equivalent to SCA (Hallauer and Miranda, 1988). The NC design II has an added advantage over diallel mating design in that: (i) It uses more parents for the same amount of resources when compared to diallel design; (ii) It has two independent sources of GCA; (iii) Dominance is determined directly from the mean squares (Hallauer and Miranda, 1988).

2.10 Fusarium management options

2.10.1 Field hygiene

It has been suggested that crop rotation with non-maize or cereal crops can aid in breaking the life cycle of the fungus which may exist in the soil from previous crops (Fandohan *et al*., 2003). Weeds that can host fungal vectors also contribute to increased infection of maize as described by (Bilgrami and Choudhary, 1998).

2.10.2 Control of insect vectors

To date insect vectors commonly implicated in the spread of *F. verticillioides* include lepidopteran maize stalk and ear borers (*Sesamia calamistis*, *Busseola fusca* ,*Ostrinia nubilalis*, *Eldanasaccharina*, *Mussidia nigrivenella* in addition to thrips and sap sucking beetles (family Nitidulidae) (Munkvold and Desjardins, 1997; Cardwell *et al*., 2000). The insects wound, expose and create entry routes for infection by the fungus as well as transfer the fungus between different fields or plants while feeding. Schulthess *et al*. (2002) noted that keeping plants free from insect pests can reduce crop infection by *Fusarium* species.

2.10.3 Biological control agents

Since *Fusarium* species has been established as an endophyte with maize, it is difficult to completely eradicate from the maize fields. However, there is strong evidence that certain endophytic bacterium (e.g. *Bacillus mojavensis*) is useful as an effective strategy to minimize damage by the fungus (Bacon and Hinton, 2000). *Trichoderma* spp was also reported by Cavaglieri *et al.* (2005) as a possible control agent of *Fusarium* spp. It was observed that *Trichoderma* acts in three ways: (i) produce antibiotics which degrades the fungus, (ii) rival for food nutrients and space, and (iii) produce lytic enzymes which digest the fungal cell wall (Hasan, 2010). *Beauveria bassiana* is also considered as a control of pathogenic fungi although the mode of action in suppressing disease is yet to be understood (Orole and Adejumo, 2009).

2.10.4 Use of resistant varieties

Development and use of genetically resistant varieties provides the most viable option for managing crop losses due to ear rots and contamination with mycotoxins (Zila *et al*., 2013, Butron *et al*., 2006). Although sources of resistance to Fusarium ear rot have been identified, the underlying basis of genetic inheritance is complicated because of the quantitative nature and that it differs from one population to population (Nankam and Pataky 1996; Pérez-brito *et al.,* 2001; Mesterházy *et al.,* 2012). In spite of this challenge, past research has established that heritability of resistance based on family means is moderate (Robertson *et al.,* 2006; Bolduan *et al.,* 2009). The commonly used conventional breeding approaches to develop resistant varieties are pedigree method, single seed descent, Bulk and backcrossing (Falconer, 1960). However, these methods are time consuming and are influenced by the environment (Korzun *et al.,* 2001). Molecular markers provide a precise option for detection of Quantitative trait location and aid in marker assisted selection.SNP markers are the most preferred markers by the breeders because they are abundant in many crops (Mammadov *et al*., 2010). With the development of the genotyping array in Maize inbred lines, it has made available nearly 50000 Single nucleotide polymorphism (SNP) molecular markers from the maize diversity panel which covers diversity in most breeding programs(Cook *et al.,* 2012).

Several researchers have proposed the use of molecular marker technology to improve maize crop.

Molecular studies done in the past established several QTLs for resistance to a Fusarium ear rot and positive correlation between Fusarium ear rot and contamination with fumonisins in maize grains (Ding *et al*., 2008; Robertson *et al.*, 2006; Xiang *et al*., 2010). In the light of these studies it is possible to accumulate and fix resistant alleles through recurrent selection methods.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site description

The experiments were conducted in four locations; Kiboko, Alupe, Kibos and Kakamega. Kiboko is 975 meters above the sea level and located at 02^0 09'S, 37^0 75'E. Kibos is 1154 meters above sea level and located at 34^0 30'N, 02^0 00'E. Alupe is 1180 meters above sea level and located at 07^0 00'N, 34^0 30'E. Kakamega is 1580 meters above sea level and located at 00^0 16'N, 34^0 45'E. The soil classification (FAO) of the locations are: Kiboko, sandy clay rhodic ferrasols; Kibos, Sandy loam eutric cambisols; Alupe, Sandy clay Orthic ferrasol; Kakamega, clay loam eutric nitisol.

3.2 Inbred Lines

Sixteen (16) maize inbred lines from the International Maize and Wheat Improvement Center (CIMMYT) breeding programs in Kenya, Zimbabwe and Mexico were used in this study (Table 3.1). The inbred lines were selected based on prior information on combining ability, per se performance, and performance in hybrid combinations. Five inbred lines from Mexico were selected based on tolerance to ear rots under natural field infestation (Dr. George Mahuku, personal communication) while one inbred line from Zimbabwe was selected based on susceptibility to ear rots under natural field infestation (Dr. Dan Makumbi, personal communication).

3.3 Population development and Breeding scheme

The 16 inbred lines were divided into ten females and six males (Table 3.1) and crossed in a North Carolina Design II (NCII) mating scheme to form 60 F_1 hybrids (Table 3.2).

The NC II creates male and female half-sib families as every male is crossed to every female. Each of the 10 female parents was crossed to each of the male parents in a factorial method. In the nursery planted at Kiboko during the short rain season (September-January) of 2013/2014, each female was planted next to a male partner in pairs e.g.1x1,1x2,1x3, 1x4, 1x5, 1x6 for female 1; 2x1, 2x2, 2x3, 2x4, 2x5, 2x6 for female 2; 3x1, 3x2, 3x3, 3x4, 3x5, 3x6 for female 3. The same pattern was followed for female parents 4, 5, 6, 7, 8, 9, 10. The row length for each entry was 4 m, spaced 0.75 m apart, with plants spaced 0.20 m apart. Each row had 21 plants after thinning. At planting, DAP fertilizer was used at a rate of 75kg/ha P_2O_5 and 25kg/ha N. Also 500 ml/ha Regent® was applied to prevent termite and cutworms attack during the crop season. Bulldock EC® (Beta-cyfluthrin) granules (6kg/ha) was applied on plant funnels at 4 and 6 weeks after planting to control stalk borers. The crop was also top dressed with CAN (50kg N/ha) eight weeks after planting. As a precaution against maize lethal necrosis (MLN) disease, spray was done weekly with Dimethoate 40 EC (dimethoate) and Swift (Labdacythalothrin) to control thrips, aphids and corn beetles that are believed to be vectors of the MLN causing viruses.

Prior to initiation of flowering, the inbred lines were checked daily for signs of ear shoot emergence and pollen shed. Before the silks emerged, all stems were covered with a shoot bag to avoid unwanted pollination. Tassels to be used as pollen sources were covered with a tassel bag to prevent foreign pollen on landing on the anthers a day before the pollen was to be used. On the day of pollination, pollen from plants in the same row was bulked and used to pollinate female parents whose silks had emerged. This was carried out very carefully to avoid contamination. Each inbred line in a row was used both as female and male parent to make reciprocal crosses. Each pollinated ear was covered with a tassel bag that was stapled on to the stem until harvest. At harvest, selection was done for the best ears with viable seeds and showing no signs of ear rots. Ears from the reciprocal crosses were bulked to form a set of 60 F1 hybrids for *Fusarium* ear rot evaluation in field trials.

3.4 Hybrids evaluation

The 60 F1 and commercial hybrid checks were evaluated in field trials for Fusarium ear rot and yield performance at four locations in Kenya in 2014 (Table 3.3). The experimental design for the trials was an alpha-lattice design (4x16) with two replications (Patterson and Williams, 1976). Plot size was two rows 5 m long, 0.75 m apart and 0.25 m between hills. Each hill was planted with two seeds but later thinned to one plant per hill four weeks after planting to give approximately 53,000 plants ha^{-1}. At planting DAP fertilizer (75kg/ha) was applied based on recommended agronomic practices. Regent® (500 ml/ha) was applied to prevent damage from soil insects at planting. To control stem borers, Bull dock 0.05 GR Beta-cyfluthrin granules (6kg/ha) was applied twice in the funnels at 5-7 leaf stage to control stem borers (*Busseola fusca)*. Additional nitrogen was applied (CAN 50kg N/ha) eight weeks after planting. Dimethoate 40 EC (dimethoate) and swift (Labdacythalothrin) were applied every fortnight until crop was mature to control MLN disease vectors. Weeding was done twice to keep the trial clean at all the sites.

In Kiboko, irrigation was done during vegetative stage and discontinued two weeks before flowering. Maize crop suffers most yield losses when drought strikes at flowering. The last irrigation was done carefully by ensuring that irrigation system was working well, with no pipe leaks or spill over water to neighboring blocks. There was relatively low air currents thus limited water and wind drift was maintained.

Figure 1: Photo showing hand pollination in progress at Kiboko in 2013 (Source: Author, 2013)

Table 3.1.Parental inbred lines used to develop hybrids using North Carolina Design II mating design.

Parents	Name/Pedigree	Origin	Characteristics
Females			
1	CKL05003	Kenya	Good GCA for yield, foliar disease resistant
2	CKL05019	Kenya	Good yield, foliar disease resistant
3	CKL05024	Kenya	Good yield, foliar disease resistant
4	(CKL05003/CML444//CKL05003)DH5-B	Kenya	DH[†] line from drought tolerant x good GCA for yield cross
5	(CKL05003/CML444//CKL05003)DH6-B	Kenya	DH line from drought tolerant x good GCA for yield cross
6	CZL00003	Zimbabwe	Drought tolerant line, foliar disease resistant
7	CML442	Zimbabwe	Drought tolerant line, foliar disease tolerant
8	VL06688	Zimbabwe	Ear rot susceptible line
9	CML548	Zimbabwe	Drought tolerant line, foliar disease resistant
10	CML538	Zimbabwe	Drought tolerant line, foliar disease resistant
Males			
1	CML247	Mexico	Ear rot tolerant line
2	CML495	Mexico	Ear rot tolerant line
3	CML264	Mexico	Ear rot tolerant line
4	P502c2-185-3-4-2-3-B-2-B*6	Mexico	Ear rot tolerant line
5	CL-RCW37	Mexico	Ear rot tolerant line
6	La Posta SeqC7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B	Kenya	DH line from drought tolerant x ear rot tolerant cross

[†] DH, doubled haploid

Table 3.2 List of 60 hybrids developed and four commercial checks tested in trials at four locations

Hybrid number	Pedigree	Hybrid number	Pedigree	Hybrid number	Pedigree
1	CKL05003/CML247	24	(CKL05003/CML444//CKL05003)DH5-B/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	47	VL06688/CL-RCW37
2	CKL05003/CML495	25	(CKL05003/CML444//CKL05003)DH6-B/CML247	48	VL06688/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B
3	CKL05003/CML264	26	(CKL05003/CML444//CKL05003)DH6-B/CML495	49	CML548/CML247
5	CKL05003/CL-RCW37	28	(CKL05003/CML444//CKL05003)DH6-B/P502c2-185-3-4-2-3-B-2-B*6	50	CML548/CML495
6	CKL05003/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	29	(CKL05003/CML444//CKL05003)DH6-B/CL-RCW37	51	CML548/CML264
7	CKL05019/CML247	30	(CKL05003/CML444//CKL05003)DH6-B/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	52	CML548/P502c2-185-3-4-2-3-B-2-B*6
8	CKL05019/CML495	31	CZL00003/CML247	53	CML548/CL-RCW37
9	CKL05019/CML264	32	CZL00003/CML495	54	CML548/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B
10	CKL05019/P502c2-185-3-4-2-3-B-2-B*6	33	CZL00003/CML264	55	CML538/CML247
11	CKL05019/CL-RCW37	34	CZL00003/P502c2-185-3-4-2-3-B-2-B*6	56	CML538/CML495
12	CKL05019/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	35	CZL00003/CL-RCW37	57	CML538/CML264
13	CKL05024/CML247	36	CZL00003/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	58	CML538/P502c2-185-3-4-2-3-B-2-B*6
14	CKL05024/CML495	37	CML442/CML247	59	CML538/CL-RCW37
15	CKL05024/CML264	38	CML442/CML495	60	CML538/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B
16	CKL05024/P502c2-185-3-4-2-3-B-2-B*6	39	CML442/CML264	61	DK8031 (commercial check)
17	CKL05024/CL-RCW37	40	CML442/P502c2-185-3-4-2-3-B-2-B*6	62	WH507 (commercial check)
18	CKL05024/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	41	CML442/CL-RCW37	63	WH505 (commercial check)
19	(CKL05003/CML444//CKL05003)DH5-B/CML247	42	CML442/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B	64	H513 (commercial check)
20	(CKL05003/CML444//CKL05003)DH5-B/CML495	43	VL06688/CML247		
21	(CKL05003/CML444//CKL05003)DH5-B/CML264	44	VL06688/CML495		
22	(CKL05003/CML444//CKL05003)DH5-B/P502c2-185-3-4-2-3-B-2-B*6	45	VL06688/CML264		
23	(CKL05003/CML444//CKL05003)DH5-B/CL-RCW37	46	VL06688/P502c2-185-3-4-2-3-B-2-B*6		

3.5 Sample collection and isolation of *Fusarium* species.

Maize cobs showing visible symptoms of *Fusarium* species were collected in Kenya Agricultural and Livestock Research Organisation (KALRO) Kakamega maize trial fields. The cobs were sun dried to 12.5% moisture content and shelled to make a sample of 1 kg of maize grain. The sample was then stored to await isolation and identification of the pathogens. Twenty symptomatic kernels were sampled using Cascade Rotary Divider (Model 1) for use in fungal isolation. A procedure described by King (1981) was used to produce a culture of *F. verticillioides*. Seed samples were tipped in 70% ethanol for 30 sec and also disinfected by immersion in 2.5% sodium hypochlorite for two minutes before rinsing with distilled water three to four times and dried using sterile filter papers. Five kernels on four Petri dishes were placed equidistant on sterilized Pentachloronitrobenzene (PCNB) media containing Chloramphenicol and benzylpenicillin (antibiotics) and incubated at 25°C for 5 days to allow the growth of fungal colonies(Alakonya *et al*.,2008)

To obtain pure cultures of *F. verticillioides,* observed fungal colonies were sub-cultured on potato dextrose agar (PDA) and incubated at 25°C for 5 days. Colonies of suspected *F. verticillioides* were then sub-cultured by placing on Sucrose Nutrient agar (SNA) and placed in none ultraviolet light for 7 days. Cultures with pink appearance were selected and observed for colony morphology and structure using microscope. So as to view the colonies, 1cm^2 blocks of agar with the colony were cut from SNA media and placed on a slide and viewed under a microscope. The laboratory guide for identification of *F. verticillioides* (Booth, 1977) was used to distinguish *F. verticillioides* isolated from other

Fusarium species. After confirmation of the *F. verticillioides,* the pure *Fusarium* cultures were stored at -20°C until preparation for inoculation in the field.

Figure 2: Isolation of *F. verticillioides* from five maize kernels in the laboratory at Kakamega (Source: Author, 2014)

3.6 Inoculation

3.6.1 Transfer of *Fusarium* inoculum to toothpicks

Five thousand pieces of round wooden toothpicks were sterilized by wrapping in an aluminum foil and autoclaved at 121°C for 15 minutes. After cooling, toothpicks were cleaned with sterile distilled water and the procedure repeated four times to ensure that no fungal strain survived on the toothpicks. From the initially prepared inoculum, five agar blocks were cut from the PDA media containing pure cultures of *F. verticillioides* and plated on a fresh PDA media in an 800ml plate. Liquid PDA media was poured on the toothpicks and arranged vertically in the 800ml plate and pressed under low hand pressure so as a third of the toothpick length was inserted into the media with *F. verticillioides*. The plate was then covered with aluminum foil and incubated at room temperature for three days (Gulya *et al*., 1980)

Figure 3: Toothpicks infected with *Fusarium verticillioides* before inoculation (Source: Author, 2014)

3.6.2 Field inoculation

Field inoculation was done using toothpick technique (Gulya *et al.*, 1980). The contaminated toothpicks were removed from the plate prior to field inoculation to air dry overnight (Figure 3). Individual ears in all the plots were inoculated 10 days after emergence of silk by inserting one toothpick per uppermost ear through the ear tip. Plants at both ends of the plots were not inoculated. The toothpicks were left in the ears until harvesting.

3.7 Data collection

Agronomic and disease severity data were recorded in all trials. Details of procedures used to collect data are given in Table 3.4 and traits recorded shown in Table 3.3. For *Fusarium* data collection, ears were harvested 8-10 weeks after inoculation depending on the location. Fusarium ear rot incidence was derived from the proportion of the symptomatic ears per plot to the total number of ears harvested per plot expressed as a percentage. The ears were scored per plot for severity of ear rot infection (estimate of portion of the ear infected) using a seven point rating (1 = No visible symptoms, 2 = 1-3%, 3 = 4 - 10%, 4 = 11-25%, 5 = 26 - 50%, 6 = 51-75%, and 7 = 76 -100% of ear showing symptoms of infection) as described by (Alakonya *et al*., 2008).

Table 3.3. List of traits recorded during trial evaluation.

Trait	Procedure
Anthesis date (AD)/Silking Date (SD)	Taken as number of days after planting to when 50 percent of plants start shedding pollen or had extruded silks.
Anthesis- silking interval (ASI)	Derived from anthesis date and silking date as follows: ASI= SD - AD
Ears per plant (EPP)	It is calculated as a ratio of the number of ears with at least one fully developed grain divided by the number of harvested plants.
Plant height (PH)	Measured as the height between the base of a plant and the insertion of the first tassel branch.
Ear height (EH)	Measured as the height between the base of a plant to the insertion of the top ear.
Ear position (EPO)	Calculated as EH divided by PH.
Root lodging (RL)	Measured as a percentage of plants that showed lodging by being inclined 45^0.
Stem lodging	Measured as a percentage of plants that were broken below the ear.
Gray leaf spot	Taken using a 1-5 score with 1 being resistant and 5 being susceptible
Field weight	Unshelled cob weight per plot taken directly after harvesting
Grain yield (GY)	It was calculated from shelled grain weight per plot adjusted to 12.5% grain moisture.
Fusarium severity (FSE)	Estimate of the infected portion of the ear expressed as a percentage
Fusarium incidence (FSI)	Number of the infected ears per plot divided by the total number of ears harvested expressed as a percentage
Husk cover	The number of ears per plot with open tips expressed as a percentage
Ear aspect	Score of 1-5 of ears with uniform cobs and preferred texture (1) and ugly cobs with undesirable texture (5).

Grain yield was calculated based on field weight, grain moisture and a shelling percentage (80%) using the formula;

Grain Yield (t/ha) = [Grain Weight (kg/plot) x (100-grain moisture) x (Shelling percent/100) x 10000)/ (100-12.5) x (Plot Area)]

3.8 Statistical Analysis

The data were subjected to analysis of variance for individual and across sites using SAS. Across locations, the adjusted means and variance components were used to estimate repeatability with replications, blocks within replications and locations considered as random factors while genotypes were considered as fixed factors. The procedure of SAS was used to compute phenotypic correlations between traits. Means were separated using Fisher's protected least significant difference (LSD) method. Based on the NC DII mating scheme, a combined ANOVA was performed for each trait using SAS according to the following linear model:

(Y_{ijk}) = μ + Environment + Replication (Environment) + Males + Females + Males*Females + Males*Env +Females*Env + Males*Females*Env + e_{ijkl}

Where Y = observed value of mating of *i*th male, the *j*th female in the *k*th replication; µ is the mean of the trial, Env is environment, and e_{ijkl}-is the residual. The outline of the ANOVA is given in Table 3.5. The source of variation due to males, females and hybrids were tested with their interaction with environment while the other terms were tested with pooled error.

The expected variation due to female and male parents in a NC Design II corresponds to GCA, and that due to the male × female interaction corresponds to SCA (Hallauer and Miranda, 1988).

The GCA estimates (g_i and g_j) for all parental lines and SCA estimates (s_{ij}) for all hybrids were calculated as follows:

$g_i= (y_i)- (y...)$

$g_j= (y_j)- (y..)$

$s_{ij}= (y_{ij} – y_i – y_j + y...)$ Where yij is the mean of the hybrid of mating the *i*th female and the *j*th male parent, yi is the mean of all hybrids involving the *i*th female parent, $y.j$ is the mean of all hybrids involving the *j*th male parent and y is the mean of all hybrids.

CHAPTER FOUR

RESULTS

4.0 Introduction

The 64 hybrids (60 F1 and four commercial hybrids) were evaluated under artificial and natural infestation at three locations to assess reaction to *Fusarium* infection, and at one location to evaluate hybrid performance under managed drought stress conditions. The results of hybrid evaluation under these conditions are presented in various sections below.

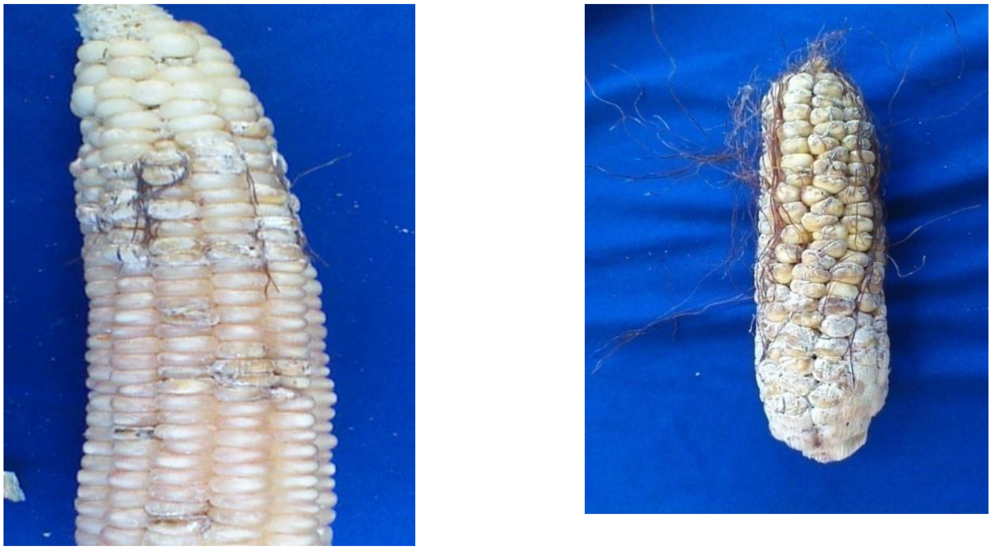

Figure 4. Symptomatic cobs with two severity levels of *F. verticillioides* infection in a field trial. The cob on the left shows 50 % severity while the cob on the right shows 100% severity (Source: Author, 2014).

4.1 Analysis of variance (ANOVA) for combined artificially inoculated trials (Kakamega, Alupe and Kibos)

Combined ANOVA for artificially inoculated trials revealed that environment and hybrids were significant ($P < 0.001$) for all agronomic traits and Fusarium disease parameters (FSE and FSI) except ear height and husk cover for both environment and hybrid effects, and plant height for hybrid effect (Table 4.1). The hybrid x environment interaction was highly significant for grain yield and days to anthesis. The F_1 hybrid and F_1 hybrid x environment interaction were highly significant ($P < 0.01$ or $P < 0.001$) for all agronomic traits and Fusarium (FSE and FSI) parameters except the ear and plant height for F1 hybrid x environment (Table 4.1). The F_1 hybrid mean square was partitioned into male GCA (GCA_m), female GCA (GCA_f), and SCA components. The mean square for GCA_m was highly significant ($P < 0.01$ or $P < 0.001$) for grain yield, FSI and HC, and significant ($P < 0.05$) for days to anthesis and plant height (Table 4.1), suggesting differences in GCA effects of the male parents for these traits. The mean square for GCA_f was highly significant ($P < 0.01$ or $P < 0.001$) for grain yield, FSE, FSI, and HC and significant ($P < 0.05$) for days to anthesis. The SCA mean square was highly significant ($P < 0.001$) for grain yield and the two Fusarium disease parameters, and significant ($P < 0.05$) for days to anthesis and plant height (Table 4.1). The mean square for GCA_m x environment interaction effect was significant for grain yield, ear and plant height, husk cover and FSE (Table 4.1). The GCA_f x environment interaction effect was significant for grain yield, all agronomic traits, and the two Fusarium disease parameters (FSE and FSI).The SCA x environment interaction was highly significant ($P < 0.01$ or $P < 0.001$) for grain yield, FSE and husk cover, and significant ($P < 0.05$) for FSI (Table 4.1). Under artificial inoculation with *Fusarium verticillioides*, the contribution of GCA (GCA_m+ GCA_f) sum of squares to the total variation among the F_1 hybrids was 39% while that of SCA was 61% for grain yield. For FSE, the contribution of GCA (41%) was smaller than that of SCA (59%). A similar case was evident for FSI in which GCA contribution (44%) was less than that of SCA (56%).

Table 4.1 Combined ANOVA of grain yield, agronomic traits, and fusarium disease parameters under artificial inoculation (Kakamega, Alupe and Kibos).

Source of Variation	DF	GY[†]	AD	EH	PH	FSE	FSI	HC	EA	EPP
		t ha^{-1}	d	cm	cm	%	%	%	1-5	#
Environment (Env)	2	47.23***	5566.85***	307.57ns	5128.91***	7151.55***	319.72***	364.67ns	15.73***	0.32***
Rep(Env)	3	21.34*	4.55ns	633.13**	391.13ns	2474.12***	29.68ns	0.54ns	0.16ns	0.16***
Hybrids	63	4.73***	13.31***	273.74ns	462.05ns	533.15***	67.91***	740.70ns	0.33***	0.03***
F1Hybrids	59	4.84***	12.55***	248.18**	455.32***	448.92* **	70.43***	779.50**	0.31***	0.03***
Hybrids*Env	126	3.34***	4.66***	176.38ns	253.72ns	369.58ns	41.67ns	278.22ns	0.20**	0.03 ns
F1Hyb *e nv	118	3.38***	4.77***	166.32ns	247.49ns	357.03***	43.14**	276.61***	0.18*	0.03**
GCA$_m$	5	8.47***	99.33*	856.74ns	3763.98*	294.61ns	103.81**	3763.98**	0.98***	0.06ns
GCA$_f$	9	7.68***	13.53*	380.10ns	1445.59ns	1050.37***	144.58***	1445.59**	0.69***	0.06ns
SCA	45	3.87***	2.71*	154.17ns	314.68*	345.77***	51.89***	314.68ns	0.16ns	0.03ns
GCA$_m$*Env	10	3.0ns	2.71***	317.15**	537.59*	443.17**	52.80ns	537.59***	0.14ns	0.03ns
GCA$_f$ *Env	18	3.40*	5.44***	256.49*	383.28**	698.98***	64.35***	383.28***	0.21*	0.03**
SCA*Env	90	3.42***	1.91ns	131.54ns	226.27ns	279.08**	37.84*	226.27**	0.17*	0.03**
Error	189	1.72	1.85	138.61	225.34	172.32	23.74	144.83	0.13	0.02
CV		3.1	10.7	8.1	13.5	1.9	0.7	0.8	5.8	5.9

* Significant at $P < 0.05$,** Significant at $P < 0.01$,*** Significant at $P < 0.001$,
ns, not significant

[†] GY, grain yield; AD, days to anthesis; EH, ear height; PH, plant height; HC, husk cover; FSE, Fusarium severity, FSI, Fusarium incidence, HC, husk cover, EPP, ears per plant.

4.2 Performance of hybrids under artificial inoculation across three locations

The performance of the top 20 hybrids is presented in Table 4.2 and Table 4.6. The best hybrid in terms of grain yield was hybrid 25 (7.8 tha^{-1}) followed by hybrid 22 (7.6 tha^{-1}) (Table 4.2). The yield of the best hybrid was significantly better than the yield of three of the commercial checks and the average yield of all the checks. The days to anthesis ranged from 60 to 68, with the best hybrid flowering at 67 days. The lowest incidence of Fusarium under artificial inoculation across locations (4.6 %) was recorded for hybrid 16 (Table 4.2). Other hybrids with low incidence of Fusarium were 58, 7, 59, and 22, with 5.3, 5.6, 5.6, and 7.8%, respectively (Table 4.2). Fusarium severity ranged from 16.5% to 58.4% (Table 4.2). Among the F1 hybrids, the lowest severity (22.3%) was recorded for entry 11. The mean ear aspect score was 3.01 with hybrids ranging from 2.4 (best) to 4.0 (most susceptible). Hybrids with good ear aspect were associated with good yield potential as seen in entries 22, 58, 7, 9, 59 and 16. Hybrids 57 (0%), 58 (0.1%), 8 (0.5%), 9 (0.7%), and 40 (1%) recorded lowest values for poor husk cover across locations.

Table 4.2 Grain yield, Fusarium and agronomic Performance of hybrids under artificial inoculation across three locations (Kakamega, Alupe and Kibos).

Hybrid	Pedigree	GY[†]	AD	EH	PH	FSI	FSE	HC	EA	EPP
#		t ha^{-1}	d	cm	cm	%	%	%	1-5	#
25	5x1	7.8	67	120	232	9.6	39.6	37.3	2.7	1.0
22	4x4	7.6	63	114	242	7.8	54.4	6.8	2.9	1.0
35	6x5	7.1	66	130	264	16	43.1	10.4	2.8	1.0
58	10x4	7.1	62	110	232	5.3	53.1	0.2	2.7	1.0
8	2x2	7	63	112	246	15.1	44	0.7	2.7	1.0
26	5x2	6.9	65	111	242	12.8	47.5	7.1	3.1	1.0
11	2x5	6.8	66	121	252	10.2	22.3	19.2	2.6	0.9
27	5x3	6.6	66	105	237	7.7	52.6	11.0	2.9	1.0
59	10x5	6.5	65	109	242	5.6	50.6	13.2	3	0.9
3	1x3	6.4	66	108	252	12	32.9	1.3	2.7	1.0
17	3x5	6.4	66	115	232	8.3	36.7	14.3	3	0.9
20	4x2	6.3	66	105	244	13	49.8	5.4	2.9	1.0
16	3x4	6.3	61	102	229	4.6	33.5	4.3	2.7	1.0
47	8x5	6.3	63	116	240	11.1	45.3	52.1	3.2	1.1
9	2x3	6.3	65	109	252	9.4	54.9	0.0	2.6	0.9
23	4x5	6.2	66	123	250	16.1	26.7	58.8	2.9	0.9
13	3x1	6.1	64	99	219	13.5	33.8	28.4	2.9	1.0
7	2x1	6.1	66	118	240	5.6	36.9	2.9	2.7	1.0
50	9x2	6.1	64	104	233	12.8	52.1	3.5	2.9	0.9
39	7x3	6.1	66	108	241	17.6	51.2	2.6	3.4	1.0
DK8031		3.9	61	107	222	32.0	38.5	24.5	4.0	0.9
WH507		4.8	67	119	237	11.4	55.1	7.5	3.1	1.0
WH505		5.8	66	129	259	19	40.1	9.7	3.1	1.0
H513		4.6	64	124	229	23.2	40.5	9	3.2	1.0
Mean		5.5	64	110	236	15.0	40.7	15.3	3.0	1.0
LSD		2.2	1.5	NS	16	22.4	23.9	NS	0.5	0.2
CV		3.1	10.7	8.1	13.5	0.7	1.9	0.8	5.8	5.9
Min		3.6	60	91	211	4.6	16.5	0.4	2.4	0.8
Max		7.8	67	130	264	57.8	58.4	58.8	4.0	1.2

[†] GY, grain yield; AD, days to anthesis; EH, ear height, PH, plant height, FSE, Fusarium severity; FSI, Fusarium incidence, HC, husk cover; EA, ear aspect, EPP, ears per plant.

4.3 Phenotypic correlation between traits under artificial inoculation.

The simple correlation coefficients among traits are presented in Table 4.3. Grain yield was negatively but significantly ($P < 0.001$) correlated with Fusarium disease incidence (FSI) and weakly correlated with Fusarium disease severity (FSE). Results also showed that grain yield was negatively correlated (r = -0.24*) with poor husk cover. Fusarium disease incidence (FSI) was negatively correlated with days to anthesis (r = -0.22) and ear per plant (r = -0.28*) while Fusarium disease severity (FSE) was negatively correlated with poor husk cover (r = -0.44*), ear height (r = -0.28*), and days to anthesis (r = -0.16).

Table 4.3. Phenotypic correlation between grain yield and other agronomic traits under artificial inoculation.

Trait	GY[†]	AD	HC	EA	EH	EPP	PH	FSI
AD	0.11 ns							
HC	-0.24*	0.32**						
EA	-0.54***	-0.16ns	0.18ns					
EH	0.16ns	0.39**	0.37**	-0.15ns				
EPP	-0.09ns	0.09ns	0.20ns	0.05ns	0.15ns			
PH	0.33ns	0.58***	0.06ns	-0.28*	0.56***	0.10ns		
FSI	-0.42***	-0.22ns	0.11ns	0.31*	-0.09ns	-0.28*	-0.14ns	
FSE	0.15ns	-0.16ns	-0.44***	0.04ns	-0.28*	-0.07ns	-0.06ns	-0.04ns

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

ns, not significant.

[†] GY, Grain yield; AD, Anthesis date; ASI, Anthesis-silking interval; HC-Husk cover; EA, Ear Aspect; EH, ear height; EPP, ears per plant; PH, plant height; FSI , Fusarium incidence; FSE, Fusarium severity

4.4. Performance of trials under natural disease pressure (Kakamega, Alupe and Kibos)

Combined ANOVA across environments under natural disease pressure revealed that environment, hybrids, and F1 hybrids were highly significant ($P < 0.01$ or $P < 0.001$) for all agronomic traits and Fusarium disease parameters (FSE and FSI) (Table 4.4). The hybrid x environment interaction was significant for grain yield, days to anthesis, plant height, FSE, FSI, and HC. The F_1 hybrid x environment interaction was highly significant ($P < 0.001$) for grain yield, FSE, and HC, and significant ($P < 0.05$) for plant height (Table 4.4). The F_1 hybrid mean square was partitioned into male GCA (GCA_m), female GCA (GCA_f), and SCA components. The mean squares for GCA_m and GCA_f were highly significant ($P < 0.01$ or $P < 0.001$) for days to anthesis, ear and plant height, FSI and husk cover (Table 4.4). The SCA mean square was highly significant ($P < 0.01$ or $P < 0.001$) for all traits except FSE (Table 4.4). The mean square for GCA_m x environment interaction effect was highly significant for all traits except ear height, FSE, and ears per plant (Table 4.4). The GCA_f x environment interaction effect was highly significant for grain yield, FSE and husk cover. The SCA x environment interaction was highly significant for grain yield and FSE, and significant ($P < 0.05$) for plant height (Table 4.4). Under natural *F. verticillioides* pressure, the contribution of GCA (GCA_m+ GCA_f) sum of squares to the total variation among the F_1 hybrids was 40% while that of SCA was 60% for grain yield. For FSE, GCA accounted for 54% while SCA accounted for 46%. A different scenario was revealed for FSI where the GCA contribution (38%) was less than that of SCA (62%).

Table 4.4. Combined analysis of variance of grain yield and other agronomic traits under natural disease pressure (Kakamega, Alupe and Kibos).

Source of variation	DF	GY†	AD	EH	PH	FSE	FSI	EPP	HC	EA
		t ha^{-1}	d	cm	Cm	%	%	#	%	1-5
Environment (Env)	2	287.07***	5416.80***	4001.11***	3171.74***	10961.00***	1149.53***	0.19***	4728.70***	26.74***
Rep(Env)	3	8.21***	19.11***	58.06ns	14.86ns	105.34ns	115.74**	0.07*	283.78ns	0.70***
Hybrids	63	5.35***	16.66***	553.07***	771.15***	247.10***	106.77***	0.04**	1102.30***	5.92***
F1Hybrids	59	5.33***	16.55***	519.68***	775.38***	195.54***	113.55***	0.04**	1155.65***	0.56***
Hybrids*Env	126	2.81***	2.19*	108.52ns	173.63*	139.11***	26.98*	0.02ns	198.06**	2.30***
F1 Hyb* Env	118	2.89***	2.00ns	99.55ns	167.35*	143.66***	24.52ns	0.03ns	205.16***	0.25***
GCA$_m$	5	19.63ns	125.18***	2256.94***	3359.61***	294.49ns	297.41***	0.05ns	6866.01**	1.27***
GCA$_f$	9	3.06ns	25.49***	677.81***	1395.37***	522.29ns	119.00***	0.10ns	1903.84***	1.98***
SCA	45	4.19***	2.69**	295.03***	364.24***	119.20ns	92.03***	0.03**	371.54***	0.21***
GCA$_m$*Env	10	85.15***	7.44***	127.44ns	330.74**	315.67***	22.56ns	0.04ns	806.53***	0.55***
GCA$_f$*Env	18	106.71***	1.44ns	59.06ns	117.80ns	269.49***	18.42ns	0.04ns	278.59**	0.57***
SCA*Env	90	150.07**	1.51ns	104.56ns	159.12*	99.38**	25.97ns	0.02ns	123.66ns	0.15**
Error	189	1.1	1.68	112.55	125.49	60.59	20.09	0.02	122.66	0.1
CV		3.0	11.0	7.6	14.5	2.1	0.9	6.3	0.8	4.5

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

ns, not significant

†GY, grain yield; AD, days to 50% pollen shed ; EH, ear height ; PH ,plant height; FSI, Fusarium incidence ;FSE, Fusarium severity; EPP, ears per plant; HC, husk cover; EA, ear aspect

Table 4.5 Percentage of total genotypic sum of squares of Fusarium ear rot disease incidence and severity, and agronomic traits attributable to general combining ability of males (GCA_m) and females (GCA_f), and specific combining ability (SCA).

	Artificial inoculation					**Natural disease pressure**				
Component	GY[†]	FSI	FSE	HC	EA	GY[†]	FSI	FSE	HC	EA
GCA_m	15.0	12.5	5.4	41.0	26.6	31.2	22.2	12.8	50.4	19.0
GCA_f	24.0	31.3	35.9	28.0	34.4	8.8	16.0	40.7	25.1	53.1
SCA	61.0	56.2	58.7	31.0	39.0	60.0	61.8	46.5	24.5	27.9

[†] GY, grain yield; FSI, Fusarium ear rot incidence; FSE, Fusarium ear rot severity; HC, husk cover; EA, ear aspect.

Table 4.6 Fusarium ear rot incidence and severity of the best 20 and worst 10 hybrids under artificial inoculation, and their performance under natural disease pressure.

Artificial Inoculation							Natural disease pressure				
Hybrid	Pedigree	FSI	FSE	HC	EA	Hybrid	Pedigree	FSI	FSE	HC	EA
		%	%	%	1-5			%	%	%	1-5
Best 20 hybrids											
16	3x4	4.6	33.5	4.3	2.7	16	3x4	1.6	45.2	3.8	2.5
58	10x4	5.3	53.1	0.2	2.7	58	10x4	1.7	50.7	0.1	2.3
7	2x1	5.6	36.9	2.9	2.7	7	2x1	6.0	47.9	4.5	2.5
59	10x5	5.6	50.6	13.2	3.0	59	10x5	2.9	42.7	6.4	2.7
57	10x3	5.7	56.0	0.4	2.7	57	10x3	2.5	56.7	2.5	2.9
6	1x6	5.8	27.5	21.9	3.1	6	1x6	0.8	43.3	10.1	2.8
41	7x5	6.6	21.1	19.2	3.1	41	7x5	5.7	38.1	27.1	3.1
52	9x4	6.7	30.9	4.8	3.1	52	9x4	1.1	42.7	0.9	2.4
10	2x4	7.0	34.5	1.1	2.4	10	2x4	2.0	30.6	2.6	2.1
27	5x3	7.7	52.6	11	2.9	27	5x3	9.2	66.1	17.4	2.9
22	4x4	7.8	54.4	6.8	2.9	22	4x4	2.3	53.1	3.4	2.5
17	3x5	8.3	36.7	14.3	3.0	17	3x5	6.4	45.0	6.1	3.0
4	1x4	9.1	28.1	2.5	2.7	4	1x4	3.4	32.9	1.7	2.5
45	8x3	9.4	56.9	17.9	3.2	45	8x3	4.6	60.3	21.5	3.1
9	2x3	9.4	54.9	0.0	2.6	9	2x3	4.5	51.2	2.6	2.4
40	7x4	9.6	54.7	0.6	3.2	40	7x4	4.7	71.7	2.2	3.1
25	5x1	9.6	39.6	37.3	2.7	25	5x1	7.6	37.7	28.9	2.8
11	2x5	10.2	22.3	19.2	2.6	11	2x5	6.2	37.1	18.0	2.6
60	10x6	11.0	48.5	1.1	3.1	60	10x6	5.9	54.7	7.8	3.0
47	8x5	11.1	45.3	52.1	3.2	47	8x5	4.8	29.1	30.2	2.9
Worst 10 hybrids											
36	6x6	20.1	57.7	7.7	3.1	36	6x6	7.1	65.4	11.4	2.4
43	8x1	21.9	28.5	50.6	3.3	43	8x1	11.3	36.5	42.7	3.2
24	4x6	21.9	41.5	51.2	2.8	24	4x6	7.4	59.5	36.8	3.1
42	7x6	22.6	44.6	20.8	3.7	42	7x6	11.7	46.6	25.6	3.8
51	9x3	22.9	37.8	16.1	3.2	51	9x3	3.1	44.2	19.2	3.1
31	6x1	23.1	27.2	27.8	3.1	31	6x1	7.6	27.4	20.1	2.7
54	9x6	24.1	41.5	16.4	3.1	54	9x6	8.4	54.6	25.9	3.3
46	8x4	24.8	46.9	1.7	2.9	46	8x4	6.5	59.4	1.3	2.8
38	7x2	32.6	41.6	2.7	3.3	38	7x2	10.1	35.5	0.7	3.1
12	2x6	57.8	43.6	7.2	2.8	12	2x6	2.5	46.0	11.8	2.4
61	DK8031	32	38.5	24.5	4.0	61	DK8031	25.4	52.4	20.8	3.6
62	WH507	11.4	55.1	7.5	3.1	62	WH507	5.1	68.6	5.1	2.7
63	WH505	19.1	40.1	9.7	3.1	63	WH505	12	57.4	5.4	3.0
64	H513	23.2	40.5	9.1	3.2	64	H513	6.4	42.5	11.9	3.1
Mean		15.0	40.7	15.3	3	Mean		6.1	47.8	14.3	2.8
CV		0.72	1.86	0.81	5.81	CV		0.9	2.1	0.8	4.5
Min		4.6	16.5	0.0	2.4	Min		0.8	23.1	0.1	2.1
Max		57.8	58.4	58.8	4.0	Max		25.4	72.9	52.3	3.8

FSI, Fusarium ear rot incidence, FSE, Fusarium ear rot severity, HC, husk cover, EA, ear aspect

4.5 Performance of hybrids across trials under natural disease pressure (Kakamega, Kibos and Alupe)

The performance of the top 20 hybrids under natural disease pressure is presented in Table 4.7. The best hybrid in terms of grain yield was hybrid 58 (7.9 tha^{-1}) followed by hybrid 5 (7.8 tha^{-1}) (Table 4.7). These two hybrids were significantly better than the best commercial check (WH505) in terms of grain yields. The days to anthesis ranged from 61 to 66, with the best hybrid flowering at 62 days (Table 4.7). The mean Fusarium incidence was 6.1% (Table 4.7) which was lower than the mean of 15% recorded in the inoculated trials at the same locations. Hybrids with high grain yield (> 6 tha^{-1}) were associated with low incidence of Fusarium ear rot as observed in hybrids 58, 5, 22, 3, 35 and 51 with 1.7, 3.5, 2.3, 1.3, 1.7 and 3.1%, respectively (Table 4.6 and Table 4.7). This was observed in both natural disease pressure and under artificial inoculation.

Low incidence of poor husk cover was noted in hybrids 58 (0.1%), 2 (0.2%), 3 (0.7%), 50 (0.7%), 38 (0.7%), 8 (1%) while higher incidence was recorded for hybrids 5, 47, 13, and 25 (Table 4.7).

4.6 Phenotypic correlation between traits under natural disease pressure

The simple correlation coefficients among traits under natural disease pressure are presented in Table 4.8. Grain yield was negatively but significantly ($P < 0.001$) correlated with Fusarium disease incidence (FSI) ($r = -0.29$*) and weakly correlated with Fusarium disease severity (FSE) ($r = -0.11$). Results also showed that grain yield was negatively correlated ($r = -0.21$) with poor husk cover. Fusarium disease incidence (FSI) was positively correlated with poor husk cover ($r = 0.40$**) and ear per plant ($r = 0.20$) while

Fusarium disease severity (FSE) was negatively correlated with poor husk cover (*r* = -0.34**), ear height (*r* = -0.35*), days to anthesis (*r* = -0.16) and ears per plant (*r* = -0.15).

Table 4.7 Grain yield and other agronomic performance of top twenty hybrids under natural disease pressure (Kakamega, Kibos, and Alupe).

Hybrid	Pedigree	GY[†]	AD	HC	EA	EH	EPP	PH	FSI	FSE
#		tha^{-1}	d	%	1-5	cm	#	cm	%	%
58	10x4	7.9	62	0.1	2.3	104	1.0	229	1.7	50.7
5	1x5	7.8	66	35.0	2.6	138	0.9	256	3.5	28.6
26	5x2	7.6	64	6.0	2.6	106	1.0	238	4.8	44.6
38	7x2	7.4	64	0.7	3.1	98	1.0	234	10.1	35.5
47	8x5	7.4	65	30.2	2.9	109	1.2	231	4.8	29.1
4	1x4	7.3	64	1.7	2.5	115	0.9	237	3.4	32.9
36	6x6	7.2	61	11.4	2.4	113	1.1	229	7.0	65.4
2	1x2	7.2	65	0.2	2.7	104	1.0	239	4.1	38.3
17	3x5	7.2	66	6.1	3.0	117	1.0	240	6.4	45.0
13	3x1	7.2	65	32.4	2.8	109	1.0	227	9.6	51.8
53	9x5	7.1	65	18.1	2.6	116	1.0	241	4.5	64.9
25	5x1	7.1	66	28.9	2.8	114	1.0	234	7.6	37.7
8	2x2	7.0	64	1.0	2.2	107	1.0	236	1.3	49.5
44	8x2	6.9	63	3.1	2.6	97	1.1	228	7.5	53.3
20	4x2	6.8	65	9.1	2.8	105	1.0	241	4.3	44.4
22	4x4	6.7	63	3.4	2.5	114	1.0	231	2.3	53.1
3	1x3	6.6	66	0.7	2.6	110	0.9	243	1.3	72.9
35	6x5	6.6	65	12.0	2.4	142	1.0	277	1.7	33.1
50	9x2	6.5	63	0.7	2.8	103	1.0	231	5.8	54.3
51	9x3	6.5	65	19.2	3.1	103	1.0	232	3.1	44.2
61	DK8031	4.8	62	20.8	3.6	103	1.0	223	25.4	52.4
62	WH507	5.2	66	5.1	2.7	107	1.0	233	5.1	68.6
63	WH505	5.5	66	5.4	3.0	117	1.0	239	12.0	57.4
64	H513	4.8	63	11.9	3.1	134	1.0	252	6.4	42.5
Mean		6.0	64	14.3	2.8	110	1.0	235	6.1	47.8
LSD		2.2	2	16.7	0.6	11	0.2	15	8.7	23.2
CV		3.0	11.0	0.8	4.5	7.6	6.3	14.5	0.9	2.1
Min		4.0	60.7	0.3	2.1	94	0.9	206	0.8	23.1
Max		7.9	66.9	52.3	3.8	142	1.3	277	25.4	72.9

[†]GY, grain yield ; AD, days to 50% anthesis; HC, husk cover; EA, ear aspect; EH, ear height; PH, plant height; FSI, Fusarium ear rot incidence ; FSE, Fusarium ear rot severity

Table 4.8.Phenotypic correlation between grain yield and other agronomic traits under natural disease pressure at Kakamega, Alupe and Kibos.

Trait	GY[†]	AD	HC	EA	EH	EPP	PH	FSI
AD	-0.03ns							
HC	-0.21ns	0.36**						
EA	-0.54***	0.08ns	0.32*					
EH	0.07ns	0.25*	0.36**	-0.14ns				
EPP	-0.29*	0.05ns	0.41***	0.17ns	-0.05ns			
PH	0.17ns	0.43***	0.00ns	-0.29*	0.69***	-0.05ns		
FSI	-0.29*	0.06ns	0.40**	0.60***	-0.01ns	0.20ns	-0.18ns	
FSE	-0.11ns	-0.15ns	-0.34**	0.13ns	-0.35*	-0.12ns	-0.19ns	0.02ns

*, **, *** Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.
ns, not significant.
[†] GY, Grain yield; AD, Anthesis date; HC, Husk cover; EA, Ear Aspect; EH, ear height; EPP, ears per plant; PH, plant height; FSI, Fusarium incidence; FSE, Fusarium severity

4.7. Performance of hybrids under managed drought stress at Kiboko

Analysis of variance under drought managed stress revealed presence of significant differences among the hybrids and F1 hybrids for grain yield and the agronomic traits (Table 4.9). There were also significant differences among male (GCA_m) and female (GCA_f) for all traits but SCA was not significant except for stalk lodging (Table 4.9). The results for yield performance and other agronomic traits are presented in Table 4.10.

Table 4.9 Analysis of variance for grain yield and other agronomic traits under managed drought stress at Kiboko.

SOV	DF	GY†	AD	ASI	SL	EA	EPP
Rep	1	14.26***	0.08ns	0.08 ns	1657.34**	4.41***	0.33***
Hybrids	63	1.19*	7.51***	5.94**	549.13***	0.47***	0.06***
F1 hybrids	59	1.24*	7.59***	5.72*	561.86***	0.48**	0.06**
GCA_m	5	5.86***	45.64***	7.18*	446.56*	2.09***	0.09**
GCA_f	9	2.16**	17.15***	11.13***	1629.35***	0.65**	0.17***
SCA	45	0.54ns	1.45ns	4.48ns	361.14**	0.26ns	0.04ns
Error	127	0.72	1.54	3.08	200.8	0.21	0.03

*, **, ***Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively
ns, not significant
†GY, grain yield; AD, days to 50% pollen shed; ASI, anthesis silking interval; SL, stem lodging; EA, ear aspect; and EPP, ears per plant

4.8. Phenotypic correlation among traits under managed drought stress

Results of Pearson's correlation analysis revealed that grain yield was negatively and significantly ($P < 0.01$ or $P < .001$) correlated with AD, SD, and EA (Table 4.11). However, grain yield was positively and significantly ($r = 0.76$, $P < 0.001$) correlated with EPP (Table 4.11). The EPP was negatively and significantly correlated with SD ($r = -0.43$, $P < 0.001$) and EA ($r = -0.55$, $P < 0.001$).

Table 4.10. Grain yield and other agronomic performance of hybrids under managed drought stress at Kiboko.

Hybrid	Pedigree	GY[†]	AD	ASI	EA	EPP
#		t ha^{-1}	d	d	1-5	#
48	8x6	3.91	66	-0.82	2.46	0.88
29	5x5	3.75	72	0.3	1.98	0.74
54	9x6	3.64	66	1.9	2.43	0.79
58	10x4	3.63	67	1.62	2.91	0.65
52	9x4	3.54	66	2.32	2.33	0.86
28	5x4	3.48	67	4.11	2.41	0.73
30	5x6	3.41	69	3.76	1.94	0.70
4	1x4	3.38	68	2.71	2.02	0.62
27	5x3	3.26	72	0.89	2.70	0.74
40	7x4	3.25	67	4.15	2.43	0.60
60	10x6	3.1	67	0.36	2.54	0.69
16	3x4	3.09	66	6.72	2.61	0.62
41	7x5	3.07	69	1.71	2.25	0.66
18	3x6	3.05	68	3.57	2.09	0.76
6	1x6	3.01	68	2.86	2.00	0.83
3	1x3	2.98	72	0.85	2.57	0.60
56	10x2	2.97	67	1.53	2.39	0.78
34	6x4	2.81	66	3.91	2.68	0.71
36	6x6	2.78	66	1.26	2.86	0.83
24	4x6	2.72	69	3.84	2.38	0.59
61	DK8031	2.13	67	6.73	3.38	0.59
62	WH507	1.56	70	1.04	3.56	0.47
63	WH505	1.74	71	4.23	3.43	0.47
64	H513	1.94	67	5.11	2.95	0.45
Mean		2.31	68.87	3.36	2.96	0.59
CV		29.19	1.8	42.1	15.1	22.79
LSD		1.58	2.3	2.5	0.76	0.29
Min		0.68	65.21	-1.5	1.94	0.26
Max		3.91	72.49	7.85	4.01	1

† GY, Grain Yield; AD, days to 50% anthesis ; ASI, anthesis silking interval; EA, ear aspect; EPP, ears per plant

Table 4.11 Phenotypic correlations between grain yield and agronomic traits under managed drought stress at Kiboko.

Trait	GY†	AD	ASI	EA
AD	-0.31**			
ASI	-0.11ns	-0.19ns		
EA	-0.86***	0.19ns	0.02ns	
EPP	0.73***	-0.39**	-0.18ns	-0.55***

*** Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively.
ns, not significant.
†GY; Grain yield; AD, days to 50 %; ASI, anthesis silking interval; EA, ear aspect

4.9. General combining ability (GCA) effects for grain yield and Fusarium disease parameters per location and across three locations (Kakamega, Alupe, and Kibos) under artificial inoculation

The results for individual and across location GCA effects for both Fusarium parameters and grain yield are presented in table 4.12. The inbred line CKL05003/CML444//CKL05003) DH-6 had positive GCA effects for grain yield in Kakamega (0.65) and Alupe (1.22*) under artificial inoculation. Similarly, inbred line CML538 had desirable GCA effects for grain yield in Kibos (0.79*) and Kakamega (0.37). CZL00003 had consistently negative GCA effects for grain yield in Kakamega (-1.31*), Alupe (-0.02) and Kibos (-1.29*). CKL05003 had negative GCA effects for both Fusarium incidence and Fusarium severity in each location, Kakamega, Kibos and Alupe (Table 4.12). VL06688 had negative GCA effects for both Fusarium parameters in Kakamega and Alupe locations.

Across locations, (CKL05003/CML444//CKL05003)DH6-B, CKL05019, CML538 , and P502c2-185-3-4-2-3-B-2-B*6 had the largest positive but non-significant GCA effects for grain yield with 0.53, 0.52, 0.47,and 0.39 t ha^{-1}, respectively. Two inbred lines

(CZL00003 and La Posta Seq C7-F64-2-6-2-2-B-B-B) had negative and significant GCA effects for grain yield (Table 4.12). Nine inbred lines (parents1, 2, 3, 5, 10, 11, 13, 14, and 15) had negative GCA values for Fusarium ear rot incidence (FSI) while ten inbred lines (parents 1, 2, 4, 5, 9, 10, 11, 12, 13, 14) had negative GCA values for Fusarium ear rot severity (FSE) (Table 4.12). The inbred line parent CKL05024 was the best in terms of Fusarium incidence (FSI) with the lowest GCA effect (-6.29). Other inbred lines with low GCA effects for Fusarium incidence (FSI) were CML538 (-5.66), CKL05019 (-5.15), CKL05003 (-5.14), CML264 (-1.69), CL-RCW37 (-1.66), CML247 (-1.31), and P502c2-185-3-4-2-3-B-2-B*6 (-1.05) (Table 4.12). Inbred lines CML 442 (9.38*) and VL06688 (6.71) had the highest and positive GCA effects for Fusarium disease incidence. Five other inbred lines had positive GCA effects for Fusarium disease incidence (Table 4.12). Results for Fusarium disease severity on cobs showed that inbred lines CKL05003 (-12.74***) and CL-RCW37 (-10.79***) had the best and significant ($P < 0.001$) GCA effects (Table 4.12). Six other inbred lines showed negative but non-significant ($P > 0.05$) GCA effects for Fusarium disease severity. Inbred lines CML495 (9.57**), CML264 (7.7*), and CML538 (7.5*) showed positive and significant ($P <0.01$ or $P< 0.05$) GCA effects for Fusarium disease severity (Table 4.12). Other inbred lines with large positive but non-significant GCA effects for Fusarium disease severity were CKL05024 (5.52), VL06688 (4.37) and CML442 (4.20). Six inbred lines showed negative GCA effects for both Fusarium disease incidence and severity across locations under artificial inoculation (Table 4.12). Five inbred lines showed positive GCA effects for both Fusarium disease incidence and severity across locations under artificial inoculation (Table 4.12).

Table 4.12.Genaral combining ability (GCA) effects of sixteen (16) maize inbred lines at each location and across three locations under artificial inoculation.

Inbred line	Pedigree	KAKAMEGA			ALUPE			KIBOS			Across locations		
		GY[†] tha^{-1}	FSI %	FSE %	GY tha^{-1}	FSI %	FSE %	GY tha^{-1}	FSI %	FSE %	GY tha^{-1}	FSI %	FSE %
1	CKL05003	-0.02ns	-8.25*	-17.39**	0.27ns	-4.34ns	-11.79ns	-0.47ns	-3.49**	0.32ns	-0.12ns	-5.14ns	-12.74***
2	CKL05019	0.16ns	-12.58**	-4.95ns	0.10ns	1.89ns	-9.75ns	1.28**	3.33**	-0.38ns	0.52ns	-5.15ns	-3.34ns
3	CKL05024	0.30ns	-15.37***	5.24ns	-0.61*	0.02ns	5.53ns	0.16ns	2.58*	-0.28ns	-0.04ns	-6.29ns	5.52ns
4	(CKL05003/CML444//CKL05003)DH6-B	0.65ns	3.51ns	-2.37ns	1.22***	-4.94ns	1.27ns	-0.29ns	-2.59*	0.22ns	0.53ns	1.32ns	-1.76ns
5	(CKL05003/CML444//CKL05003)DH5-B	-0.19ns	8.375*	-4.77ns	0.40ns	-4.68ns	-0.32ns	0.51ns	0.83ns	0.18ns	0.25ns	-0.29ns	-2.69ns
6	CZL00003	-1.31*	-3.21ns	3.31ns	-0.02ns	3.29ns	-4.68ns	-1.29**	-1.17ns	0.14ns	-0.86*	2.68ns	0.61ns
7	CML442	-0.17ns	23.58***	8.15ns	-0.43ns	0.49ns	7.89ns	-0.17ns	0.83ns	0.20ns	-0.25ns	9.38*	4.20ns
8	VL06688	-0.03ns	14.55***	3.25ns	-1.07**	6.54ns	14.53*	-0.37ns	-3.76**	-0.26ns	-0.48ns	6.71ns	4.37ns
9	CML548	0.24ns	-5.58ns	-2.36ns	-0.09 ns	6.83 ns	-2.74ns	-0.19ns	0.66ns	0.48ns	-0.01ns	2.30ns	-2.02ns
10	CML538	0.37ns	-5.70ns	10.45ns	0.25 ns	-5.45 ns	-0.94ns	0.79*	2.49*	-0.60*	0.47ns	-5.66ns	7.5*
11	CML247	-0.18ns	-3.98ns	-11.49*	0.13 ns	-0.14 ns	-2.28ns	-0.53ns	-2.78**	-0.03ns	-0.22ns	-1.31ns	-4.82ns
12	CML495	-0.10ns	2.90ns	11.64*	0.07 ns	4.08 ns	12.51*	0.48ns	3.12**	0.12ns	0.16ns	2.12ns	9.57**
13	CML264	0.18ns	-3.73ns	8.85 ns	-0.17 ns	1.79 ns	12.21*	0.31ns	-2.17**	-0.37ns	0.11ns	-1.69ns	7.7*
14	P502c2-185-3-4-2-3-B-2-B*6	0.01 ns	5.49*	-6.57 ns	0.45*	-2.17 ns	-6.58ns	0.68*	-0.42ns	-0.78**	0.39ns	-1.05ns	-3.56ns
15	CL-RCW37	0.35 ns	-2.42ns	-11.94*	-0.10 ns	-7.68*	-12.93*	0.33ns	2.22*	0.97**	0.20ns	-1.66ns	-10.79***
16	La Posta Seq C7-F64-2-6-2-2-B-B-B	-0.28ns	1.55ns	8.95ns	-0.39 ns	4.11ns	-3.05ns	-1.28**	-0.12ns	0.08ns	-0.65**	3.57ns	1.82ns

*, **, ***Significant at *P* < 0.05, *P* < 0.01, and *P* < 0.001, respectively
ns, not significant.

4.10. General combining ability (GCA) under natural disease pressure (Kakamega, Alupe and Kibos)

The results under natural disease pressure at each location and across locations are presented in Table 4.13. Inbred lines CML495 and CL-RCW37 had positive effects for grain yield GCA in Kakamega (1.27*** and 1.29***) and Kibos (0.82** and 0.79*) respectively. Also, inbred line (CKL05003/CML444//CKL05003) DH5-B had positive but no significant GCA effects for grain yield in all the locations. Inbred line CKL05019 had negative GCA effects for both Fusarium parameters in Kakamega, Alupe and Kibos. Negative GCA effects for Fusarium incidence and severity were recorded for inbred lines CKL05024 and CL-RCW37 in Kakamega and Alupe while inbred lines CML442 had positive effects for Fusarium incidence and Fusarium severity GCA in Alupe and Kibos (Table 4.13).

Across locations under natural disease pressure, the best GCA effects for grain yield were recorded for inbred lines CML495 (0.70), CL-RCW37 (0.60), CKL05003 (0.50) and (CKL05003/CML444//CKL05003) DH5-B (0.40) but none of these GCA effects was significant (Table 4.13). Across locations, the inbred line with desirable GCA effects for Fusarium incidence were CKL05024 (-4.41), CKL05003 (-2.90), (CKL05003/CML444//CKL05003) DH6-B (-2.85) and CML442 (-2.81) although these GCA effects were not significant (Table 4.13). Inbred line VL06688 (7.93**) had the most undesirable GCA effects for Fusarium incidence under natural disease pressure (Table 4.13). Inbred line CKL05003 had a highly significant ($P < 0.001$) GCA effect (-14.23) for Fusarium severity under natural disease pressure. Other inbred lines with negative GCA effects for Fusarium severity were CL-RCW37 (-5.00), CKL05019 (-

4.94), P502c2-185-3-4-2-3-B-2-B*6 (-3.77), CML495 (-3.72) and VL06688 (-2.29). On the other hand inbred line CML 442 had a significant ($P < 0.01$) positive GCA effect (9.5) for disease severity across location under natural disease pressure

Table 4.13.Genaral combining ability (GCA) effects of sixteen (16) maize inbred lines at each location and across three locations under natural disease pressure (Kakamega, Alupe and Kibos).

Inbred line	Pedigree	KAKAMEGA			ALUPE			KIBOS			Across locations		
		GY[†] tha^{-1}	FSI %	FSE %	GY tha^{-1}	FSI %	FSE %	GY tha^{-1}	FSI %	FSE %	GY tha^{-1}	FSI %	FSE %
1	CKL05003	-0.06ns	-3.40ns	-13.37*	0.44ns	0.04ns	-8.16ns	1.32***	-5.61*	-20.94**	0.50ns	-2.90ns	-14.23***
2	CKL05019	0.67*	-10.07**	4.38ns	-0.34ns	-1.96ns	-15.19ns	0.00ns	-1.22ns	-4.29ns	0.10ns	-1.45ns	-4.94ns
3	CKL05024	1.09**	-7.82*	1.08	-0.67*	-0.89ns	5.92ns	-0.08ns	0.13ns	1.26ns	0.10ns	-4.41ns	2.85ns
4	(CKL05003/CML444//CKL05003) DH6-B	-0.11ns	-2.76ns	4.20ns	0.57*	0.21ns	-0.47ns	-0.44ns	4.69ns	6.95ns	0.00ns	-2.85ns	3.65ns
5	(CKL05003/CML444//CKL05003) DH5-B	0.39ns	1.62ns	-6.29ns	0.30ns	1.24ns	5.88ns	0.46ns	2.53ns	8.04ns	0.40ns	0.72ns	2.64ns
6	CZL00003	0.43ns	-8.37**	-1.05ns	0.45ns	0.92ns	-1.86ns	-1.26**	-1.00ns	-0.06ns	-0.10ns	1.81ns	-0.90ns
7	CML442	-0.92**	16.98***	-0.36ns	-0.97**	3.75**	13.94ns	0.35ns	3.03ns	14.65*	-0.50ns	-2.81ns	9.50**
8	VL06688	-0.42ns	12.02***	0.57ns	-0.28ns	-0.97ns	-0.75ns	-0.48ns	1.56ns	-6.97ns	-0.40ns	7.93**	-2.29ns
9	CML548	-1.15**	1.54ns	8.34ns	0.15ns	-0.17ns	3.28ns	0.83*	-2.38ns	-2.97ns	0.00ns	4.21ns	2.98ns
10	CML538	0.07ns	-0.01ns	1.40ns	0.39ns	-2.19*	-3.25ns	-0.59ns	-2.19ns	2.58ns	0.00ns	-0.33ns	0.34ns
11	CML247	-0.62*	0.55ns	-13.19*	0.14ns	1.15ns	8.57ns	-1.10**	10.46***	6.83ns	-0.60ns	3.87ns	0.23ns
12	CML495	1.27***	1.67ns	7.98ns	-0.08ns	0.87ns	-3.66ns	0.82**	-4.83*	-15.75*	0.70ns	-0.75ns	-3.72ns
13	CML264	-0.87**	-2.08ns	0.17ns	-0.18ns	-0.05ns	19.54*	-0.34ns	-0.52ns	-0.18ns	-0.50ns	-0.87ns	6.61ns
14	P502c2-185-3-4-2-3-B-2-B*6	-0.44*	0.72ns	0.67ns	0.69**	-0.52ns	-11.48ns	0.44ns	-4.25*	-0.77ns	0.20ns	-1.34ns	-3.77ns
15	CL-RCW37	1.29***	-6.69*	-5.69ns	-0.36ns	-0.84ns	-12.29ns	0.79**	0.64ns	2.70ns	0.60ns	-2.29ns	-5.00ns
16	La Posta Seq C7-F64-2-6-2-2 -B-B-B	-0.67*	5.85*	9.40*	-0.21ns	-0.56ns	-0.25ns	-0.66*	-0.97ns	7.52ns	-0.50ns	1.45ns	5.65ns

*, **, ***Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively
ns, not significant.
[†] GY, grain yield; FSI, Fusarium incidence; FSE, Fusarium severity

4.11. Specific combining ability (SCA) effects for Fusarium ear rot resistance, grain yield and other agronomic traits of hybrids under artificial inoculation at three locations (Kibos, Alupe and Kakamega)

For grain yield, the SCA effect (1.34) for hybrid 22 (CKL05003/CML444//CKL05003) DH5-B/CL-RCW37) was significant ($P < 0.05$) across locations. The results indicated that SCA effects for grain yield of 33 hybrids were positive (Table 4.14). Hybrids 41 (CML442/CL-RCW37) with -12.83, 6 (CKL05003/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B) with -10.39, 22 (CKL05003/CML444//CKL05003)DH5-B/CL-RCW37) with -10.36, and 45 (VL06688/CML264) with -9.51 had the largest negative SCA effects for Fusarium incidence (Table 4.14). The SCA effect for hybrid 14 was significant ($P < 0.05$). On the other hand hybrids 5 (CKL05003/CL-RCW37), 28 (CKL05003/CML444//CKL05003)DH6-B/P502c2-185-3-4-2-3-B-2-B*6*6), 38 (CML442/CML495) and 46 (VL06688/P502c2-185-3-4-2-3-B-2-B*6) had significant ($P < 0.05$ or $P < 0.01$) SCA effects for Fusarium incidence, suggesting increased susceptibility of these hybrids to *Fusarium verticillioides* (Table 4.14). For Fusarium severity, hybrids 3 (CKL05024/P502c2-185-3-4-2-3-B-2-B*6) with -17.03 and 16 (CKL05003/CML264) with -15.43 had significant ($P < 0.05$) SCA effects for disease severity (Table 4.14), indicating that these hybrids had some of the lowest disease severity compared the other hybrids. These two hybrids (3 and 16) also had negative SCA effects for Fusarium incidence (Table 4.14). In total 18 hybrids had negative SCA effects for both Fusarium incidence and severity across locations (Table 4.14). Hybrid 1 (CKL05003/CML247) (17.53*) had positive and significant ($P < 0.05$) SCA effects for

Fusarium severity suggesting increased susceptibility to *Fusarium verticillioides* in this hybrid.

Table 4.14 Specific combining ability (SCA) effects for Fusarium ear rot resistance, grain yield and other agronomic traits of the 60 F1 hybrids under artificial inoculation.

Hybrid	F	M	GY†	AD	EA	EH	EPP	FSI	FSE	HC	PH
1	1	1	0.18	1.09	0.09	6.45	0.05	-1.51	17.53*	9.30	0.00
2	1	2	-0.38	-0.50	0.04	-4.85	-0.03	1.96	-1.94	-9.16	-6.61
3	1	3	0.89	1.08	-0.01	-1.52	0.03	-5.02	-15.43*	-5.11	0.31
4	1	4	-0.51	-1.67	-0.22	2.15	-0.03	0.24	8.36	-6.18	1.12
5	1	5	-0.26	1.25	-0.04	5.57	0.00	14.26*	-2.00	8.11	0.06
6	1	6	0.08	-1.22	0.15	-6.35	-0.01*	-10.39	-4.32	3.19	4.81
7	2	1	0.29	1.09	0.09	-4.77	0.05	-5.39	-2.70	9.30	-1.88
8	2	2	0.71	-0.50	0.04	-0.07	-0.03	4.01	-0.55	-9.16	-9.00*
9	2	3	0.08	1.08	-0.01	1.60	0.03	-1.90	14.34	-5.11	-4.58
10	2	4	-0.75	-1.67	-0.22	3.60	-0.03	-6.85	-7.70	-6.18	12.07**
11	2	5	0.11	1.25	-0.04	-4.65	0.00	-1.04	-9.85	8.11	-6.50
12	2	6	-0.44	-1.22	0.15	4.26	-0.01**	11.21	6.53	3.19	9.92*
13	3	1	0.75	1.09	0.09	1.34	0.05	1.67	-2.89	9.30	-3.00
14	3	2	-1.35*	-0.50	0.04*	11.87**	-0.03	-0.33	6.89	-9.16	14.06**
15	3	3	-0.35	1.08	-0.01	-0.63	0.03	7.93	6.43	-5.11	0.98
16	3	4	0.75	-1.67	-0.22	-1.13	-0.03	-5.86	-17.03*	-6.18	-5.71
17	3	5	0.57	1.25**	-0.04	-1.04	0.00	-1.00	5.93	8.11	5.73
18	3	6	-0.36	-1.22	0.15	-10.46*	-0.01	-2.40	0.75	3.19	-12.02**
19	4	1	-1.34*	1.09	0.09	-2.96	0.05	2.79	-1.75	9.30	-5.50
20	4	2	0.15	-0.50	0.04	-3.27	-0.03	-7.77	6.71	-9.16	3.23
21	4	3	-0.23	1.08	-0.01	-1.60	0.03	10.46	1.76	-5.11	0.98
22	4	4	1.34*	-1.67	-0.22	1.23	-0.03	-10.36	3.55	-6.18	1.79
23	4	5	0.41	1.25	-0.04	1.32	0.00	3.97	-7.18	8.11*	0.73
24	4	6	-0.33	-1.22	0.15	5.23	-0.01	0.93	-3.00	3.19**	-1.19
25	5	1	0.60	1.09	0.09	-2.96	0.05	0.64	7.76	9.30	3.50
26	5	2	0.23	-0.50	0.04	-2.43	-0.03	2.64	4.68	-9.16	-3.61
27	5	3	1.10	1.08	-0.01	0.90	0.03	-8.32	2.15	-5.11	-3.36
28	5	4	-0.45	-1.67	-0.22	1.23	-0.03	12.80*	3.06	-6.18	9.29*
29	5	5	-2.03**	1.25	-0.04*	-1.18	0.00	-0.92	-3.81	8.11	-4.44
30	5	6	0.54	-1.22	0.15	4.40	-0.01	-6.81	-13.77	3.19	-1.36
31	6	1	0.24	1.09	0.09	3.29	0.05	5.73	-6.42	9.30	-1.05
32	6	2	0.21	-0.50	0.04	3.82	-0.03	-4.85	-9.02	-9.16	1.84

33	6	3	-0.75	1.08	-0.01	-7.85*	0.03*	-2.27	-10.32	-5.11	-6.25
34	6	4	-1.07	-1.67	-0.22	1.65	-0.03	-0.97	-1.23	-6.18	6.24
35	6	5	0.50	1.25*	-0.04	-0.77	0.00	1.19	8.10	8.11	-3.16
36	6	6	0.88	-1.22	0.15	-0.18	-0.01	1.18	18.97	3.19	2.42
37	7	1	0.37	1.09	0.09	-1.44	0.05	-7.85	2.30	9.30***	8.81
38	7	2	-0.87	-0.50	0.04	4.10	-0.03	16.51**	-9.28	-9.16	-0.80
39	7	3	0.31	1.08	-0.01	0.76	0.03	6.40	2.72	-5.11	5.28
40	7	4	0.20	-1.67	-0.22	-11.40**	-0.03	-3.93	14.59	-6.18	-16.40***
41	7	5	0.72	1.25	-0.04	7.01	0.00	-12.83*	-11.12	8.11	7.53
42	7	6	-0.73	-1.22	0.15	0.93	-0.01	1.72	0.87	3.19	-4.38
43	8	1	-1.06	1.09	0.09	-0.88	0.05	-0.96	-6.76	9.30	3.81
44	8	2	0.68	-0.50	0.04	-10.35*	-0.03	-8.42	4.44	-9.16	-1.63
45	8	3	-0.94	1.08**	-0.01	7.98*	0.03	-9.51	-1.20	-5.11*	6.12
46	8	4	-0.44	-1.67	-0.22	4.98	-0.03	15.77**	-0.37	-6.18*	-0.57
47	8	5	0.89	1.25**	-0.04	-5.77	0.00	3.76	14.86	8.11	-4.97
48	8	6	0.86	-1.22	0.15*	3.98	-0.01	-0.64	-10.89	3.19	-2.72
49	9	1	-0.55	1.09	0.09	3.29	0.05	-1.80	-2.02	9.30	-1.88
50	9	2	0.66	-0.50	0.04	-2.85	-0.03	-4.55	7.93	-9.16	0.17
51	9	3	0.71	1.08	-0.01	-0.35	0.03	5.99	-3.13	-5.11	-1.25
52	9	4	0.28	-1.67	-0.22	0.82	-0.03	-6.02	-5.79	-6.18	-2.93
53	9	5	-0.88	1.25	-0.04	-1.60	0.00	-1.04	-1.64	8.11	-2.33
54	9	6	-0.22	-1.22	0.15	0.65	-0.01	7.43	4.73	3.19	8.25
55	10	1	0.54	1.09	0.09	0.09	0.05	5.71	-3.91	9.30	-2.30
56	10	2	-0.03	-0.50	0.04	3.96	-0.03	0.94	-9.50	-9.16	2.25
57	10	3	-0.83	1.08	-0.01	0.62	0.03	-3.62	3.03	-5.11	1.67
58	10	4	0.65	-1.67	-0.22	-3.21	-0.03	5.30	2.92	-6.18	-5.01
59	10	5	-0.04	1.25	-0.04	1.04	0.00	-6.22	7.07	8.11	7.25
60	10	6	-0.29	-1.22	0.15	-2.54	-0.01	-2.10	0.47	3.19	0.00

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

[†] GY, grain yield; AD, days to 50% pollen shed; EA, Ear Aspect; EH, ear height; EPP, ears per plant; FSI, Fusarium incidence; FSE, Fusarium severity; HC, husk cover; PH , plant height

4.12. Specific combining ability (SCA) effects for Fusarium ear rot resistance, grain yield and other agronomic traits of hybrids under natural disease pressure across locations (Kibos, Alupe and Kakamega)

The results of the SCA effects estimated for the different agronomic traits and Fusarium disease parameters of the 60 hybrids under natural disease pressure are presented in Table 4.15.

Hybrids 41 (CML442/CL-RCW37) had negative SCA effects (-06.94*) for Fusarium incidence. Hybrids 37 (CML442/CML247), 22 (CKL05003/CML444//CKL05003)DH5-B/P502c2-185-3-4-2-3-B-2-B*6), 6 (CKL05003/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B), 16 (CKL05024/P502c2-185-3-4-2-3-B-2-B*6), and 52 (CML548/P502c2-185-3-4-2-3-B-2-B*6) had negative SCA effects for both Fusarium incidence and severity. In contrast, hybrids 54 (CML548/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B) with 9.91** , 39 (CML442/CML264) with 9.37**, and 28 (CKL05003/CML444//CKL05003)DH6-B/P502c2-185-3-4-2-3-B-2-B*6*6) with 8.67*, had positive and significant effects ($P < 0.05$) for Fusarium incidence. Hybrids 36 (CZL00003/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495)DH19-B-B) with 1.76***, 58 (CML538/P502c2-185-3-4-2-3-B-2-B*6) with 1.61***, 13 (CKL05024/CML247) with 1.47** and 47 (VL06688/CL-RCW37) with 1.12* had positive and significant ($P < 0.05$) SCA effects for grain yield. Hybrid 33 (CZL00003/CML264) had positive and significant SCA effects (0.21***) for ears per plant, while hybrids 22 (CKL05003/CML444//CKL05003) DH5-B/P502c2-185-3-4-2-3-B-2-B*6) with -10.82**, 17(CKL05024/CL-RCW37) with -12.57** and 7 (CKL05019/CML247) with -14.78*** had negative SCA effects for husk cover.

Table 4.15 Specific combining ability (SCA) effects for Fusarium ear rot resistance, grain yield and other agronomic traits of the 60 F1 hybrids under natural disease pressure across locations (Kibos, Alupe and Kakamega).

Hybrid	F	M	GY[†]	AD	EA	EH	EPP	FSI	FSE	HC	PH
1	1	1	-1.41**	0.76	0.19	3.73	0.09	1.94	-4.34	7.22	1.15
2	1	2	0.16	-0.40	0.04	-4.18	0.06	-1.07	10.39	-0.93	-0.09
3	1	3	0.49	-0.40	-0.13	-3.68	-0.05	-3.22	4.76	-7.74*	-2.17
4	1	4	0.16	0.98*	0.11	-0.18	-0.03	4.49	5.39	-0.81	0.25
5	1	5	0.87	-0.24	-0.05	11.82**	-0.07	3.12	-3.99	11.15**	4.66
6	1	6	-0.59	-0.39	-0.11	-6.77	0.01	-4.35	-12.90	-5.76	-4.17
7	2	1	0.00	-0.60	0.01	-1.40	-0.14**	-0.95	14.07	-14.78***	3.17
8	2	2	0.16	-0.20	-0.05	2.53	0.00	-1.73	-8.65	6.27	-3.40
9	2	3	0.70	-0.03	-0.05	12.19***	0.02	0.50	5.20	0.41	7.85
10	2	4	-0.35	0.02	-0.06	9.86**	-0.02	-0.84	-4.01	5.50	12.76**
11	2	5	-0.99*	0.80	0.35	-7.31*	0.07	2.96	-1.53	1.79	0.51
12	2	6	0.49	-0.01	-0.20	-15.89***	0.07	0.01	-5.10	0.59	-20.82***
13	3	1	1.47**	-0.44	-0.21	1.38	0.06	-0.46	10.03	11.47**	-3.08
14	3	2	-1.29**	0.14	0.22	1.14	-0.07	1.86	-17.43	2.98	-4.65
15	3	3	0.08	-0.20	-0.03	-1.70	-0.04	5.63	5.98	2.83	-3.40
16	3	4	-0.07	-0.65	-0.12	0.97	0.02	-3.75	-11.38	4.91	6.51
17	3	5	0.48	0.30	0.13	-0.36	0.03	3.35	12.77	-12.57**	-3.24
18	3	6	-0.66	0.82	-0.01	-1.45	0.01	-6.69	0.03	-9.83*	7.93
19	4	1	-0.03	-0.35	-0.22	-7.65*	0.01	6.16	-3.11	9.18*	-4.61
20	4	2	0.09	0.55	0.13	-0.39	0.01	-1.64	-6.88	-5.28	2.15
21	4	3	0.53	-0.11	0.04	-1.56	-0.08	-2.97	-5.45	-2.20	0.07
22	4	4	0.50	-0.89*	-0.13	1.11	0.03	-4.94	3.09	-10.82**	-2.52
23	4	5	-0.20	-1.28	0.04	0.61	0.01	6.29	-0.77	2.02	1.90
24	4	6	-0.88	2.06*	0.14	7.86*	0.01	-2.98	13.11	6.89	3.07
25	5	1	0.89	0.26	-0.03	1.66	-0.05	-1.74	-9.66	-8.45*	6.64
26	5	2	0.27	-0.17	-0.18	3.08	0.00	-3.41	5.38	-6.72	5.90
27	5	3	0.29	0.00	0.07	-6.42	-0.01	1.76	10.35	-1.83	-6.18
28	5	4	-0.72	0.05	0.06	2.92	-0.01	8.67*	1.32	1.90	0.40
29	5	5	-0.83	-0.17	-0.02	-1.75	0.07	-1.98	6.01	17.85***	-1.85
30	5	6	0.11	0.01	0.09	0.50	0.01	-3.36	-13.40	-2.96	-4.85
31	6	1	0.55	0.59	-0.04	-3.20	-0.12	3.50	-4.91	-3.03	-1.42
32	6	2	-0.47	-0.17	0.06	1.56	0.00	-2.60	3.56	6.28	2.01
33	6	3	-1.35**	0.66	-0.03	-4.61	0.21***	-1.76	-19.96	0.22	0.76
34	6	4	-0.47	-0.12	0.47**	-6.95	0.00	1.45	11.32	7.87*	-12.65**

35	6	5	-0.01	0.50	-0.12	16.72***	-0.10	-2.03	-13.63	-7.93	19.26***
36	6	6	1.76***	-1.48***	-0.34	-3.53	0.01	1.38	23.61**	-3.62	-7.90
37	7	1	-0.14	0.40	-0.07	6.38	-0.02	-4.36	-6.58	-2.25	4.00
38	7	2	0.98*	-0.03	-0.05	-2.20	-0.01	1.54	-4.94	-1.12	2.43
39	7	3	0.52	-0.53	-0.05	9.97**	-0.03	9.37**	-1.92	-6.81	7.85
40	7	4	-0.38	-0.15	0.02	-1.53	0.02	-3.15	19.35	-1.79	-2.24
41	7	5	-0.19	-0.20	-0.15	-3.70	0.02	-6.94*	-1.55	4.07	-8.65*
42	7	6	-0.77	0.49	0.30	-8.95*	0.02	3.49	-4.36	7.68	-3.32
43	8	1	-1.24**	-1.10	0.24	7.63*	0.09	-2.50	-1.70	9.21*	1.92
44	8	2	0.70	0.47	-0.25	-3.45	-0.06	1.69	6.88	-5.93	-5.49
45	8	3	-1.15*	0.47	0.09	-0.45	-0.01	-0.81	2.83	5.77	-0.90
46	8	4	-0.03	0.35	0.16	-2.78	-0.06	5.99	10.42	-8.19*	-0.15
47	8	5	1.12*	0.80	-0.01	-10.78**	0.07	-2.69	-14.27	-1.20	-13.24**
48	8	6	0.60	-1.01	-0.23	9.81**	-0.04	-1.75	-4.15	0.12	17.93***
49	9	1	-0.02	0.12	-0.12	-8.2*	0.02	-3.31	-4.12	-2.27	-11*
50	9	2	-0.27	0.19	-0.03	3.22	0.03	2.99	-0.03	-2.76	1.60
51	9	3	0.77	-0.14	0.14	0.39	0.02	-3.67	-5.50	8.32*	0.35
52	9	4	-0.28	-0.09	-0.20	-5.28	0.06	-5.08	-20.26	-4.49	-5.57
53	9	5	0.40	0.03	-0.12	0.06	-0.02	-0.91	20.28	-6.35	4.68
54	9	6	-0.59	-0.12	0.32*	9.81**	-0.11	9.91**	9.62	7.33	10.01*
55	10	1	-0.26	0.67	0.26	1.24	0.07	1.64	7.63	-5.32	4.28
56	10	2	-0.34	-0.42	0.11	-1.50	0.04	2.45	12.12	7.25	-0.63
57	10	3	-0.88	0.25	-0.05	-4.33	-0.03	-4.74	4.09	1.07	-4.38
58	10	4	1.61***	0.46	-0.31*	1.67	0.00	-2.75	-14.84	5.96	3.04
59	10	5	-0.66	-0.59	-0.06	-5.50	-0.08	-1.07	-2.92	-8.79	-4.21
60	10	6	0.53	-0.40	0.05	8.42*	0.00	4.42	-6.08	-0.39	1.96

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

[†]GY, grain yield; AD, days to 50% pollen shed ; EA, ear Aspect; EH, ear height ; EPP, ears per plant; FSI, Fusarium incidence; FSE, Fusarium severity; HC, husk Cover; PH, plant height

4.13 General combining ability (GCA) effects for grain yield and agronomic traits under managed drought stress

The GCA effects of the inbred lines for various traits under managed drought stress are presented in Table 4.16. The results indicate inbred lines CKL05003/CML444//CKL05003) DH5-B (0.65*), P502c2-185-3-4-2-3-B-2-B*6, La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B (0.59**) had positive and significantly different ($P < 0.01$) effects for yield general combining ability. Other lines showing positive effects for yield GCA were CKL05003, CML538, VL06688, CML442 and CML548. CML 247 had negative (-0.86***) and significant ($P < 0.01$) GCA for grain yield (Table 4.16).

Desirable inbred lines for shorter AD were VL0668 (-1.84***) , P502c2-185-3-4-2-3-B-2-B*6 (-2.14***) , La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B (-1.34**), CZL00003 (-1.17**) and CKL05019 (-1.17**), for anthesis silking interval was VL0668 (-2.06***), CLM 264(-0.99**) and CKL05003/CML444//CKL05003) DH6-B (-1.14**) , for ear aspect were La Posta Seq C7-F64-2-6-2-2-B-B-B / CML495) DH19-B-B (-0.43**) , CKL05003 (-0.39**) , CKL05003/CML444//CKL05003) DH5-B (-0.31**) , VL0668 (0.24***), and La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B (0.12**).

Table 4.16 General combining ability (GCA) effects for agronomic traits of 16 maize inbred lines under managed drought stress at Kiboko.

Inbred line	Pedigree	GY†	AD	ASI	EA	EPP	SL
#		tha^{-1}	d	d	1-5	#	%
1	CKL05003	0.40	0.89*	-0.14	-0.39**	0.04	15.95**
2	CKL05019	-0.79	-1.17**	1.19**	0.44***	-0.13**	2.25
3	CKL05024	-0.30	0.41	-0.06	0.11	-0.11*	-2.03
4	CKL05003/CML444//CKL05003)DH6-B	-0.41	1.49***	-1.14*	0.07	-0.16**	1.23
5	CKL05003/CML444//CKL05003)DH5-B	0.65*	1.41**	0.61	-0.31**	0.10	16.64**
6	CZL00003	-0.23	-1.17**	0.11	0.07	0.02	-23.61***
7	CML442	0.11	0.83*	0.77	-0.10	0.00	-3.68
8	VL06688	0.23	-1.84***	-2.06***	0.19*	0.24***	4.86
9	CML548	0.11	-0.26	0.52	-0.02	0.00	-9.37*
10	CML538	0.26	-0.51	0.19	-0.10	0.02	-0.93
11	CML247	-0.86**	0.9**	0.23	0.46***	-0.1*	-2.98
12	CML495	-0.20	-0.14	-0.04	0.17*	-0.03	-4.75
13	CML264	-0.13	1.56***	-0.99*	0.17*	-0.01	-4.74
14	P502c2-185-3-4-2-3-B-2-B*6	0.62**	-2.14***	0.86*	-0.28**	0.03	3.38
15	CL-RCW37	-0.06	1.21**	-0.19	-0.06	-0.01	6.8*
16	La Posta Seq C7-F64-2-6-2-2-B-B-B	0.59**	-1.34**	0.16	-0.43***	0.12**	2.14

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

†GY, grain yield; AD, days to 50% pollen shed, ASI, Anthesis silking interval, EA, ear Aspect, EPP, ears per plant, SL, stem lodging

4.14 Specific combining ability (SCA) effects for grain yield and other agronomic traits for the 60 F1 hybrids in managed drought stress (Kiboko)

The results of the SCA effects assessed for grain yield and agronomic traits of the 60 hybrids under drought stress condition are presented in Table 4.17. The SCA effects for grain yield of 30 hybrids were positive. Hybrid 48 (VL06688/ (La Posta SeqC7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B) had the best SCA effects (0.8) for grain yield. The SCA effects for grain yield of hybrids 42 (CML442/(La Posta Seq C7-F64-2-6-2-2-B-B-B/CML495) DH19-B-B(-1.17*) and 51CML548/CML264 (-0.95*) were negative and significant (0.05). Hybrids 1(CKL05003/CML247) (-1.62*), 33 (CZL00003/CML264 (-1.73*) and 9 (CKL05019/CML264) (-2.23**) had negative SCA effects for days to anthesis while hybrids 17 (CKL05024/CL-RCW37) (1.04), 3 (CKL05003/CML264) (1.21) and 57 (CML538/CML264) (1.61) had positive effects for days to anthesis, hybrids 11 (CKL05019/CL-RCW37) (0.26**), 45 (VL06688/CML264) (0.21*), 56 (CML538/CML495) (0.19*) had positive and significant SCA effects for ear per plant (Table 4.17).

Table 4.17 Specific combining ability for grain yield and other agronomic traits of 60 F1 hybrids in Kiboko (drought stress).

Hybrid	Pedigree		GY†	AD	ASI	EA	EPP	SL
#	F	M	tha^{-1}	d	D	1-5	#	%
1	1	1	0.51	-1.62*	2.77**	-0.01	0.15	2.07
2	1	2	-0.25	-0.09	-0.96	0.29	-0.05	2.58
3	1	3	0.11	1.21	-0.51	0.04	-0.05	5.88
4	1	4	0.02	0.91	-0.36	-0.26	-0.03	-5.13
5	1	5	-0.07	-0.44	-0.31	0.26	-0.05	-4.14
6	1	6	-0.45	-0.39	0.84	-0.11	0.06	-1.57
7	2	1	0.00	0.94	-2.06*	0.16	-0.08	-7.13
8	2	2	0.38	0.97	-0.29	-0.54*	0.04	-3.89
9	2	3	0.10	-2.23**	0.16	-0.29	-0.04	-1.02
10	2	4	-0.58	0.47	-0.19	0.41	-0.07	-4.68
11	2	5	0.57	0.12	1.86*	-0.07	0.26**	9.56
12	2	6	-0.43	-0.33	0.51	0.31	-0.11	7.31
13	3	1	-0.03	-0.65	-2.31**	0.00	-0.03	13.62
14	3	2	-0.35	0.39	0.46	0.04	-0.12	12.06
15	3	3	-0.58	0.19	-1.09	0.54*	-0.10	-8.62
16	3	4	0.58	-1.11	2.06*	-0.26	0.15	-9.79
17	3	5	-0.09	1.04	-0.39	0.27	-0.09	6.22
18	3	6	0.52	0.09	1.26	-0.61**	0.19*	-13.34
19	4	1	0.19	0.27	-1.23	-0.21	0.05	14.12
20	4	2	-0.43	-0.19	-0.96	0.33	-0.13	-25.89**
21	4	3	0.24	0.11	1.99*	0.08	0.05	2.32
22	4	4	-0.05	-1.19	-1.86*	-0.22	0.03	9.54
23	4	5	-0.27	0.96	-0.81	0.31	-0.06	-6.49
24	4	6	0.36	0.01	2.84***	-0.32	0.06	6.54
25	5	1	-0.13	0.35	1.02	0.16	0.15	4.96
26	5	2	-0.74	-0.11	0.79	0.46*	-0.17*	-0.67
27	5	3	0.52	-0.31	-0.76	-0.04	0.08	6.71
28	5	4	-0.18	-0.61	0.39	0.16	-0.01	-1.41
29	5	5	0.77	0.54	-2.06*	-0.57**	0.07	-7.77
30	5	6	-0.19	0.09	0.59	-0.19	-0.10	-1.68
31	6	1	-0.36	0.44	-0.48	0.29	-0.16	33.25
32	6	2	0.18	0.47	2.29**	-0.17	0.06	10.62
33	6	3	0.64	-1.73*	0.74	-0.67**	0.14	-25.01**
34	6	4	0.27	-0.03	0.89	-0.22	0.06	4.42

35	6	5	-0.64	0.62	-2.06*	0.31	-0.17*	-8.51
36	6	6	-0.06	0.17	-1.41	0.43*	0.08	-14.62
37	7	1	-0.19	-0.06	-0.64	0.20	-0.07	2.34
38	7	2	-0.06	-0.03	1.13	0.00	0.00	-0.43
39	7	3	0.43	0.77	0.58	0.00	0.14	10.42
40	7	4	0.45	-0.03	0.23	-0.30	0.03	-28.31**
41	7	5	0.58	-1.38	-0.72	-0.53*	0.06	8.20
42	7	6	-1.17*	0.67	-0.57	0.6**	-0.15	7.93
43	8	1	-0.06	0.10	0.69	0.16	0.07	-14.30
44	8	2	0.36	-0.86	-1.54	-0.04	0.13	9.34
45	8	3	0.14	-0.56	0.41	-0.29	0.21*	-2.39
46	8	4	-0.96	0.64	1.56	0.41	-0.29***	4.52
47	8	5	-0.24	-0.21	0.11	-0.07	-0.07	5.17
48	8	6	0.80	0.84	-1.24	-0.19	-0.05	-2.18
49	9	1	0.06	0.52	1.11	-0.38	-0.01	-35.14***
50	9	2	0.39	0.06	0.38	0.17	0.05	-12.03
51	9	3	-0.95*	0.86	-1.17	0.42*	-0.28**	14.37
52	9	4	0.12	0.06	-1.02	-0.13	0.16	17.77*
53	9	5	-0.19	-0.29	1.53	-0.11	0.03	1.91
54	9	6	0.62	-1.24	-0.82	0.02	0.06	13.28
55	10	1	0.44	-0.73	2.44**	-0.55	0.02	-6.10
56	10	2	0.48	-0.69	-1.29	-0.5*	0.19*	6.98
57	10	3	-0.68	1.61	-0.34	0.25	-0.13	-3.99
58	10	4	0.30	0.81	-1.69*	0.45*	-0.04	11.73
59	10	5	-0.46	-1.04	2.86***	0.22	0.00	-5.47
60	10	6	-0.04	0.01	-1.99*	0.10	-0.04	-3.00

Significance levels *** $P < 0.001$, ** $P < 0.01$,* $P < 0.05$

[†] GY, grain yield; AD, days to 50% pollen shed ; ASI, anthesis silking Interval ; EA, ear Aspect ; EPP, ears per plant ; SL, stem lodging

CHAPTER FIVE

DISCUSSION

5.0 Introduction

Understanding the genetics of host plant resistance is an important prerequisite in resistance breeding against diseases. The objectives of this study were to estimate general combining ability (GCA) effects of maize inbred lines and specific combining ability (SCA) effects of hybrids for *Fusarium* ear rot resistance, elucidate the mode of gene action for resistance to *Fusarium* ear rot in tropical maize inbred lines under artificial inoculation with *Fusarium* ear rot and under natural disease pressure, and evaluate the performance of single cross hybrids between mid-altitude adapted and lowland tropical inbred lines. The work was carried out at three locations namely Kakamega, Alupe, and Kibos in western Kenya under both artificial inoculation and natural disease pressure.

5.1 Artificial inoculation with *Fusarium verticillioides*

To build a successful resistance breeding program, there should be genotypic differences for host-plant response to the pathogen, reliable techniques for pathogen isolation and inoculation, and techniques to reliably detect differences among the genotypes. In this study there was significant variation among the hybrids for all traits (Table 4.1) indicating that large genetic variation exists among the hybrids for these traits which should allow good progress from selection under artificial inoculation. Genotypic variation for Fusarium ear rot ratings and severity has been reported in several studies under artificial inoculation (Lunsford *et al*., 1976; Gendloff *et al*., 1986; Robertson *et al*., 2006; Hung and Holland, 2012; Balconi *et al*., 2014). The Fusarium ear rot incidence was higher in the artificially inoculated trials (15%) than under natural condition (6%)

implying that artificial inoculation using the toothpick technique was effective in triggering disease development in the hybrids. F1 hybrid x environment interaction was significant for all traits except ear and plant height in this study. The presence of a highly significant G×E interaction for Fusarium ear rot incidence (FSI) and severity (FSE) suggests the need for the extensive testing of cultivars in several environments over years in order to identify resistant hybrids that can be recommended to farmers.

The male GCA (GCA_m), female GCA (GCA_f), and SCA were highly significant for Fusarium ear rot incidence and grain yield while GCA_f and SCA were significant for Fusarium disease severity suggesting the importance of both additive and non-additive gene effects in the inheritance of Fusarium disease resistance and grain yield under artificial inoculation. These results are consistent with findings reported in studies with Fusarium ear rot in maize (Lunsford *et al*., 1976; Odiemah and Manninger, 1982; Chungu *et al*., 1996b; Nankam and Pataky, 1996; Mukanga *et al*., 2010; Hung and Holland, 2012) and fumonisin accumulation (Williams and Windham, 2009).

The significant SCA reported in this study is contrary to the results of Hart *et al*. (1984) and Lunsford *et al*. (1975) who reported non-significant SCA for Gibberella ear rot. Although both additive and non-additive genetic effects were important, the non-additive effects were slightly more important than additive genetic effects for Fusarium incidence (56% to 44%) and severity (59% to 41%) under artificial inoculation (Table 4.5). This result is consistent with the findings of Hung and Holland (2012) who also reported SCA contributing more than half of variation in hybrids but contrary to the findings of Odiemah and Manninger (1982) who reported greater importance of GCA for Fusarium ear rot. In other studies preponderance of additive gene action over dominance has been reported for Gibberella ear rot (Chungu *et al*., 1996b; Martin *et al*., 2012). The significance of SCA suggests that multiple testers, both inbred line and single-cross may be needed in order to screen for disease resistance (Hung and Holland, 2012). The variation in findings of gene action could be attributed to the different germplasm used in these various studies. The studies of Hung and Holland (2012) and Odiemah and Manninger (1982) utilized temperate maize germplasm as opposed to tropical maize germplasm in this study. For grain yield SCA was more important than GCA (61% to 39%) while the reverse was true for husk cover (31% to 69%) and ear aspect (39% to 61%).

In this study maternal effects appeared to have a bigger role in the inheritance of resistance to Fusarium as evidenced by the larger GCA_f sum of squares compared with GCA_m sums of squares for Fusarium ear rot incidence and severity under artificial inoculation (Table 4.5). The role of maternal and non-maternal effects has been reported in some studies with Fusarium ear rot. The results of this study are consistent with the findings of Lunsford *et al*. (1975, 1976) who reported the importance of maternal effects for Fusarium seedling blight resistance in temperate maize and Mukanga *et al*. (2010) who reported significant maternal effects for ear rot resistance in tropical maize. Headrick and Pataky (1991) reported that factors operating in maternal tissues of kernels could be responsible for resistance to ear rot.

The GCA_m x environment, GCA_f x environment, and SCA x environment were significant for Fusarium disease severity and husk cover, while GCA_f x environment and SCA x environment were significant for Fusarium disease incidence, grain yield, and ear aspect. This indicates that the combining ability of the lines and hybrids were not consistent under the varying environmental conditions at each of the locations used in this study. This suggests that inbred lines and hybrids need to be tested in multiple years under artificial inoculation to obtain reliable inbred lines GCA effects and hybrids SCA effects for *Fusarium verticillioides* resistance. This result corroborates the findings of Mukanga *et al.* (2010) in tropical maize using diallel analysis.

General combining ability (GCA) effects allow the identification of superior parents that could be used to make and select better crosses for direct use or for further breeding (Simmonds, 1979). In disease resistance studies like this one, negative GCA effects are desirable as they indicate contribution of a genotype towards resistance while positive GCA effects indicate a tendency towards susceptibility. Three inbred lines (CKL05003, CKL05019 and CKL05024) showed significant negative GCA effects for Fusarium ear rot incidence at Kakamega and were parents to eight of the best 20 hybrids in terms of low Fusarium ear rot incidence across locations (Table 4.6). Among these inbred lines CKL05003 showed significant negative GCA effects for Fusarium ear rot incidence at a second location (Kibos) and negative but non-significant GCA effects for Fusarium ear rot incidence at Alupe and across locations. This inbred line also showed significant negative GCA effects for Fusarium ear rot severity across locations. This suggests that this inbred line likely possesses some favorable alleles for resistance to Fusarium ear rot. This line could be a good candidate for use in further studies on inheritance of Fusarium ear rot resistance through generation mean analysis for example, and development of mapping populations for Fusarium resistance quantitative trait loci (QTL) verification and/or identification. Such mapping populations could be developed using this inbred line and inbred lines identified as resistant to Fusarium ear rot in Nigeria (Afolabi *et al.*, 2007), and others identified in temperate areas (Henry *et al*., 2009; Santiago *et al*., 2013) or those with resistance to *Fusarium graminearum* (Reid *et al.*, 2001, 2003; Bolduan *et al*., 2009; Butrón *et al*., 2015). This inbred line can also be used to start biparental breeding populations to develop new lines with resistance or tolerance to Fusarium ear rot.

An interesting observation was that two doubled haploid inbred lines (CKL05003/CML444//CKL05003)DH6-B and (CKL05003/CML444//CKL05003)DH5-B) derived from backcross populations with inbred line CKL05003 did not show consistent negative GCA effects at the various locations and across locations. The differences in reaction for these lines could be attributed to varying climatic conditions at the different locations that may not have favored symptom development. Other inbred lines (e.g. CML442, VL06688 and LaPostaSeqC7-F64-2-6-2-2-B-B-B) showing susceptibility to Fusarium ear rot but otherwise good for agronomic traits and other stresses can be used in a recycling program in crosses with inbred lines from the same heterotic group that show increased resistance to Fusarium ear rot.

The SCA effects for Fusarium ear rot incidence and severity varied in magnitude with the majority (40 out of 60) being negative for Fusarium ear rot incidence while half of the hybrids showed negative SCA effects for Fusarium ear rot severity. Only one SCA effect (P7 x P5) was significant and negative for Fusarium ear rot incidence while two SCA effects (P1 x P3 and P3 x P4) were significant and negative for Fusarium ear rot severity. One of the hybrids with negative SCA effects Fusarium ear rot severity had inbred line CKL05003 (P1) which had good GCA effects for Fusarium ear rot incidence and severity as one of the parents. The hybrids showing negative SCA effects for Fusarium ear rot incidence and severity need to be tested further in multiple locations under artificial inoculation coupled with quantification of fumonisin accumulation to confirm resistance or tolerance to Fusarium ear rot. Similar observations were reported by Hung and Holland (2012).

5.2 Natural *Fusarium verticillioides* disease pressure

There was significant variation among the hybrids for all traits (Table 4.4) indicating that there was genetic variation among the hybrids, which suggests that some progress from selection under natural disease pressure inoculation. In terms of selection for Fusarium ear rot resistance, locations with heavy natural inoculum can be used for pre-screening large numbers of genotypes with minimal costs. Genotypic variation under natural inoculum was reported for Fusarium ear rot severity (Afolabi *et al*., 2007), and for Gibberella ear rot rating (Bolduan *et al*., (2009). In other studies no genotypic differences were recorded for Fusarium ear rot incidence and severity (Blandino and Reyneri, 2008) and fumonisin concentration (Cao *et al*., 2013) among hybrids evaluated under natural disease pressure. The Fusarium ear rot incidence was lower in hybrids under natural disease pressure compared with trials under artificial inoculation. This further confirmed that artificial inoculation is the best way to detect genotypic differences for Fusarium ear rot incidence and severity. The F1 hybrid x environment interaction was significant for Fusarium ear rot severity, grain yield, plant height, husk cover, and ear aspect but not significant for Fusarium ear rot incidence and three other agronomic traits under natural disease pressure. The presence of a highly significant G×E interaction for Fusarium ear rot severity suggests the need for wide scale testing of maize hybrids in multiple environments and possibly over seasons in order to identify potentially resistant or tolerant hybrids whose reaction can be confirmed under artificial inoculation.

The male GCA (GCA_m), female GCA (GCA_f), and SCA were highly significant for Fusarium ear rot incidence suggesting the importance of both additive and non-additive gene effects in the inheritance of this trait under natural disease pressure. This result was similar to the observation under artificial inoculation in this study. The SCA, GCA_m x environment, GCA_f x environment, and SCA x environment interaction were significant for grain yield under natural disease pressure. Under natural disease pressure both additive and non-additive genetic effects were important for Fusarium ear rot incidence, the non-additive effects were more important than additive genetic effects (62% to 38%). This result was similar to what was observed for Fusarium ear rot incidence under artificial inoculation in this study and is consistent with the findings of Hung and Holland (2012) also under artificial inoculation. This suggests that under heavy Fusarium infestation conditions like what normally happens at Kakamega due to heavy rainfall and increased humidity, it may be possible to get preliminary information on inheritance of Fusarium ear rot resistance that can be verified under artificial inoculation. For grain yield non-additive gene effects (60%) were more important than additive effects (40%) while the reverse was true for husk cover (24% to 76%) and ear aspect (28% to 72%).

Under natural disease pressure, non-maternal effects appeared to play a slightly bigger role in the inheritance of resistance to Fusarium as evidenced by the larger GCA_m sum of squares compared with GCA_f sums of squares for Fusarium ear rot incidence (Table 4.5). The role of maternal and non-maternal effects has been reported in some studies with Fusarium ear rot. The results of this study are consistent with the findings of Lunsford e*t* *al*. (1975, 1976) reported the importance of maternal effects for Fusarium seedling blight resistance in temperate maize and Mukanga *et al*. (2010) who reported significant maternal effects for ear rot resistance in tropical maize. Headrick and Pataky (1991) reported that factors operating in maternal tissues of kernels could be responsible for resistance to ear rot.

The GCA_m x environment, GCA_f x environment, and SCA x environment were significant for Fusarium disease severity, grain yield, and ear aspect. This indicates that the combining ability of the lines and hybrids were not consistent under the different climatic conditions at each of the locations used in this study. Indeed Kakamega is a high rainfall area as opposed to Alupe and Kibos that receive less rainfall over the course of the season. This suggests that maize germplasm like large numbers of testcross hybrids need to be tested in more locations than the three used in this study to determine the GCA effects of the inbred lines and SCA of hybrids under natural Fusarium ear rot disease pressure.

Under natural Fusarium ear rot disease pressure, two inbred lines (CKL05019 and CKL05024) showed significant negative GCA effects for Fusarium ear rot incidence at Kakamega while CKL05003 had significant negative GCA effects for Fusarium ear rot severity at Kakamega, Kibos, and across locations. The Fusarium ear rot incidence and severity GCA effects of inbred line CKL05003 under natural disease pressure almost mirrored its GCA effects under artificial inoculation save for Fusarium ear rot incidence at Alupe (Tables 4.12 and 4.13). The utility of this inbred line for Fusarium ear rot resistance can be confirmed if it is used to develop a large number of testcrosses that can be evaluated under artificial inoculation. Inbred line VL06688 that showed poor GCA effects (6.71) for Fusarium ear rot incidence under artificial inoculation again exhibited the worst GCA effect (7.93**) for Fusarium ear rot incidence under natural disease pressure. The SCA effects for Fusarium ear rot incidence and severity varied in magnitude with the majority (34 out of 60) being negative for Fusarium ear rot incidence while 33 out of 60 hybrids showed negative SCA effects for Fusarium ear rot severity. Interestingly the hybrid (P7 x P5) that had a significant and negative SCA effect for Fusarium ear rot incidence under artificial inoculation was again the only hybrid with a significant SCA effect under natural disease pressure. This is one of the hybrids that need further testing for use as single cross parent.

5.3 Phenotypic correlation between agronomic traits and Fusarium disease resistance traits

In maize breeding programs, simultaneous selection for a number of traits can result into faster progress in selection and ultimately hybrid development. This can be achieved when the traits of interest are highly and significantly correlated. In this study, the negative and significant correlation(-0.42**) between Fusarium ear rot incidence and grain yield suggests low Fusarium ear rot incidence would result in higher grain yield. The trend was observed in artificially inoculated trials and under natural disease pressure. This relationship is useful in selection for minimum grain loss in hybrids caused by Fusarium ear rots. This result corroborates the findings of Horne *et al.* (2016) under recurrent selection Fusarium ear rot resistance. There was positive and significant correlation between husk cover and Fusarium ear rot incidence under natural disease pressure and a positive but non-significant correlation under artificial inoculation. The implication of this relationship is that poor husk cover (open tips) among maize genotypes would lead to higher Fusarium ear rot incidence. Warfield and Davis (1996) reported that split husks significantly increased Fusarium disease severity in resistant temperate maize hybrids. Tight husk cover has been suggested as an important trait in breeding for ear rot resistance (Farrar and Davis, 1991). In this study there was a significant negative correlation between husk cover and Fusarium ear rot severity under both experimental conditions. This implies that genotypes with tight husk covers had less severe diseased cobs. This result corroborates the finding of Warfield and Davis (1996) that showed the importance of husk cover in temperate maize. There was negative but non-significant correlation between plant height and Fusarium ear rot incidence and severity under artificial inoculation and natural disease pressure. This result is contrary to the report of Robertson-Hoyt *et al*. (2007) who reported a positive but small correlation between Fusarium ear rot and plant height. Robertson-Hoyt *et al.* (2007) attributed the positive correlation between the two traits to a quantitative trait loci (QTL) region that affects both Fusarium ear rot and plant height. A study by Martin *et al*. (2012) did not find a genotypic correlation between plant height and Gibberella ear rot severity.

The foliar diseases northern leaf blight and gray leaf spot (GLS) were negatively correlated with grain yield in trials under both artificial inoculation and natural disease pressure, suggesting that low foliar disease incidence favored increased grain yield. Plant height had a positive correlation with grain yield, but this relationship has a negative consequence in that taller plants will suffer from increased lodging. Indeed there was a positive correlation between plant height and both root and stem lodging.

5.4 Gene effects and combining abilities under Managed drought stress in Kiboko

The significance of male (GCA_m) and female (GCA_f) GCA for grain yield and other agronomic traits suggests that additive gene effects were important for these traits under managed drought stress environment. This result is in agreement with the findings of Betran *et al*. (2003a), Makumbi *et al*. (2011), Badu-Apraku *et al*. (2011), and Mhike *et al.* (2012) who also reported that additive effects were more important for grain yield under managed drought stress conditions. This suggests that both parents need to carry alleles for drought tolerance for hybrids to have the potential to perform well under drought conditions. There was a strong positive correlation between grain yield and ears per plant ($r = 0.73$, $P < 0.001$) under managed drought stress. Higher grain yield is associated with a higher number of ears per plant. This result is consistent with findings of Betrán *et al*. (2003b) under managed stress conditions. The GCA effects for grain yield under managed drought stress varied in magnitude with eight positive and eight negative GCA effects. Three inbred lines (P502c2-185-3-4-2-3-B-2-B*6 (0.62*), La PostaSeqC7-F64-2-6-2-2-B-B-B (0.59**) and CKL05003/CML444//CKL05003)DH5-B (0.65*) had significant positive GCA effects for grain yield. It is interesting to note that two of the lines with significant positive GCA effects for grain yield (P502c2-185-3-4-2-3-B-2-B*6 and La PostaSeqC7-F64-2-6-2-2-B-B-B) are from the lowland maize program in Mexico. Inbred line LaPostaSeqC7-F64-2-6-2-2-B-B-B was identified as a donor for drought and heat tolerance (Cairns *et al*., 2013). Indeed this line should be considered for use in breeding program in eastern Africa. It is also worth noting that inbred line CKL05003 which had the best GCA effects for Fusarium ear rot incidence and severity also had positive GCA effects for grain yield under managed drought, suggesting that this inbred line carries good alleles for both Fusarium ear rot resistance and grain yield and should be considered for inclusion in maize breeding programs in eastern Africa.

5.5 Performance of hybrids in different environments

In this study disease pressure was sufficient to differentiate hybrids in their potential for resistance to Fusarium ear rot resistance and grain yield performance. Re-isolation of *F. verticillioides* on symptomatic kernels after harvesting indicated that indeed it is the same species that was introduced during inoculation following the protocols described by Booth (1977). The field inoculation of the experiments coincided with a favorable climatic condition for *F. verticillioides* growth. The trials under artificial inoculation had higher Fusarium ear rot incidence while under natural disease pressure there was lower Fusarium ear rot disease incidence (Table 4.6). On average, hybrids under artificial inoculation had 59% higher Fusarium ear rot incidence compared with natural disease pressure. This result is consistent with the findings of Bolduan *et al*. (2009) in European maize in which average disease ratings for both Fusarium and Gibberella ear rot under artificial inoculation were 30% higher than under the natural conditions. In this study, hybrids under artificial inoculation had less Fusarium ear rot disease severity than hybrids under natural disease pressure. Contrary to the results in this study, Presello *et al*. (2008) found that hybrids under artificial inoculation had higher Fusarium disease severity compared to the same hybrids under natural disease pressure. The lower severity in trials under artificial inoculation with *Fusarium verticillioides* was also reported by Reid *et al.* (2002) and Clements *et al.* (2004) in experiments with temperate maize.

The significance of the hybrid source of variation indicated that useful variation exists between the hybrids which can be exploited to select for genotypes combining high grain yield and resistance or tolerance to Fusarium ear rot. Inoculation with *Fusarium verticillioides* was effective and resulted in grain yield reduction for the majority of hybrids tested. The average yield reduction was 12.3% for the F1 hybrids and 10.2% among the commercial hybrids. Some few hybrids performed reasonably well in terms of grain yield despite higher disease severity under artificial inoculation conditions (hybrids 35 and 8 with 7.1 and 7.0 tha^{-1}, respectively) and under natural disease pressure conditions (hybrids 26 and 38 with 7.6 and 7.4 tha^{-1}, respectively). It is interesting to note that hybrid 8 (P2 x P2) maintained the same yield level under both artificial inoculation and natural disease pressure. These results are encouraging and these hybrids and others with comparable performance should be tested further in multiple environments over years under artificial inoculation with quantification of fumonisin accumulation so that the proper conclusions on their utility in terms of yield and Fusarium ear rot resistance or tolerance can be made. Presello *et al*. (2008) were also able to identify hybrids that maintained grain yield under both artificial inoculation and natural disease pressure in their study.

Under managed drought stress, the results suggested that there are some hybrids with potential drought tolerance. In this trial, the mean grain yield of the F1 hybrids was 2.4 tha^{-1} with 15 hybrids yielding more than 3 tha^{-1}. The commercial checks averaged 1.8 tha^{-1}. The anthesis silking interval (ASI) in this trial ranged from -1.5 to 7 days, suggesting large differences in synchronization among these hybrids under managed drought stress. Hybrids with shorter ASI had higher grain yield. Studies conducted under managed drought stress have shown that ASI is an important secondary trait for stress tolerance and better grain yield performance (Bolaños and Edmeades, 1996; Betrán *et al*., 2003b).

CHAPTER SIX

CONCLUSION

Selection for fusarium ear rot resistance will be effective in both hybrid and inbred lines as shown by significant additive and non-additive gene effects. Hybrids 16 (P3 X P4), 58 (P10 X P4), 7 (P2 X P1), 59 (P10 X P5) and 22 (P4 X P4) were the best bet hybrids for ear rot resistance. Inbred line CKL05003 emerged as the best bet for fusarium ear rot resistance breeding.

RECOMMENDATION

1. Hybrids identified should be tested further to confirm the low Fusarium ear rot incidence and severity
2. Mycotoxin accumulation on grains should be studied before the hybrids are used as parents in three way cross hybrids programs
3. The isolate of *Fusarium verticillioides* commonly found in Western Kenya should be race typed to enable race specific breeding for the pathogen

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APPENDICES

Appendix 1: Analysis of variance for grain yield, agronomic traits, and fusarium disease parameters at Kibos under artificial inoculation.

SOV	DF	GY†	AD	PH	EH	RL	EPP	HC	EA	FSE	FSI
		t/ha^{-1}	d	cm	cm	%	#	%	1-5	%	%
Entries	63	4.78***	9.55	351.67***	229.71**	457.83***	0.02***	540.82***	0.26***	302.60	26.54*
F1 hybrids	59	4.88***	9.49***	360.30***	104.6***	225.39***	0.02***	569.79***	0.21**	261.11	266.44*
Rep	1	62.42***	7.50**	187.50 ns	1203.33**	331.67 ns	0.01 ns	1.47 ns	0.17 ns	71.38 ns	7410.57***
Male (GCA$_m$)	5	11.69***	81.82***	1998.50***	651.00***	465.82*	0.03**	2847.7***	0.46**	371.24 ns	443.78*
Female (GCA$_f$)	9	6.50**	9.35***	445.28**	375.93**	1405.95***	0.03**	900.56***	0.53***	604.28 *	308.00 ns
Male*Female (SCA)	45	3.79**	1.49*	161.28 ns	147.48 ns	226.88 ns	0.02**	249.92***	0.12 ns	180.24 ns	238.42 ns
Error	63	1.76	0.86	128.37	107.74	168.06	0.01	61.84	0.09	282.14	16.76

Significance levels ***= $P < 0.001$, **= $P < 0.01$, *= $P < 0.05$

GY, grain yield, AD, days to 50% pollen shed ,PH, plant height EH, ear height , RL, root lodging, EPP-,ears per plant, HC, husk cover, EA, ear aspect, FSI, Fusarium incidence, FSE, Fusarium severity

Appendix 2: Analysis of variance for grain yield, agronomic traits, and fusarium disease parameters at Kibos under natural disease pressure.

SOV	DF	GY†	AD	ASI	PH	EH	RL	EPP	HC	EA	FSE	FSI
		t/ha-1	d	d	cm	cm	%	#	%	5-Jan	%	%
Entries	63	5.29***	9.50***	2.17***	299.55**	280.11***	525.24***	0.02*	927.63***	0.55***	715.83	6.89**
Rep	1	1.54ns	0.41ns	0.13ns	1.88ns	163.33ns	107.11ns	0.03ns	676.63*	0.60*	45.17ns	302.13*
F1 Hybrids	59	5.37***	9.33***	2.24***	285.80**	264.19***	155.67***	0.023*	965.41***	0.52***	715.11ns	107.87**
Male (GCA$_m$)	5	13.73***	73.95***	5.89***	737.21***	870***	1150.83***	0.04*	5214.02***	1.44***	1421.92*	567.34***
Female (GCA$_f$)	9	5.83***	10.13***	7.78***	502.52**	283.8**	1438.89***	0.06***	1505.44***	1.54***	1034.58ns	105.92ns
Male*Female (SCA)	45	4.34***	1.98ns	0.72ns	192.30ns	192.96**	221.70ns	0.01ns	385.34**	0.22**	572.69ns	57.21ns
Error	63	1.30	1.64	0.64	148.40	95.62	153.44	0.01	173.99	0.11	667.44	3.55

Significance levels ***= $p< 0.001$, **= $p< 0.01$,*= $p< 0.05$

ns, not significant † GY, grain yield; AD, days to 50% pollen shed ; ASI, Anthesis Silking Interval; PH, plant height; EH, ear height ; RL, root lodging; EPP, ears per plant; HC, husk cover ; EA, ear Aspect; FSE, Fusarium severity; FSI, Fusarium incidence.

Appendix 3: Analysis of variance for grain yield, agronomic traits, and fusarium disease parameters at Alupe under artificial inoculation.

SOV	DF	GY†	AD	ASI	PH	EH	EPP	HC	EA	FSE	FSI
		tha^{-1}	d	d	cm	cm	#	%	1-5	%	%
ENTRIES	63	3.58***	9.29***	2.32***	125.84**	230.57*	0.03*	356.06***	0.18**	871.52 ns	14.93*
F1 HYBRIDS	59	3.55***	8.73***	2.27***	254.1**	204.85*	0.02**	363.88***	0.17**	912.81 ns	282.15ns
REP	1	0.58ns	4.88*	0.78ns	984.57**	876.75*	0.11*	7.42ns	0.44*	725.94ns	14.93*
Male	5	1.64 ns	71.29***	3.65ns	471.37**	753.83***	0.03 ns	1458.08***	0.44***	2146.56*	402.65 ns
Female	9	4.62***	11.05***	7.58ns	822.43***	292.96*	0.03**	787.37***	0.37***	792.23 ns	268.15 ns
Male*Female	45	3.56***	1.33 ns	1.064 ns	116.37ns	126.24 ns	0.03*	157.61***	0.11ns	799.84	271.56 ns
Error	63	0.94	1.15	0.43	125.84	132.31	0.02	56.39	0.09	689.73	9.21

Significance levels ***= $p< 0.001$, **= $p< 0.01$,*= $p< 0.05$ ns, not significant † GY, grain yield; AD, days to 50% pollen shed ; ASI, Anthesis Silking Interval; PH, plant height; EH, ear height ; RL, root lodging; EPP, ears per plant; HC, husk cover ; EA, ear Aspect; FSE, Fusarium severity; FSI, Fusarium incidence.

***Appendix 4*: Analysis of variance for grain yield, agronomic traits, and fusarium disease parameters at Alupe under natural disease pressure.**

SOV	DF	GY†	AD	ASI	PH	EH	RL	EPP	HC	EA	FSE	FSI
		t/ha	d	d	cm	cm	%	#	%	1-5	%	%
Entries	63	1.93ns	6.54***	1.24**	215.48***	247.46**	22.64*	0.01ns	414.52***	0.18*	1128.35ns	3.46***
F1 Hybrids	59	1.85***	6.33***	1.30***	221.39***	217.6**	19.86*	0.014ns	437.43***	0.18**	1119.80ns	18.72ns
REP	1	4.47*	6.13*	0.63ns	12.50ns	56.44ns	0.09ns	0.01ns	80.85ns	1.03**	2388.44ns	0.50ns
Male (GCA$_m$)	5	2.76*	48.22***	1.06ns	625.50***	964.50***	22.30ns	0.03*	2536.84 ***	0.42**	2883.70*	11.53ns
Female (GCA$_f$)	9	3.27***	8.36***	4.61***	343.98***	292.69**	24.77ns	0.02ns	773.52***	0.30**	828.97ns	35.94*
Male*Female (SCA)	45	1.48*	1.28ns	0.66ns	151.98**	119.69ns	18.62ns	0.01ns	136.95**	0.13ns	981.96ns	16.08ns
Error	63	0.92	1.46	0.63	67.66	124.70	14.89	0.01	74.38	0.11	1095.13	1.26

Significance levels ***= *p*< 0.001, **= *p*<0.01,*= *p*<0.05, ns, not significant

†GY, grain yield; AD, days to 50% pollen shed ; ASI, Anthesis Silking Interval; PH, plant height; EH, ear height ; RL, root lodging; EPP, ears per plant; HC, husk Cover; EA, ear Aspect ; FSE, Fusarium severity ; FSI, Fusarium incidence

***Appendix 5*: Analysis of variance for grain yield, agronomic traits, and fusarium disease parameters at Kakamega under artificial inoculation**.

SOV	DF	GY†	AD	ASI	PH	EH	EPP	HC	EA	FSE	FSI
		t/ha	d	d	cm	cm	#	%	5-Jan	%	%
Entries	63	3.05ns	3.77ns	1.6ns	368.70ns	166.22ns	0.04ns	400.30ns	0.28ns	584.03ns	39.38***
F1Hybrids	59	3.18ns	3.86ns	1.63ns	335.90ns	150.97ns	0.037*	399.50ns	0.29ns	610.63ns	614.39***
REP	1	0.16ns	0.08ns	0.01ns	210.67ns	175.20ns	0.37***	0.11ns	0.01ns	700.10ns	3.32ns
Male (GCA$_m$)	5	1.18ns	5.02ns	4.21ns	98.91ns	86.21ns	0.06ns	533.40ns	0.37ns	2241.19**	334.51*
Female (GCA$_f$)	9	3.37ns	4.01ns	0.84ns	587.90ns	224.19ns	0.07*	524.20ns	0.24ns	592.55ns	1872.18***
Male*Female (SCA)	45	3.37ns	3.70ns	1.51ns	311.80ns	143.52ns	0.03ns	359.70ns	0.29ns	433.08	393.94***
Error	63	2.41	3.53	1.86	421.8	175.76	0.03	316.2	0.21	484.56	11.93

Significance levels *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ †GY, grain yield; AD, days to 50% pollen shed ; PH, plant height; EH, ear height; EPP, ear per plant; HC, husk Cover; EA, Ear Aspect; FSE, Fusarium severity; FSI, Fusarium incidence.

Appendix 6: Analysis of variance for grain yield, agronomic traits, and fusarium disease parameters at Kakamega under natural disease pressure.

SOV	DF	GY	AD	ASI	PH	EH	EPP	HC	EA	FSE	FSI
		t/ha	d	d	cm	cm	#	%	5-Jan	%	%
Entries	63	3.75***	4.99***	0.47ns	603.37***	242.53*	0.05ns	156.29	0.39***	406.76	29.53***
F1 Hybrids	59	3.90***	4.89***	0.49ns	602.89***	236.93**	0.05ns	163.14	0.36***	356.28***	423.24ns
REP	1	18.59***	49.40***	0.00ns	1.87ns	7.50ns	0.17*	5.69**	0.20ns	1075.80ns	13.85ns
Male (GCA$_m$)	5	20.16***	17.89***	0.29ns	2658.38***	677.33***	0.05ns	728.22***	0.52***	1416.10*	346.98*
Female (GCA$_f$)	9	5.81***	9.89***	0.22ns	784.47***	219.44*	0.11*	182.05ns	1.29***	427.85ns	919.42***
Male*Female (SCA)	45	1.71ns	2.45ns	0.56ns	338.19**	191.5*	0.05ns	96.57ns	0.17*	312.01	244.69**
Error	63	1.08	1.95	0.51	160.40	117.33	0.04	119.19	0.09	442.94	10.00

Significance levels ***= $p < 0.001$, **= $p < 0.01$,*= $p < 0.05$ ns, not significant †GY, grain yield; AD, days to 50% pollen shed ; ASI, Anthesis Silking Interval; PH, plant height; EH, ear height ; EPP, ears per plant; HC, Husk cover; EA, Ear Aspect; FSE, Fusarium severity; FSI, Fusarium incidence

Appendix7.Table of means for grain yield, agronomic traits, and fusarium disease parameters across trials under artificial inoculation.

		GY†	RGY	AD	ASI	HC	EA	EH	EPP	MOI	GLS	ET	PA	PH	RL	FSI	FSE	FWR
Entries	cross	t ha^{-1}	%	d	d	%	1-5	cm	#	%	1-5	1-5	1-5	cm	%	%	%	t ha^{-1}
25	5x1	7.8	140.1	67	1.7	37.3	2.7	119.8	1.0	17.1	4.2	2.0	2.3	232.4	19.5	9.6	39.6	0.5
22	4x4	7.6	136.4	63	1.8	6.8	2.9	114.3	1.0	17.4	4.7	1.8	2.3	242.0	8.9	7.8	54.4	0.4
35	6x5	7.1	128.3	65	0.8	10.4	2.8	130.3	1.0	16.8	6.3	2.3	2.9	263.8	11.3	16.0	43.1	1.1
58	10x4	7.1	127.5	61	0.7	0.2	2.7	109.8	1.0	16.9	5.6	2.2	2.1	231.7	4.9	5.3	53.1	0.6
8	2x2	7.0	127.0	63	0.2	0.7	2.7	111.8	1.0	13.2	2.9	1.6	2.2	245.9	12.0	15.1	44.0	1.3
26	5x2	6.9	123.9	65	0.7	7.1	3.1	111.3	1.0	17.2	3.5	1.7	2.2	241.9	13.0	12.8	47.5	0.7
11	2x5	6.8	122.8	66	-0.5	19.2	2.6	121.0	0.9	15.4	3.6	2.1	2.6	251.3	13.7	10.2	22.3	1.2
27	5x3	6.6	118.9	66	0.3	11.0	2.9	105.3	1.0	14.3	5.4	1.7	1.9	236.4	14.5	7.7	52.6	0.5
59	10x5	6.5	117.5	65	0.3	13.2	3.0	108.9	0.9	15.7	1.3	2.7	2.2	241.5	8.4	5.6	50.6	0.3
3	1x3	6.4	116.0	66	0.5	1.3	2.7	107.9	1.0	15.1	2.5	1.7	2.3	251.7	10.2	12.0	32.9	0.7
17	3x5	6.4	115.3	66	0.7	14.3	3.0	114.9	0.9	16.6	6.5	1.7	2.2	231.8	6.4	8.3	36.7	0.6
20	4x2	6.3	114.0	66	1.2	5.4	2.9	105.4	1.0	17.4	2.0	1.6	2.3	244.2	8.0	13.0	49.8	0.8
16	3x4	6.3	113.7	61	3.3	4.3	2.7	102.4	1.0	15.9	1.2	1.8	2.2	228.9	4.5	4.6	33.5	0.4
47	8x5	6.3	113.5	63	-1.3	52.1	3.2	116.0	1.1	15.7	1.2	1.7	2.3	239.8	3.5	11.1	45.3	0.5
9	2x3	6.3	113.0	65	0.2	0.0	2.6	109.1	0.9	16.5	4.0	2.2	2.5	251.7	12.8	9.4	54.9	0.5
23	4x5	6.2	112.5	66	1.3	58.8	2.9	123.0	0.9	15.9	4.2	2.1	2.4	249.7	9.0	16.1	26.7	1.0
13	3x1	6.1	110.9	64	1.5	28.4	2.9	98.9	1.0	15.7	6.7	2.0	2.0	218.7	9.6	13.5	33.8	1.0
7	2x1	6.1	110.9	65	0.5	2.9	2.7	118.4	1.0	14.9	4.3	2.1	2.4	240.2	24.8	5.6	36.9	0.3
50	9x2	6.1	110.0	64	0.2	3.5	2.9	103.8	0.9	16.4	6.1	1.8	2.4	232.7	7.4	12.8	52.1	0.9
39	7x3	6.1	109.6	66	0.2	2.6	3.4	108.0	1.0	14.4	5.0	2.2	2.4	241.2	7.8	17.6	51.2	1.0
10	2x4	5.9	106.1	62	1.7	1.1	2.4	108.9	0.9	15.7	1.2	1.9	2.5	231.1	14.1	7.0	34.5	0.9
63	WH505	5.8	105.3	66	-0.5	9.7	3.1	129.4	1.0	16.1	1.7	1.8	2.8	258.7	12.6	19.0	40.1	1.1

40	7x4	5.8	105.2	62	2.2	0.6	3.2	105.4	0.9	14.7	2.0	2.0	3.0	220.1	11.2	9.6	54.7	0.5
56	10x2	5.8	104.1	64	-0.5	3.2	3.1	109.1	0.9	16.2	3.5	2.2	1.9	235.7	2.0	11.1	42.6	0.8
44	8x2	5.8	103.9	63	-0.3	1.6	3.1	99.9	1.0	16.5	3.3	1.7	2.1	234.0	4.1	14.1	56.1	1.1
2	1x2	5.8	103.9	64	0.3	1.1	3.2	103.5	1.0	16.3	4.5	1.7	2.0	236.2	17.2	14.6	31.7	1.1
4	1x4	5.7	102.7	63	1.5	2.5	2.7	111.5	0.9	16.1	6.7	1.8	2.5	231.2	9.1	9.1	28.1	0.7
21	4x3	5.7	102.4	66	1.3	21.7	2.9	107.6	1.0	15.8	3.4	1.9	2.3	243.7	8.5	16.1	44.9	1.0
46	8x4	5.6	101.5	60	0.3	1.7	2.9	109.3	0.9	16.0	6.2	1.6	2.0	221.9	1.7	24.8	46.9	1.0
28	5x4	5.6	100.9	63	1.3	15.1	2.9	105.8	1.1	14.3	2.9	1.8	2.4	227.2	11.2	14.4	42.4	0.6
52	9x4	5.6	100.9	61	-0.2	4.8	3.1	94.7	1.0	16.6	2.4	1.7	2.5	214.1	4.8	6.7	30.9	0.4
34	6x4	5.5	100.0	60	2.5	4.0	2.7	104.6	0.9	16.5	6.7	2.1	2.4	232.1	6.3	18.4	40.3	1.1
55	10x1	5.5	99.7	66	0.0	12.2	2.7	100.3	1.0	16.8	3.4	2.9	2.4	228.6	6.3	11.5	44.6	0.8
30	5x6	5.5	99.5	63	0.8	20.8	3.0	110.6	1.2	15.4	4.5	1.8	2.5	214.4	14.3	11.8	26.2	0.9
5	1x5	5.5	98.8	67	0.3	27.8	2.9	129.8	1.0	17.7	6.6	2.0	3.0	259.4	19.0	16.1	16.5	1.6
41	7x5	5.4	98.3	66	0.5	19.2	3.1	109.5	0.9	15.7	1.4	2.4	2.4	235.2	11.4	6.6	21.1	0.8
51	9x3	5.4	97.7	65	0.3	16.0	3.2	97.7	0.9	14.6	5.0	1.8	2.8	232.9	7.7	22.9	37.8	1.3
14	3x2	5.4	97.4	64	1.8	2.1	3.2	100.5	1.0	16.6	6.1	1.5	2.1	238.1	2.4	12.2	58.4	0.6
60	10x6	5.4	97.2	63	-0.5	1.1	3.1	110.6	0.9	14.1	3.5	2.4	2.6	226.2	5.7	11.0	48.5	0.6
31	6x1	5.3	96.0	65	1.3	27.8	3.1	115.5	1.0	17.0	2.9	2.3	2.5	243.1	7.5	23.1	27.0	1.0
48	8x6	5.3	94.9	61	-0.3	28.4	3.0	109.0	1.1	15.8	5.3	1.7	2.4	224.2	3.8	19.6	33.6	1.0
32	6x2	5.2	94.3	63	2.3	2.5	3.3	109.1	0.9	17.7	1.2	1.9	2.1	235.7	4.3	17.0	35.9	1.2
57	10x3	5.2	93.6	66	-0.3	0.4	2.7	108.4	0.9	14.7	3.6	2.6	2.1	242.9	10.5	5.7	56.0	0.5
37	7x1	5.2	93.1	65	0.8	47.2	3.6	110.1	0.9	16.3	8.4	2.2	2.7	234.3	14.6	13.4	38.0	1.1
53	9x5	5.0	90.7	65	-0.8	21.5	2.9	116.0	0.9	15.2	4.0	1.7	2.7	250.4	18.6	17.4	22.8	1.5
19	4x1	5.0	90.6	67	1.3	39.5	2.9	110.0	0.9	17.4	3.9	2.0	2.2	234.2	10.3	13.7	37.7	0.7
12	2x6	5.0	90.4	62	0.8	7.2	2.8	100.0	0.8	15.6	6.5	2.0	2.5	224.6	20.0	57.8	43.6	1.0
18	3x6	5.0	90.1	64	1.7	4.0	3.3	108.0	0.9	15.5	2.9	1.7	2.4	218.6	4.2	13.9	44.1	0.7
15	3x3	4.9	87.7	65	2.0	2.0	2.9	90.7	0.9	15.4	4.1	1.8	2.1	228.0	6.4	16.9	56.7	1.0
62	WH507	4.8	87.2	67	0.7	7.5	3.1	118.9	1.0	15.5	3.7	1.9	2.4	237.2	15.6	11.4	55.1	0.9
38	7x2	4.8	87.1	63	1.3	2.7	3.3	92.9	0.9	18.2	6.5	1.9	2.2	242.2	10.3	32.6	41.6	1.9
24	4x6	4.8	86.7	65	0.8	51.0	2.8	116.7	1.0	15.7	3.4	2.1	2.5	233.7	3.1	21.9	41.5	1.2
1	1x1	4.7	85.4	68	1.5	35.5	3.0	121.4	1.1	15.1	5.9	1.9	2.3	239.0	6.2	15.1	33.2	1.0

29	5x5	4.7	84.5	66	0.8	46.9	2.9	120.8	1.0	14.7	2.1	2.1	2.9	251.4	17.3	14.7	31.4	2.2
36	6x6	4.6	83.3	62	1.8	7.7	3.0	123.0	1.0	16.6	3.5	2.1	2.9	238.2	10.3	20.1	57.7	1.3
64	H513	4.6	82.3	64	0.5	9.0	3.2	124.2	1.0	14.8	6.3	2.1	3.0	229.0	27.9	23.2	40.5	1.0
54	9x6	4.4	79.2	62	0.7	16.4	3.1	102.8	0.9	15.4	6.8	1.7	3.2	218.0	19.5	24.1	41.5	1.2
33	6x3	4.3	77.7	65	0.8	13.4	3.3	109.4	1.2	15.1	6.2	2.0	2.1	251.0	5.3	15.7	35.8	0.6
6	1x6	4.3	77.1	64	1.3	21.9	3.1	107.8	1.2	15.5	4.8	2.0	2.2	234.9	13.5	5.8	27.5	1.1
61	DK8031	3.9	71.2	61	2.0	24.5	4.0	107.4	0.9	14.9	3.0	1.8	3.1	221.6	6.2	32.0	38.5	1.4
45	8x3	3.9	70.9	65	-0.7	17.9	3.2	103.4	1.2	14.7	1.8	2.2	2.1	238.0	16.2	9.4	56.9	0.7
49	9x1	3.8	68.5	65	1.3	25.1	3.1	103.2	1.0	15.6	6.6	1.8	2.8	219.6	8.6	18.5	27.4	1.2
42	7x6	3.6	65.1	63	1.2	20.8	3.7	102.4	0.9	15.3	1.8	2.2	3.0	210.9	10.6	22.6	44.6	1.0
43	8x1	3.6	65.0	64	-0.2	50.6	3.3	118.1	1.0	17.3	6.7	1.8	2.2	232.0	2.6	21.9	28.5	0.9
Mean	-	5.5	100.0	64	0.8	15.3	3.0	110.0	1.0	15.9	4.2	2.0	2.4	235.5	10.2	15.0	40.7	0.9
LSD		2.23		1.54	1.60	16.77	0.53	11.98	0.18	2.27	5.10	0.59	0.75	16.26	15.26	22.43	23.87	1.17
CV		3.10		10.74	0.54	0.81	5.81	8.07	5.91	8.34	1.09	3.30	4.95	13.55	0.63	0.72	1.86	0.86
SEM		0.64		0.31	0.33	36.14	0.04	18.46	0.00	0.66	3.32	0.05	0.07	33.98	29.92	64.64	73.04	0.18
SED		1.13		0.78	0.81	8.50	0.27	6.08	0.09	1.15	2.57	0.30	0.38	8.24	7.74	11.37	12.09	0.59
Min		3.6	65.0	60	-1.3	0.0	2.4	90.7	0.8	13.2	1.2	1.5	1.9	210.9	1.7	4.6	16.5	0.3
Max		7.8	140.1	68	3.3	58.8	4.0	130.3	1.2	18.2	8.4	2.9	3.2	263.8	27.9	57.8	58.4	2.2

†GY-,grain yield; RGY, relative grain yield; AD-,days to 50% pollen shed ; ASI, Anthesis Silking Interval; HC, husk Cover ; EA, ear Aspect ; EH, ear height; EPP, ears per plant; MOI, grain moisture; GLS, grey leaf spot; ET , *exserohilum turcicum*; PA, plant aspect; PH, plant height; RL, root lodging; FSI, Fusarium incidence; FSE, Fusarium severity ; FWR, field weight rotten ears

Appendix 8: **Table of mean for grain yield, agronomic traits, and fusarium disease parameters across trials under natural disease pressure.**

ENTRY	cross	GY†	RGY	AD	ASI	HC	EA	EH	EPO	EPP	ET	PA	PH	RL	SL	FSI	FSE	FWR
#		t/ha	%	d	d	%	1-5	cm	0-1	#	1-5	1-5	cm	%	%	%	%	t/ha
58	10x4	7.9	130.9	62	0.2	0.1	2.3	104.4	0.5	1.0	2.0	2.1	229.4	6.9	4.9	1.7	50.7	0.3
5	1x5	7.8	129.8	66	0.3	35.0	2.6	138.1	0.5	0.9	2.3	2.6	255.8	29.3	32.1	3.5	28.6	0.1
26	5x2	7.6	126.8	64	0.3	6.0	2.6	105.7	0.4	1.0	1.8	1.9	237.6	24.8	4.4	4.8	44.6	1.0
38	7x2	7.4	123.5	64	0.7	0.7	3.1	98.3	0.4	1.0	2.0	2.3	234.0	18.8	5.7	10.1	35.5	0.8
47	8x5	7.4	122.5	65	-0.3	30.2	2.9	109.4	0.5	1.2	1.8	2.1	230.9	8.3	11.2	4.8	29.1	0.0
4	1x4	7.3	121.0	64	1.0	1.7	2.5	114.9	0.5	0.9	2.3	2.4	236.2	18.4	15.3	3.4	32.9	0.8
36	6x6	7.2	120.6	61	1.2	11.4	2.4	112.5	0.5	1.1	2.0	2.3	228.8	5.8	4.8	7.0	65.4	0.3
2	1x2	7.2	120.5	65	0.5	0.2	2.7	104.2	0.4	1.0	2.2	1.8	239.2	20.9	7.9	4.1	38.3	0.4
17	3x5	7.2	120.4	66	1.2	6.1	3.0	116.6	0.5	1.0	1.7	2.4	240.5	5.9	6.2	6.4	45.0	0.6
13	3x1	7.2	119.6	65	1.2	32.4	2.8	108.6	0.5	1.0	1.7	2.5	227.0	26.7	0.7	9.6	51.8	0.1
53	9x5	7.1	118.0	65	0.0	18.1	2.6	116.3	0.5	1.0	2.2	2.5	242.9	25.1	26.3	4.5	64.9	0.5
25	5x1	7.1	117.8	66	1.2	28.9	2.8	113.8	0.5	1.0	1.8	2.3	234.5	25.6	9.2	7.6	37.7	1.6
8	2x2	7.0	117.1	64	0.3	1.0	2.2	107.3	0.5	1.0	1.5	2.0	235.9	27.8	2.8	1.3	49.5	0.9
44	8x2	6.9	114.7	63	0.2	3.1	2.6	96.6	0.4	1.1	1.8	1.8	228.0	5.6	1.6	7.5	53.3	1.0
20	4x2	6.8	112.6	65	0.2	9.1	2.8	105.2	0.4	1.0	1.8	1.9	241.2	20.7	1.3	4.3	44.4	0.4
22	4x4	6.7	112.3	63	1.7	3.4	2.5	113.8	0.5	1.0	2.2	2.1	231.2	13.6	9.8	2.3	53.1	0.3
3	1x3	6.6	110.4	66	0.7	0.7	2.6	110.0	0.5	0.9	2.2	1.9	243.4	17.1	9.0	1.3	72.9	0.1
35	6x5	6.6	109.2	65	1.3	12.0	2.4	142.4	0.5	1.0	2.1	2.8	277.4	13.6	7.9	1.7	33.1	0.1
50	9x2	6.5	108.8	63	0.8	0.7	2.8	102.7	0.4	1.0	2.0	2.4	230.8	6.8	1.3	5.8	54.3	0.9
51	9x3	6.5	108.3	65	0.5	19.2	3.1	102.6	0.4	1.0	2.1	2.4	231.6	30.7	6.3	3.1	44.2	0.2
23	4x5	6.5	107.7	65	0.7	38.4	2.8	124.5	0.5	1.1	2.2	2.8	250.4	25.1	21.0	10.3	31.8	0.1
9	2x3	6.4	106.7	65	-0.3	2.6	2.4	119.1	0.5	1.0	2.3	2.6	249.5	18.9	7.2	4.5	51.2	0.4
16	3x4	6.4	105.8	62	2.3	3.8	2.5	105.7	0.5	1.0	2.0	2.8	233.1	7.6	1.3	1.6	45.2	0.3

27	5x3	6.3	105.5	66	1.0	17.4	2.9	101.6	0.4	1.1	1.9	2.3	230.8	23.1	16.9	9.2	66.1	0.4
56	10x2	6.3	104.9	63	0.2	0.3	2.9	93.8	0.4	1.0	1.9	1.9	230.6	7.1	3.5	4.5	62.7	0.6
29	5x5	6.3	104.8	66	0.5	52.3	2.8	119.7	0.5	1.1	2.3	2.8	240.9	17.0	18.7	5.3	49.1	0.5
21	4x3	6.2	102.9	67	1.2	19.5	2.9	107.9	0.4	1.0	2.1	2.4	242.9	22.1	5.1	4.0	58.8	0.1
12	2x6	6.1	101.6	63	1.0	11.8	2.4	96.5	0.5	1.1	1.9	2.3	205.8	25.4	1.7	2.5	46.0	0.3
60	10x6	6.1	100.9	62	0.3	7.8	3.0	112.3	0.5	1.0	1.8	2.3	223.3	9.0	7.3	5.9	54.7	1.0
41	7x5	6.0	100.6	65	0.3	27.1	3.1	112.2	0.5	1.0	2.4	2.1	231.4	10.5	13.0	5.7	38.1	0.2
32	6x2	6.0	100.3	63	1.5	3.9	2.6	109.3	0.4	1.0	1.8	1.9	248.8	5.6	0.1	2.9	56.6	1.0
59	10x5	6.0	99.5	65	-0.2	6.4	2.7	110.5	0.5	0.9	2.5	2.6	238.5	7.1	9.0	2.9	42.7	0.3
30	5x6	6.0	99.4	63	1.2	26.4	3.1	112.2	0.5	1.1	2.1	2.8	216.4	18.5	13.1	6.0	31.1	0.5
31	6x1	6.0	99.1	65	0.8	20.1	2.7	112.7	0.5	1.0	2.0	2.5	241.3	21.2	7.6	7.6	27.4	0.3
52	9x4	6.0	99.0	61	0.7	0.9	2.4	98.0	0.5	1.0	2.3	2.9	215.3	5.4	10.3	1.0	42.7	0.1
10	2x4	5.9	99.0	62	1.0	2.6	2.1	119.2	0.5	0.9	1.9	2.6	245.5	21.4	9.6	2.0	30.6	0.7
11	2x5	5.9	98.7	66	-0.2	18.0	2.6	114.9	0.5	1.1	1.7	2.9	250.8	22.4	7.7	6.2	37.1	0.4
28	5x4	5.9	98.4	63	1.0	15.8	2.6	112.3	0.5	1.0	2.3	2.4	226.9	10.7	14.0	10.8	37.6	0.8
34	6x4	5.9	97.8	62	2.0	7.8	2.8	106.8	0.5	1.0	2.0	2.3	229.2	14.4	5.6	6.3	50.3	0.3
48	8x6	5.8	96.6	61	0.2	24.3	2.8	118.5	0.5	1.2	1.9	2.1	240.0	8.8	6.1	5.5	51.9	0.6
46	8x4	5.8	96.4	61	0.3	1.3	2.8	104.0	0.5	1.0	1.9	2.1	228.1	4.1	0.5	6.5	59.4	1.1
39	7x3	5.7	94.8	65	1.0	3.2	3.3	114.1	0.5	1.0	2.5	2.6	240.7	8.5	1.0	12.4	62.0	1.0
7	2x1	5.7	94.5	65	0.2	4.5	2.5	110.2	0.5	0.9	1.9	2.6	236.4	27.9	8.9	6.0	47.9	0.5
15	3x3	5.6	93.6	65	1.5	8.1	2.9	100.2	0.4	1.0	2.0	2.4	232.1	4.8	0.1	7.6	49.8	0.5
14	3x2	5.6	92.4	64	1.8	0.5	3.0	101.5	0.4	0.9	1.6	2.1	229.5	11.3	0.1	2.7	51.7	0.0
63	WH505	5.5	92.2	66	0.8	5.4	3.0	117.2	0.5	1.0	2.1	2.8	238.9	14.3	6.3	12.0	57.4	0.7
40	7x4	5.5	91.7	62	1.2	2.2	3.1	105.5	0.5	1.0	2.0	2.6	223.5	9.9	2.6	4.7	71.7	0.6
49	9x1	5.4	90.0	64	0.8	24.9	2.8	96.4	0.5	1.0	2.2	2.6	212.0	19.2	8.1	6.3	34.8	0.2
19	4x1	5.4	89.9	67	1.3	47.4	2.8	107.9	0.5	1.1	1.7	2.6	230.3	25.0	5.2	13.6	47.5	0.3
62	WH507	5.2	87.0	66	0.2	5.1	2.7	107.4	0.5	1.0	2.0	2.9	232.9	24.7	12.4	5.1	68.6	1.2
6	1x6	5.2	86.4	64	1.0	10.0	2.8	110.3	0.5	1.0	1.9	2.4	226.9	19.6	5.5	0.8	43.3	0.0
55	10x1	5.1	85.2	66	0.2	13.7	3.1	106.0	0.5	1.1	2.3	3.1	232.2	7.1	6.5	8.1	51.8	0.4
54	9x6	5.0	83.0	62	0.3	25.9	3.3	115.7	0.5	0.9	2.0	3.0	226.2	23.0	12.7	8.4	54.6	0.8
18	3x6	4.9	82.1	64	1.0	2.5	3.1	104.6	0.5	1.0	1.7	2.5	228.3	7.5	6.3	1.6	67.9	0.3

37	7x1	4.9	81.1	66	0.8	24.8	3.3	113.8	0.5	1.0	2.1	3.0	228.7	26.5	12.4	12.5	38.6	0.5
64	H513	4.8	80.4	63	1.3	11.9	3.1	134.3	0.5	1.0	2.3	2.9	252.3	39.5	5.2	6.4	42.5	0.6
61	DK8031	4.8	80.3	62	1.0	20.8	3.6	103.3	0.5	1.0	1.8	3.0	223.4	10.1	3.0	25.4	52.4	0.6
57	10x3	4.8	79.5	66	-0.2	2.5	2.9	96.3	0.4	1.0	2.5	2.5	232.9	10.6	0.5	2.5	56.7	0.2
24	4x6	4.6	77.3	66	1.2	36.8	3.1	122.8	0.5	1.1	2.3	2.8	232.2	12.1	15.9	7.4	59.5	0.3
1	1x1	4.6	77.2	67	0.7	40.2	2.8	119.7	0.5	1.1	2.0	2.8	240.4	24.9	11.8	6.9	23.1	0.8
33	6x3	4.2	69.4	66	0.0	4.7	2.8	107.5	0.4	1.3	2.2	2.4	252.8	9.0	4.0	4.0	35.2	0.1
42	7x6	4.1	68.8	63	0.8	25.6	3.8	98.1	0.5	1.1	2.3	3.3	214.9	6.9	2.8	11.7	46.6	0.4
45	8x3	4.0	66.8	65	-0.3	21.5	3.1	103.9	0.4	1.1	1.8	2.1	235.6	7.5	1.4	4.6	60.3	0.2
43	8x1	4.0	65.8	63	0.2	42.7	3.2	116.4	0.5	1.2	2.0	2.8	231.1	14.4	12.9	11.3	36.5	0.0
Mean		6.0		64	0.7	14.3	2.8	110.1	0.5	1.0	2.0	2.4	234.5	15.9	7.7	6.1	47.8	0.5
LSD		2.2		1.7	1.2	16.7	0.6	11.1	0.0	0.2	0.6	0.7	14.9	21.3	17.4	8.7	23.2	0.7
SED		1.1		0.9	0.6	8.5	0.3	5.6	0.0	0.1	0.3	0.4	7.6	10.8	8.8	4.4	11.7	0.4
CV		3.0		11.0	0.7	0.8	4.5	7.6	9.0	6.3	3.0	4.9	14.5	0.8	0.7	0.9	2.1	1.1
Min			65.8	60.7	-0.3	0.1	2.1	93.8	0.4	0.9	1.5	1.8	205.8	4.1	0.1	0.8	23.1	0.0
Max			130.9	66.9	2.3	52.3	3.8	142.4	0.5	1.3	2.5	3.3	277.4	39.5	32.1	25.4	72.9	1.6

†GY, grain yield; RGY, relative grain yield; AD, days to 50% pollen shed ; ASI, Anthesis Silking Interval; HC ,husk Cover ; EA, ear Aspect; EH, ear height; EPO, ear position; EPP, ears per plant; *exserohilum turcicum*; PA, plant aspect; PH, plant height; RL, root lodging; SL, stem lodging; FSI, Fusarium incidence; FSE, Fusarium severity; FWR, field weight of rotten ears

Appendix 9: **Table of means of grain yield and agronomic traits at Kiboko under managed drought stress.**

Hybrid	Cross	GY†	AD	ASI	SD	EA	EPP	MOI
#		t ha^{-1}	d	d	d	1-5	#	%
48	8x6	3.9	66	-0.8	66	2.5	0.9	20.9
29	5x5	3.8	72	0.3	72	2.0	0.7	17.5
54	9x6	3.6	66	1.9	68	2.4	0.8	17.5
58	10x4	3.6	67	1.6	69	2.9	0.7	18.2
52	9x4	3.5	66	2.3	69	2.3	0.9	17.6
28	5x4	3.5	67	4.1	71	2.4	0.7	18.3
30	5x6	3.4	69	3.8	72	1.9	0.7	18.7
4	1x4	3.4	68	2.7	71	2.0	0.6	18.7
27	5x3	3.3	72	0.9	73	2.7	0.7	18.9
40	7x4	3.3	67	4.1	71	2.4	0.6	19.2
60	10x6	3.1	67	0.4	67	2.5	0.7	19.0
16	3x4	3.1	66	6.7	73	2.6	0.6	18.1
41	7x5	3.1	69	1.7	71	2.3	0.7	17.6
18	3x6	3.1	68	3.6	72	2.1	0.8	17.6
6	1x6	3.0	68	2.9	71	2.0	0.8	18.8
3	1x3	3.0	72	0.9	73	2.6	0.6	18.5
56	10x2	3.0	67	1.5	69	2.4	0.8	18.8
34	6x4	2.8	66	3.9	70	2.7	0.7	18.2
36	6x6	2.8	66	1.3	68	2.9	0.8	18.4
24	4x6	2.7	69	3.8	73	2.4	0.6	19.2
5	1x5	2.7	71	4.6	75	2.7	0.6	17.9
44	8x2	2.7	66	-1.5	65	3.2	0.9	19.6

50	9x2	2.6	68	4.1	73	3.3	0.6	18.0
39	7x3	2.6	72	2.4	74	3.0	0.7	19.3
22	4x4	2.5	67	7.9	75	2.6	0.5	19.6
46	8x4	2.4	65	2.7	68	3.0	0.6	20.9
45	8x3	2.4	68	-0.3	68	3.1	1.0	19.5
33	6x3	2.4	68	1.9	70	2.8	0.7	19.3
2	1x2	2.3	69	1.7	71	2.9	0.5	19.1
26	5x2	2.3	70	7.2	77	3.1	0.5	19.0
1	1x1	2.2	71	3.9	75	3.0	0.7	18.2
55	10x1	2.2	69	5.2	74	2.7	0.5	18.1
47	8x5	2.2	68	-0.2	68	3.3	0.7	19.0
42	7x6	2.1	69	3.6	73	2.9	0.6	18.2
61	DK8031	2.1	67	6.7	73	3.4	0.6	17.0
38	7x2	2.1	70	3.8	74	3.0	0.5	20.1
32	6x2	2.1	68	4.2	73	3.1	0.6	19.7
21	4x3	2.1	72	4.8	77	3.3	0.5	14.5
53	9x5	2.1	70	4.1	74	2.9	0.6	18.3
25	5x1	2.0	71	3.9	75	3.2	0.7	18.0
17	3x5	2.0	71	0.8	72	3.1	0.4	18.0
64	H513	1.9	67	5.1	73	3.0	0.5	19.2
57	10x3	1.9	71	2.9	74	3.2	0.5	19.1
11	2x5	1.9	69	6.8	76	3.4	0.7	16.7
59	10x5	1.9	69	5.9	75	3.3	0.6	19.2
49	9x1	1.9	70	4.3	74	2.8	0.5	18.5
14	3x2	1.9	70	6.5	76	3.0	0.4	18.8
8	2x2	1.8	68	3.2	72	2.9	0.5	18.6
63	WH505	1.7	71	4.2	75	3.4	0.5	20.8
12	2x6	1.7	66	5.3	71	3.4	0.5	17.6
23	4x5	1.6	72	-1.1	71	3.2	0.4	18.7
35	6x5	1.6	69	1.9	71	3.1	0.4	18.5
62	WH507	1.6	70	1.0	71	3.6	0.5	19.2

51	9x3	1.6	70	0.7	71	3.3	0.3	18.1
10	2x4	1.5	66	7.0	73	3.5	0.4	17.6
19	4x1	1.5	71	-1.3	70	3.1	0.4	18.3
15	3x3	1.4	71	-1.3	70	3.7	0.4	19.0
43	8x1	1.4	68	1.2	69	4.0	0.8	18.1
9	2x3	1.4	68	4.3	72	3.5	0.4	17.6
37	7x1	1.3	70	6.6	77	3.5	0.4	17.6
13	3x1	1.2	69	0.8	70	3.6	0.4	19.6
20	4x2	1.2	70	-1.5	69	3.5	0.3	20.1
31	6x1	0.8	69	4.2	73	3.9	0.3	16.6
7	2x1	0.7	70	3.3	73	4.0	0.3	17.4
Mean		2.3	69	3.4	72	3.0	0.6	18.5
LSD		1.6	2.3	2.5	2.5	0.8	0.3	2.2
SEM		0.3	0.6	0.7	0.7	0.1	0.0	0.6
Min		0.7	65	-1.5	65	1.9	0.3	14.5
Max		3.9	72	7.9	77	4.0	1.0	20.9

[†] GY , grain yield; AD, days to 50% pollen shed ; ASI, Anthesis Silking Interval; SD, days to 50% silking; EA, ear Aspect; EPP, ears per plant; MOI, grain moisture

Appendix 10: **Table of means of grain yield, agronomic traits, and fusarium disease parameters at Kibos under artificial inoculation.**

Hybrid	Cross	GY†	AD	ASI	HC	SD	EA	EH	EPO	EPP	ET	PA	PH	RL	SL	FSE	FSI	FWR
26	5x2	8.9	61	0.5	0.0	62	2.3	105.0	0.4	1.0	1.5	2.2	239.9	33.0	1.5	17.5	26.1	0.8
27	5x3	8.8	62	0.5	6.5	63	2.3	102.5	0.4	1.0	1.8	1.8	236.3	43.5	0.0	3.2	51.9	0.4
22	4x4	8.7	59	1.5	3.5	61	2.0	110.0	0.4	1.0	1.5	2.3	247.4	26.5	0.0	15.4	56.9	0.7
9	2x3	8.7	62	0.0	1.5	61	2.0	105.0	0.4	0.9	2.0	2.2	253.0	35.5	0.0	11.4	44.7	0.8
59	10x5	8.6	62	-0.5	10.0	61	2.5	115.0	0.5	0.9	2.0	1.8	245.6	22.5	0.0	14.4	28.8	0.5
12	2x6	8.0	59	1.0	8.0	60	2.3	95.0	0.5	1.0	1.8	2.3	221.9	50.0	5.5	12.8	51.5	0.5
4	1x4	7.9	59	1.5	0.0	60	2.3	105.0	0.5	1.0	1.5	2.4	232.5	24.0	1.5	5.6	19.4	0.6
41	7x5	7.7	62	0.5	12.0	63	2.5	107.5	0.5	0.9	1.8	2.5	231.9	33.0	1.5	16.9	20.3	1.9
46	8x4	7.6	55	2.0	3.0	57	2.5	102.5	0.5	0.9	1.5	2.5	220.6	1.5	0.0	4.3	51.9	0.3
20	4x2	7.5	62	1.0	4.0	63	2.5	102.5	0.4	1.0	1.5	2.5	244.0	23.5	0.0	24.0	33.4	1.6
47	8x5	7.5	60	-2.5	43.5	58	2.8	120.0	0.5	1.0	1.5	2.0	243.8	9.0	0.0	11.6	17.7	1.4
3	1x3	7.4	63	0.0	0.0	63	2.3	117.5	0.5	1.0	1.5	2.3	260.5	28.5	0.0	44.6	35.1	1.4
17	3x5	7.3	62	1.5	9.5	63	2.5	112.5	0.5	0.9	1.5	2.3	243.0	19.0	0.0	14.6	21.3	1.3
7	2x1	7.2	61	0.0	1.5	62	2.3	110.0	0.5	0.9	2.0	2.0	229.5	66.5	4.0	12.8	43.3	0.5
58	10x4	7.1	57	1.0	0.0	58	2.5	112.5	0.5	0.9	1.5	2.2	233.3	9.5	0.0	16.0	69.1	1.0
56	10x2	7.1	59	-0.5	0.0	59	2.5	117.5	0.5	0.9	1.5	1.5	236.7	4.0	0.0	18.7	41.3	1.4
25	5x1	7.0	62	1.5	31.5	63	2.5	125.0	0.6	1.0	1.8	2.5	235.4	56.0	6.0	13.8	26.7	0.9
51	9x3	7.0	61	0.0	35.5	61	2.5	95.0	0.4	1.0	1.5	2.4	238.9	22.5	0.0	26.4	35.3	2.1
16	3x4	6.9	57	5.0	7.0	62	3.0	107.5	0.5	0.9	1.5	2.3	234.9	12.0	0.0	14.3	39.7	0.9
39	7x3	6.6	62	0.5	0.0	62	2.8	100.0	0.4	1.0	1.8	2.3	241.3	21.0	0.0	30.7	31.1	1.9
8	2x2	6.6	60	0.0	0.0	60	2.3	130.0	0.5	0.9	1.5	2.5	260.9	36.5	0.0	28.6	24.8	3.1
10	2x4	6.5	57	2.0	0.0	59	2.3	117.5	0.5	0.9	1.5	2.5	238.8	39.5	0.0	18.7	27.8	0.9
14	3x2	6.5	58	4.0	3.0	62	2.5	107.5	0.5	0.9	1.5	2.5	235.1	7.0	0.0	7.9	67.5	0.4
40	7x4	6.5	57	3.0	3.0	60	3.0	95.0	0.5	0.8	1.8	2.9	215.6	26.0	0.0	12.0	28.9	0.7
11	2x5	6.3	62	-0.5	14.5	62	2.5	125.0	0.5	0.8	1.8	2.5	260.4	38.5	8.0	27.0	23.8	2.3

52	9x4	6.3	57	0.0	3.5	57	2.5	100.0	0.5	0.9	1.5	2.0	223.8	15.0	2.0	6.7	27.5	0.9
50	9x2	6.3	59	0.0	5.5	59	2.5	100.0	0.5	1.0	1.5	2.5	234.2	23.5	0.0	16.8	46.0	1.2
55	10x1	6.2	61	-0.5	11.5	60	2.5	105.0	0.5	1.0	2.0	1.7	237.5	19.5	1.5	24.4	38.4	1.9
35	6x5	6.2	62	0.5	7.0	63	2.8	120.0	0.5	1.1	1.5	2.4	261.3	30.5	6.0	28.0	36.5	2.6
44	8x2	6.2	59	-0.5	0.0	58	3.0	95.0	0.4	1.0	1.5	2.8	232.0	12.0	0.0	21.7	38.2	2.1
13	3x1	6.2	59	2.5	24.0	62	2.8	87.5	0.4	0.9	1.5	2.2	222.5	28.5	1.5	36.0	32.5	2.4
57	10x3	6.1	62	0.0	0.0	62	2.5	107.5	0.5	0.9	1.8	2.2	242.4	31.5	0.0	4.8	42.5	0.6
64	H513	5.8	60	1.0	13.5	61	3.0	120.0	0.6	1.0	1.8	2.5	229.3	63.0	3.0	30.6	54.0	2.0
21	4x3	5.8	62	0.5	26.5	63	2.5	110.0	0.5	1.1	1.5	2.5	248.8	24.5	0.0	24.8	26.3	2.4
23	4x5	5.8	62	1.0	47.0	63	2.5	117.5	0.5	0.9	1.5	2.3	239.6	22.5	1.5	37.8	33.1	2.8
62	WH507	5.6	61	0.0	12.5	62	3.0	117.5	0.6	1.0	1.5	2.2	227.2	43.5	0.0	29.4	62.3	1.4
37	7x1	5.6	62	1.0	68.0	63	3.3	105.0	0.4	1.0	1.5	2.5	236.2	38.5	0.0	24.0	31.3	2.0
30	5x6	5.5	58	1.5	20.5	59	3.0	105.0	0.5	1.1	1.5	2.5	211.7	36.5	0.0	28.4	25.6	2.1
2	1x2	5.4	60	0.0	0.0	60	3.0	105.0	0.5	0.9	1.5	2.5	237.8	44.5	1.5	22.6	23.8	2.5
38	7x2	5.2	59	1.5	0.0	60	2.5	87.5	0.4	1.0	1.5	2.4	242.1	30.5	2.0	32.1	28.4	3.0
28	5x4	5.1	59	0.5	19.0	59	2.5	102.5	0.5	0.9	1.5	2.3	233.7	33.5	0.0	23.6	43.3	1.4
49	9x1	5.1	61	1.0	22.5	62	2.8	92.5	0.5	1.0	1.5	2.6	215.9	26.0	1.5	34.1	23.3	2.6
63	WH505	5.1	62	0.0	18.0	61	3.0	122.5	0.5	1.1	1.5	3.0	253.3	35.5	1.5	34.1	18.3	2.5
60	10x6	5.1	58	-0.5	3.0	57	3.0	110.0	0.5	0.9	1.8	2.4	229.2	12.5	0.0	22.1	45.7	1.2
53	9x5	5.0	62	-1.5	27.0	60	2.5	115.0	0.5	1.0	1.5	2.5	256.7	49.5	1.5	43.2	22.0	4.3
15	3x3	5.0	61	3.0	5.0	64	2.8	80.0	0.3	0.9	1.5	2.0	234.7	19.0	0.0	31.0	31.6	1.9
54	9x6	4.8	57	1.0	20.0	58	3.0	95.0	0.5	0.9	1.5	2.8	221.1	52.0	1.5	29.9	28.1	2.2
18	3x6	4.7	58	3.0	7.0	61	3.0	105.0	0.5	0.9	1.5	2.7	222.5	9.5	5.5	27.9	30.1	1.7
36	6x6	4.7	57	2.0	15.0	59	3.0	122.5	0.6	0.9	1.8	3.0	221.7	22.0	1.5	34.4	35.6	1.9
48	8x6	4.7	55	0.0	34.0	56	2.8	105.0	0.5	1.0	1.5	2.5	226.0	9.0	0.0	27.9	30.7	1.7
5	1x5	4.6	63	0.5	27.0	63	2.5	137.5	0.5	1.0	1.8	2.8	277.5	50.5	4.0	47.7	11.7	4.2
34	6x4	4.5	55	4.5	7.5	60	2.5	100.0	0.5	0.8	1.5	2.8	215.0	15.5	8.0	39.5	29.8	1.9
32	6x2	4.4	58	3.5	3.0	62	3.0	100.0	0.5	0.9	1.5	2.5	233.1	9.0	1.5	38.8	29.1	2.4
31	6x1	4.3	61	2.0	23.0	64	3.0	107.5	0.5	0.8	1.8	2.8	231.6	22.5	1.5	29.4	19.1	1.6
43	8x1	4.2	59	0.0	53.5	59	3.0	110.0	0.5	1.0	1.5	2.0	233.7	7.0	0.0	40.9	26.6	2.3
33	6x3	3.8	61	0.5	9.5	62	3.5	102.5	0.4	1.4	1.5	2.5	256.3	16.0	3.5	21.6	57.0	0.8

19	4x1	3.7	62	-1.0	47.0	61	2.8	110.0	0.5	0.9	1.8	2.2	233.6	29.0	3.0	21.9	23.3	1.0
1	1x1	3.7	63	2.5	39.0	65	3.0	120.0	0.5	1.2	1.5	2.1	241.8	16.5	0.0	32.8	24.0	1.8
61	DK8031	3.4	56	3.5	30.5	60	4.0	120.0	0.5	0.9	1.5	3.0	232.9	12.5	10.5	59.6	45.9	2.7
29	5x5	3.4	61	0.0	34.0	62	2.8	117.5	0.5	1.1	1.5	3.0	233.5	48.5	3.0	39.1	23.5	5.7
24	4x6	3.3	61	0.5	49.0	62	2.8	117.5	0.5	1.0	2.0	2.6	243.1	9.0	0.0	48.9	19.2	3.1
45	8x3	3.2	62	-1.0	26.0	61	2.8	107.5	0.5	1.1	1.8	2.2	247.9	49.5	0.0	15.9	21.7	1.1
42	7x6	3.0	59	2.0	20.0	60	3.5	107.5	0.5	0.8	1.8	2.9	213.5	23.0	1.5	43.3	27.4	2.0
6	1x6	2.9	58	1.5	43.0	60	2.8	97.5	0.4	1.2	2.0	2.5	229.1	35.5	0.0	10.3	15.0	1.8
Mean		5.87	59.85	0.92	15.93	60.77	2.69	108.28	0.46	0.97	1.61	2.41	236.64	27.58	1.51	24.73	33.54	1.76
LSD		2.7	1.5	1.6	15.9	1.8	0.6	20.9	0.1	0.2	0.4	0.6	20.5	25.1	5.6	22.8	30.5	1.9
CV		22.7	1.2	0.6	49.1	1.4	12.2	9.6	11.6	8.8	12.3	11.4	9.6	46.2	88.8	43.5	42.0	54.8

†GY ,grain yield, AD; days to 50% pollen shed ; ASI, Anthesis Silking Interval; HC, husk Cover ; SD, days to 50% silking; EA, ear Aspect ; EH, ear height; EPO, ear position; EPP, ears per plant, ET, *ersohilum turcicum*; PA, plant aspect; PH, plant height; RL, root lodging; SL, stem lodging; FSE, Fusarium severity; FSI, Fusarium incidence; FWR, field weight of rotten ears

Appendix 11: Table of means of grain yield, agronomic traits and fusarium disease parameters at Kibos under natural disease pressure.

Hybrid	cross	GY†	AD	ASI	HC	EA	EH	EPO	EPP	ET	PA	PH	RL	SL	FSI	FSE
2	1x2	10.0	61	0.0	0.0	1.9	95.0	0.4	1.0	1.5	2.0	231.7	39.0	2.9	0.0	0.0
26	5x2	10.0	61	0.0	1.5	1.8	102.5	0.4	0.9	1.5	2.0	230.9	50.3	4.5	1.7	40.0
4	1x4	9.9	60	1.5	0.0	1.8	115.0	0.5	1.0	1.8	2.2	234.7	35.1	1.9	0.0	0.0
38	7x2	9.9	59	1.0	0.0	2.4	87.5	0.3	0.9	1.5	2.7	231.3	32.0	5.7	6.4	26.7
51	9x3	9.9	61	0.5	33.8	2.3	97.5	0.4	1.0	1.5	2.2	235.0	62.3	1.3	2.9	25.0
53	9x5	9.9	62	0.0	27.9	2.0	107.5	0.5	0.9	1.5	2.2	241.1	45.6	3.1	8.5	41.7
25	5x1	9.7	63	1.0	43.8	2.1	107.5	0.5	1.0	1.5	2.2	231.5	49.0	1.6	12.4	32.9
5	1x5	9.6	63	0.5	36.8	1.9	135.0	0.5	0.9	1.5	2.2	242.0	56.9	1.7	3.4	55.0
47	8x5	9.1	61	-1.0	41.3	2.6	100.0	0.4	1.0	1.5	2.0	236.0	18.9	1.5	8.8	26.7
20	4x2	8.9	62	1.0	1.3	2.2	102.5	0.4	1.0	1.5	2.3	240.6	36.7	0.0	1.6	10.0
58	10x4	8.9	58	0.5	0.0	2.2	92.5	0.4	0.9	1.8	2.0	232.9	9.7	1.4	0.0	0.0
3	1x3	8.7	63	0.0	0.0	2.0	105.0	0.4	1.0	1.5	2.0	245.2	34.1	0.0	0.0	0.0
41	7x5	8.7	62	0.0	31.4	2.7	102.5	0.5	1.0	1.8	2.3	224.3	21.2	4.0	6.5	20.0
17	3x5	8.6	62	2.0	6.8	2.5	105.0	0.5	0.9	1.5	2.2	229.1	9.5	0.0	9.4	38.3
22	4x4	8.4	58	3.0	1.5	1.8	105.0	0.5	1.0	1.5	2.3	220.7	19.1	1.6	1.7	100.0
39	7x3	8.4	61	1.0	3.3	2.7	102.5	0.4	0.9	1.8	2.5	242.3	16.5	0.0	17.3	65.0
13	3x1	8.3	62	1.5	42.2	2.6	107.5	0.5	1.0	1.5	2.7	228.9	51.6	1.6	22.3	36.2
9	2x3	8.1	63	-1.0	3.4	1.8	117.5	0.5	1.0	1.6	2.3	254.7	26.4	1.7	6.8	32.5
40	7x4	8.1	57	2.0	0.0	2.3	100.0	0.4	0.9	1.4	2.5	227.1	18.9	0.0	1.7	100.0
16	3x4	8.0	57	4.0	3.0	1.8	100.0	0.4	0.9	1.5	2.3	227.4	15.2	0.0	3.4	45.0
35	6x5	8.0	62	1.5	12.1	1.8	152.5	0.6	1.0	1.5	2.5	270.7	27.4	3.6	0.0	0.0
44	8x2	8.0	59	-0.5	0.0	1.4	85.0	0.4	1.1	1.5	2.1	224.3	10.4	0.0	6.3	20.0
27	5x3	7.8	62	1.5	27.6	2.4	100.0	0.4	1.0	1.5	2.5	232.1	42.8	1.5	16.1	63.0
8	2x2	7.7	63	-0.5	0.0	1.5	100.0	0.4	0.9	1.5	2.0	227.0	54.1	1.3	0.0	0.0
28	5x4	7.6	58	1.0	30.8	1.3	110.0	0.5	1.1	2.0	2.3	227.9	20.7	0.0	12.7	38.3

49	9x1	7.6	61	1.5	22.2	2.3	82.5	0.4	1.0	1.5	2.5	201.3	38.9	7.4	7.3	23.3
54	9x6	7.6	58	0.5	36.3	2.7	112.5	0.5	1.0	1.5	2.7	212.0	30.3	6.1	8.3	44.2
10	2x4	7.5	57	1.0	3.5	1.0	107.5	0.4	0.9	1.8	2.2	242.7	43.9	1.6	1.9	10.0
21	4x3	7.5	64	0.5	23.7	2.0	107.5	0.5	1.1	1.6	2.5	235.2	44.5	0.0	6.5	56.7
23	4x5	7.5	63	0.5	45.0	2.5	115.0	0.5	1.1	1.7	2.5	249.7	43.7	1.4	15.4	45.3
50	9x2	7.5	61	0.0	1.3	2.3	90.0	0.4	0.9	1.5	2.8	218.8	11.9	0.0	5.2	40.0
60	10x6	7.5	59	0.0	4.6	2.7	112.5	0.5	1.0	1.5	2.3	215.4	17.6	0.0	4.6	50.0
6	1x6	7.3	58	1.5	18.1	2.1	110.0	0.5	1.1	1.5	2.3	225.8	35.3	1.6	0.0	0.0
12	2x6	7.3	59	1.5	9.9	1.6	100.0	0.4	1.0	1.8	2.1	223.6	47.2	0.0	1.6	40.0
52	9x4	7.2	57	0.5	0.0	1.7	87.5	0.4	1.0	1.7	2.2	216.4	10.9	4.2	0.0	0.0
36	6x6	7.1	57	2.0	12.4	1.9	102.5	0.5	1.0	1.5	2.5	224.8	10.5	1.6	10.6	53.5
56	10x2	7.1	60	0.0	0.0	2.9	85.0	0.4	0.9	1.5	2.2	215.3	14.6	0.0	5.3	65.0
46	8x4	7.0	57	0.5	4.6	2.3	100.0	0.4	1.0	1.5	2.3	231.1	7.2	0.0	1.7	100.0
7	2x1	6.9	62	1.0	1.8	1.7	97.5	0.4	0.7	1.5	2.5	229.8	53.7	10.7	10.7	41.3
30	5x6	6.8	60	1.5	53.2	3.1	115.0	0.5	1.1	1.5	2.8	219.2	33.1	4.7	8.5	45.0
48	8x6	6.7	57	0.0	34.1	2.5	122.5	0.5	1.1	1.5	2.0	251.3	18.2	0.0	4.0	15.0
15	3x3	6.6	62	2.0	7.9	2.5	97.5	0.4	0.9	1.5	2.5	231.7	9.2	0.0	10.3	52.5
11	2x5	6.5	63	0.0	24.6	1.9	95.0	0.4	0.8	1.5	2.7	238.5	42.4	1.5	18.2	47.5
14	3x2	6.5	59	3.0	0.0	2.4	95.0	0.4	0.8	1.5	2.7	230.4	20.7	0.0	0.0	0.0
29	5x5	6.5	63	1.0	64.9	2.4	112.5	0.5	1.1	1.5	2.8	232.5	30.3	1.6	10.3	52.5
31	6x1	6.5	62	1.0	44.4	2.5	115.0	0.4	1.0	1.5	2.6	254.3	40.4	3.5	11.4	25.0
63	WH505	6.5	62	1.0	11.1	2.6	102.5	0.4	0.9	1.5	2.4	238.6	23.9	1.6	9.4	57.5
59	10x5	6.2	61	-1.0	8.4	2.6	110.0	0.5	0.8	2.3	2.7	242.7	14.0	1.5	3.3	55.0
62	WH507	6.2	62	0.0	7.6	2.4	115.0	0.5	1.0	1.5	2.5	257.9	50.0	0.0	3.7	75.0
64	H513	6.2	60	2.0	13.3	2.8	125.0	0.5	1.0	1.7	2.5	247.1	67.6	2.0	9.3	50.0
32	6x2	5.9	59	2.0	5.6	1.7	97.5	0.4	1.0	1.5	2.3	245.7	9.7	0.0	2.9	30.0
18	3x6	5.7	60	2.0	3.1	3.1	95.0	0.4	0.9	1.5	2.7	224.4	14.9	4.4	1.9	60.0
37	7x1	5.5	63	1.5	45.6	3.5	107.5	0.5	1.0	1.8	3.0	230.0	49.8	3.0	20.1	45.8
42	7x6	5.5	60	1.0	44.8	3.4	102.5	0.5	1.1	2.0	3.0	213.5	6.7	0.0	12.7	52.5
55	10x1	5.5	63	0.5	17.2	2.9	100.0	0.4	0.8	2.0	2.8	233.9	13.7	3.4	16.8	57.5
61	DK8031	5.2	57	1.5	41.5	3.4	82.5	0.4	0.9	1.5	3.0	219.5	12.9	2.8	35.6	41.7

34	6x4	4.8	56	3.5	20.2	2.8	102.5	0.5	0.9	1.5	2.5	222.2	22.6	8.3	12.0	63.1
43	8x1	4.8	60	0.0	76.2	3.1	110.0	0.5	1.1	1.5	2.7	236.1	27.4	0.0	29.6	34.4
45	8x3	4.8	62	-0.5	40.3	2.4	100.0	0.4	1.3	1.4	2.3	225.6	11.7	0.0	5.6	30.0
19	4x1	4.6	63	1.5	75.7	2.4	105.0	0.5	1.3	1.5	2.8	217.4	47.8	3.9	33.9	25.9
57	10x3	4.5	64	-0.5	0.0	2.4	97.5	0.4	1.1	2.0	2.7	224.3	19.5	0.0	3.3	40.0
24	4x6	4.2	63	1.0	55.3	2.8	107.5	0.5	1.0	1.8	2.6	217.7	19.4	0.0	15.6	59.2
33	6x3	3.7	64	0.0	3.5	2.2	87.5	0.4	1.2	1.5	2.5	238.3	16.3	0.0	3.6	30.0
1	1x1	3.6	64	1.0	70.9	2.4	105.0	0.4	1.0	1.5	2.5	245.9	50.0	0.0	12.2	30.0
MEAN		7.2	61	0.9	20.3	2.3	103.9	0.4	1.0	1.6	2.4	232.0	29.5	1.8	8.2	38.4
LSD		2.1	1.9	1.6	24.7	0.6	19.1	0.1	0.2	0.3	0.5	21.2	23.3	5.7	15.2	44.5
SED		1	0.9	0.8	12.2	0.3	9.4	0	0.1	0.2	0.3	10.4	11.5	2.8	7.5	16

†GY, grain yield; AD ,days to 50% pollen shed ; ASI, Anthesis Silking Interval; HC, husk Cover ; EA, ear Aspect ; EH, ear height; EPO, ear position; EPP, ears per plant; ET, *ersohilum turcicum*, PA, plant aspect; PH, plant height; RL, root lodging; SL,s tem lodging; FSE, Fusarium severity; FSI, Fusarium incidence

Appendix 12: **Table of means of grain yield, agronomic traits, and fusarium disease parameters at Alupe under artificial inoculation.**

Hybrid	Cross	GY†	AD	ASI	HC	RUST	EA	EH	EPO	EPP	MOI	GLS	ET	PH	RL	SL	FSI	FSE
22	4x4	8.7	59	3.0	11.1	100.0	2.8	118.8	0.5	1.0	16.6	5.6	1.8	236.3	0.0	24.6	1.4	100.0
25	5x1	8.2	63	3.0	24.8	51.3	3.0	114.5	0.5	1.1	18.7	6.0	1.5	227.8	1.9	18.0	9.5	51.3
58	10x4	8.1	57	1.0	0.0	40.0	2.8	111.3	0.5	1.1	17.1	11.8	1.8	225.2	4.9	8.0	8.1	40.0
20	4x2	8.0	62	1.5	9.7	53.4	3.0	105.2	0.4	1.0	18.4	0.2	1.5	239.3	0.0	9.4	7.5	53.3
11	2x5	8.0	63	0.0	19.1	0.0	3.0	120.1	0.5	0.8	14.5	0.0	1.8	236.0	1.5	11.0	0.0	0.0
7	2x1	7.6	62	0.0	3.2	0.0	3.5	128.5	0.5	1.0	15.4	0.0	1.5	239.6	8.9	17.5	0.0	0.0
28	5x4	7.6	59	2.5	3.2	50.0	3.3	109.6	0.5	1.0	15.1	0.0	1.8	218.5	0.0	-0.2	1.6	50.0
39	7x3	7.3	63	0.0	7.1	57.5	3.5	107.0	0.5	0.9	15.5	5.7	2.3	229.9	1.6	5.4	8.1	57.5
35	6x5	7.2	62	2.0	15.3	14.0	3.2	137.9	0.5	0.9	16.1	10.9	2.0	253.3	2.8	8.3	7.4	14.0
21	4x3	7.1	63	2.0	18.1	50.9	3.3	106.8	0.5	0.9	16.3	3.6	2.0	234.4	1.5	10.4	10.9	50.8
13	3x1	7.0	62	1.0	18.3	50.0	3.4	112.8	0.5	1.1	15.4	11.1	2.0	217.4	0.0	11.6	6.9	50.0
8	2x2	6.9	59	0.5	2.8	56.3	3.0	113.6	0.5	1.0	14.0	4.2	1.5	246.9	0.0	5.5	10.7	56.3
24	4x6	6.8	61	2.0	44.6	44.0	3.3	112.8	0.5	1.0	16.4	3.8	1.5	227.7	0.0	12.6	10.0	44.0
2	1x2	6.7	61	1.0	4.6	38.3	3.5	102.5	0.5	0.9	16.6	5.5	1.8	227.5	5.9	19.9	15.3	38.3
48	8x6	6.7	57	0.0	27.6	21.7	3.0	110.5	0.5	0.9	16.3	9.2	1.5	229.4	2.1	4.9	9.6	21.7
52	9x4	6.7	57	0.5	5.3	30.0	3.1	88.0	0.4	0.9	16.7	0.2	1.5	203.8	0.0	5.6	1.7	30.0
6	1x6	6.7	60	1.5	9.1	10.0	3.2	118.8	0.5	1.2	16.0	0.0	1.8	231.4	4.6	23.7	2.2	10.0
51	9x3	6.6	61	1.0	11.3	30.6	3.5	98.4	0.4	0.8	14.8	5.5	1.5	226.3	1.4	3.0	37.4	30.6
44	8x2	6.6	58	0.5	1.3	60.0	3.0	106.3	0.5	0.8	16.2	4.5	1.5	231.1	0.0	-3.8	10.1	60.0
23	4x5	6.5	63	1.5	52.2	0.0	3.5	121.1	0.5	0.9	16.7	5.3	1.8	242.9	1.8	36.8	0.0	0.0
50	9x2	6.5	59	1.0	4.1	45.7	3.3	101.7	0.5	0.8	17.1	9.3	1.8	222.1	0.0	-1.9	17.3	45.6
63	WH505	6.5	63	0.5	5.3	40.0	3.3	132.3	0.5	0.8	15.6	0.2	1.8	243.3	2.9	15.5	1.5	40.0
3	1x3	6.4	64	1.0	1.6	0.0	3.3	92.2	0.4	1.0	15.1	0.2	1.5	242.3	3.7	20.9	0.0	0.0
31	6x1	6.4	62	2.0	17.6	24.5	3.6	116.8	0.5	0.9	17.2	3.8	1.8	243.6	0.0	17.5	25.0	24.5
10	2x4	6.3	58	2.5	1.5	0.0	3.0	110.8	0.5	1.0	16.2	0.1	1.5	224.9	3.4	3.6	0.0	0.0

56	10x2	6.3	59	0.0	8.8	27.5	3.4	102.5	0.5	0.9	15.7	5.6	2.0	220.1	1.5	8.6	4.5	27.5
34	6x4	6.3	57	3.5	1.5	50.0	3.0	105.7	0.5	0.9	17.4	10.4	1.8	224.6	1.5	10.5	9.6	50.0
1	1x1	6.3	64	2.0	6.5	26.7	3.2	128.3	0.5	1.0	16.6	10.4	1.5	237.2	2.2	15.0	7.8	26.7
16	3x4	6.2	57	4.0	0.0	0.0	2.9	103.9	0.5	1.1	15.4	0.2	1.8	222.6	1.6	-6.2	0.0	0.0
27	5x3	6.2	63	1.5	18.2	60.4	3.5	103.8	0.5	0.9	14.9	8.0	1.5	233.1	0.0	16.4	11.6	60.4
30	5x6	6.2	60	1.0	12.5	10.0	3.3	114.7	0.5	1.1	14.5	5.9	1.5	215.3	6.5	13.9	1.6	10.0
37	7x1	6.2	61	1.5	44.3	45.0	3.8	108.8	0.5	0.9	18.3	13.6	1.8	227.9	5.4	25.9	8.8	45.0
32	6x2	6.1	60	3.0	2.9	26.3	3.8	114.7	0.5	1.0	16.5	0.1	1.8	239.8	5.4	1.2	8.4	26.3
47	8x5	6.1	58	0.5	39.1	84.6	3.5	110.9	0.5	1.0	16.6	0.2	1.5	222.5	1.5	21.2	11.4	84.6
17	3x5	6.1	63	1.0	2.8	18.8	3.5	117.2	0.5	0.9	17.2	11.3	1.5	222.3	0.0	14.3	5.6	18.8
54	9x6	6.0	58	1.0	19.7	45.5	3.3	99.6	0.5	0.8	15.4	9.6	1.5	209.8	6.6	17.4	29.4	45.5
60	10x6	6.0	60	0.0	0.0	36.7	3.5	125.0	0.5	0.9	15.3	5.6	2.5	231.8	4.4	4.5	8.0	36.7
59	10x5	5.9	61	1.5	5.2	100.0	3.5	100.5	0.5	1.0	16.7	0.1	2.0	215.0	3.5	13.1	2.4	100.0
19	4x1	5.9	64	3.0	15.6	67.5	3.3	111.5	0.5	0.9	17.6	5.5	1.5	236.7	1.5	19.0	8.9	67.5
57	10x3	5.9	63	0.0	0.0	37.5	3.2	104.1	0.5	0.9	14.9	5.5	2.0	227.1	0.0	8.9	11.2	37.5
26	5x2	5.8	62	2.0	12.4	58.8	3.5	110.4	0.5	0.9	16.1	3.8	1.5	229.7	5.7	16.6	16.1	58.8
40	7x4	5.7	58	2.0	0.0	48.4	3.5	113.8	0.5	1.0	14.7	0.3	1.8	221.6	6.9	6.0	7.0	48.3
9	2x3	5.6	62	1.0	0.0	72.5	3.3	112.4	0.5	0.9	17.1	4.8	1.8	245.0	1.5	19.3	11.4	72.5
5	1x5	5.5	64	1.5	9.6	30.0	3.6	115.9	0.5	1.0	17.1	10.5	2.0	230.6	8.4	66.9	4.0	30.0
55	10x1	5.4	63	0.0	3.3	50.0	3.1	105.3	0.5	1.0	16.9	5.0	2.3	227.8	0.0	23.2	1.6	50.0
4	1x4	5.3	60	2.5	0.0	40.7	3.0	121.6	0.5	0.8	17.5	9.4	1.8	225.0	3.3	26.0	11.6	40.6
15	3x3	5.3	61	3.0	1.7	72.3	3.4	89.9	0.4	0.8	16.3	5.2	2.0	214.5	0.0	0.8	18.2	72.3
42	7x6	5.2	60	1.5	34.4	42.5	4.0	104.7	0.5	1.0	16.1	0.1	1.5	207.2	9.6	5.7	8.3	42.5
36	6x6	5.1	59	3.0	6.1	63.8	3.5	118.9	0.5	0.9	15.4	4.1	1.5	235.1	7.7	25.7	18.2	63.8
53	9x5	5.0	62	0.0	24.5	27.5	3.5	112.7	0.5	0.9	16.1	4.1	1.8	224.4	6.2	36.5	4.6	27.5
18	3x6	4.9	61	1.0	4.3	49.5	4.0	105.8	0.5	0.8	14.4	4.3	1.5	211.7	4.3	16.3	10.2	49.5
64	H513	4.8	60	1.5	11.0	29.2	3.5	130.5	0.6	1.0	15.1	8.4	1.8	231.0	21.0	17.3	18.9	29.2
49	9x1	4.6	62	1.5	30.9	21.7	3.7	115.3	0.5	0.9	15.2	10.4	1.5	226.2	0.0	9.7	18.9	21.7
38	7x2	4.5	59	2.5	6.0	51.3	4.0	92.2	0.4	0.7	19.2	9.8	1.8	222.4	0.0	12.0	37.3	51.3
41	7x5	4.4	62	1.0	19.0	10.0	3.8	110.0	0.5	0.9	16.9	0.1	2.5	219.9	1.6	33.3	1.9	10.0
33	6x3	4.3	62	1.0	2.8	27.8	3.5	117.1	0.4	1.0	14.7	9.9	1.8	262.7	0.0	11.4	19.6	27.7

61	DK8031	4.2	57	3.5	32.3	34.0	4.0	96.5	0.4	0.8	15.4	3.8	2.0	219.5	5.3	7.7	19.2	34.0
29	5x5	4.2	63	1.0	46.5	0.0	3.2	126.2	0.5	0.9	15.5	0.2	2.0	246.5	3.6	44.6	0.0	0.0
62	WH507	4.2	65	0.5	6.8	30.0	3.5	109.0	0.5	1.1	15.1	5.0	1.8	228.5	4.6	51.4	1.8	30.0
45	8x3	3.5	62	-0.5	12.3	100.0	3.4	102.9	0.5	1.1	17.4	0.1	2.3	223.7	0.0	19.2	3.6	100.0
46	8x4	3.4	57	0.0	0.0	47.5	3.5	109.4	0.5	0.9	16.4	9.9	1.5	216.9	4.3	6.6	51.4	47.5
43	8x1	3.1	62	0.0	32.2	25.9	3.5	126.8	0.6	0.8	18.8	11.4	1.5	226.7	0.0	51.3	21.7	25.8
14	3x2	2.8	61	3.0	0.0	45.0	4.0	94.7	0.4	1.0	17.8	10.7	1.5	229.0	0.0	-1.0	27.6	45.0
12	2x6	2.1	58	1.5	1.7	15.1	3.5	101.5	0.5	0.3	15.5	10.4	1.5	215.5	10.0	16.4	157.7	15.1
MEAN		5.9	61	1.4	12.4	39.0	3.4	110.8	0.5	0.9	16.2	5.3	1.7	228.6	3.0	15.5	12.8	39.0
LSD		1.9	1.9	1.4	14.5	46.6	0.6	20.9	0.1	0.2	2.0	10.3	0.6	20.6	9.5	22.5	54.0	46.6
SED		0.9	0.9	0.7	7.1	20.6	0.3	10.3	0.0	0.1	1.0	4.9	0.3	10.1	4.7	11.0	26.5	20.6

† GY ,grain yield; AD, days to 50% pollen shed; ASI, Anthesis Silking Interval; HC, husk Cover ; EA, ear Aspect ; EH, ear height; EPO, ear position; EPP, ears per plant; MOI, grain moisture; GLS, grey leaf spot ; ET ,*ersohilum turcicum*; PH, plant height; RL, root lodging; SL, stem lodging; FSI, Fusarium incidence ; FSE, Fusarium severity

Appendix 13**: Table of means for grain yield, agronomic traits, and fusarium disease parameters at Alupe under natural disease pressure.**

Hybrid	Cross	GY†	AD	ASI	HC	EA	EH	EPO	EPP	ET	PH	RL	SL	FSE	FSI
4	1x4	9.3	59	1.0	4.3	2.7	120.0	0.5	1.1	1.8	235.0	0.0	29.2	5.3	33.3
58	10x4	9.0	58	0.5	0.0	2.4	112.5	0.5	1.0	1.5	227.5	3.3	6.3	0.0	0.0
36	6x6	8.8	58	1.0	14.8	2.9	125.0	0.6	1.1	1.8	227.5	1.5	8.6	4.1	75.0
22	4x4	8.3	58	2.0	8.3	2.8	115.0	0.5	1.0	1.5	230.0	9.0	16.7	1.7	35.0
21	4x3	7.8	62	1.5	31.1	3.6	115.0	0.5	1.0	1.5	247.5	0.0	10.7	1.9	95.0
19	4x1	7.7	62	1.5	51.5	2.9	110.0	0.5	1.1	1.6	235.0	2.0	6.8	1.8	85.0
26	5x2	7.5	61	1.0	11.0	3.1	115.0	0.5	1.1	1.6	235.0	0.0	2.2	5.6	55.0
52	9x4	7.5	57	0.5	0.0	2.6	102.5	0.5	1.0	1.5	212.5	0.0	18.1	0.0	0.0
44	8x2	7.5	59	0.5	7.5	3.1	110.0	0.5	1.0	1.7	235.0	0.0	3.6	4.3	71.6
13	3x1	7.4	61	2.0	30.4	3.0	110.0	0.5	1.1	1.7	220.0	1.5	0.6	4.5	75.0
28	5x4	7.3	58	2.0	7.6	2.8	115.0	0.5	1.0	1.8	235.0	1.9	30.2	11.3	38.5
47	8x5	7.3	61	-0.5	43.1	3.2	120.0	0.5	1.1	1.7	230.0	1.7	21.9	0.0	0.0
31	6x1	7.3	62	1.0	14.7	3.1	127.5	0.5	1.0	2.0	245.0	1.3	12.2	5.5	36.7
2	1x2	7.3	61	1.0	0.0	3.1	112.5	0.5	1.0	1.5	235.0	4.4	15.1	9.7	53.0
25	5x1	7.2	61	2.0	21.6	3.2	120.0	0.5	1.1	1.7	235.0	3.4	15.8	2.8	55.0
50	9x2	7.2	58	2.0	0.0	3.3	107.5	0.5	1.0	1.7	225.0	0.0	2.4	2.8	50.0
34	6x4	7.1	57	2.0	1.5	2.9	107.5	0.5	1.0	1.7	225.0	6.0	2.7	4.0	20.0
48	8x6	7.1	57	0.0	16.7	3.1	117.5	0.5	1.1	1.5	225.0	0.0	12.2	3.0	65.0
55	10x1	7.0	62	0.0	3.1	3.2	105.0	0.5	1.3	2.0	230.0	0.0	9.9	1.4	75.0
51	9x3	7.0	61	0.5	16.0	3.4	105.0	0.5	1.0	1.5	225.0	0.0	11.2	2.8	70.0
46	8x4	7.0	57	0.0	0.0	2.8	110.0	0.5	1.0	1.8	227.5	1.5	2.3	4.3	38.4
56	10x2	7.0	60	0.0	0.0	3.0	100.0	0.5	1.1	1.5	222.5	0.0	5.9	2.9	65.0
57	10x3	6.8	61	0.0	0.0	3.0	90.0	0.4	1.1	2.5	235.0	0.0	0.6	3.2	80.0
24	4x6	6.8	62	2.0	30.2	3.6	132.5	0.6	1.0	2.0	235.0	4.7	30.9	4.4	42.5

32	6x2	6.8	60	2.5	7.6	2.9	112.5	0.5	1.0	1.8	237.5	1.6	0.0	3.3	30.0
49	9x1	6.8	60	1.5	35.4	3.2	107.5	0.5	1.0	1.6	215.0	0.0	10.5	8.6	31.7
9	2x3	6.7	62	0.0	4.5	2.9	117.5	0.5	1.0	2.0	240.0	11.7	14.3	4.2	51.7
12	2x6	6.7	58	1.0	10.0	3.1	105.0	0.5	1.0	1.5	202.5	4.2	3.9	1.4	25.0
5	1x5	6.7	63	0.5	44.5	3.1	147.5	0.6	0.9	2.2	255.0	3.3	63.3	0.0	0.0
53	9x5	6.6	60	0.0	28.4	3.3	127.5	0.5	0.9	1.8	240.0	3.1	49.5	1.9	95.0
1	1x1	6.6	62	0.5	27.6	3.4	130.0	0.6	1.1	1.5	235.0	0.0	24.4	4.0	0.0
27	5x3	6.5	62	2.5	15.5	3.2	102.5	0.4	1.1	1.5	235.0	2.9	30.8	6.6	86.3
11	2x5	6.5	61	0.0	26.1	3.1	125.0	0.5	1.0	1.7	255.0	1.9	13.5	0.0	0.0
35	6x5	6.5	61	2.5	19.1	3.0	135.0	0.5	0.9	2.0	265.0	0.0	11.9	3.2	25.0
3	1x3	6.4	62	1.5	1.7	3.3	122.5	0.5	1.0	1.6	242.5	0.0	18.0	1.4	85.0
29	5x5	6.4	62	0.5	56.6	3.3	120.0	0.5	1.1	2.5	235.0	3.5	35.5	1.6	25.0
60	10x6	6.4	58	0.5	0.0	3.2	120.0	0.5	1.0	1.7	227.5	0.0	14.1	0.0	0.0
30	5x6	6.3	60	1.5	17.3	3.3	115.0	0.5	1.0	1.5	217.5	4.7	22.5	1.6	15.0
16	3x4	6.3	57	2.5	8.1	3.1	105.0	0.5	1.0	1.8	227.5	0.0	1.4	0.0	0.0
15	3x3	6.2	60	2.5	6.2	3.7	102.5	0.5	1.0	1.7	225.0	0.0	1.2	4.6	67.5
23	4x5	6.2	61	1.5	53.8	3.1	135.0	0.6	1.0	1.8	240.0	7.8	41.9	7.6	15.4
39	7x3	6.1	61	1.0	5.0	2.7	117.5	0.5	1.0	2.2	225.0	0.0	1.5	1.8	95.0
10	2x4	6.1	58	1.5	1.5	3.0	125.0	0.5	1.0	1.5	245.0	0.0	16.7	1.6	15.0
7	2x1	6.1	60	0.5	6.9	3.2	120.0	0.5	1.1	1.5	235.0	1.8	7.7	3.2	55.0
20	4x2	6.1	61	1.0	10.4	3.4	110.0	0.5	1.1	1.7	225.0	6.6	1.3	5.9	52.5
37	7x1	6.0	62	1.0	20.9	3.2	125.0	0.5	0.9	2.0	230.0	3.6	23.9	11.9	30.6
40	7x4	6.0	58	1.5	5.2	3.5	115.0	0.5	1.0	1.5	225.0	1.7	4.8	3.5	80.0
38	7x2	5.9	59	1.0	3.4	3.3	105.0	0.5	1.0	1.7	230.0	3.5	5.5	11.0	34.2
6	1x6	5.9	60	1.0	11.8	3.1	115.0	0.5	1.1	1.7	220.0	4.8	9.3	0.0	0.0
63	WH505	5.9	62	1.0	5.7	3.4	127.5	0.5	1.0	2.0	235.0	6.0	10.1	15.0	49.0
33	6x3	5.9	62	0.0	8.0	3.4	107.5	0.4	1.2	1.8	245.0	0.0	8.3	7.5	58.4
64	H513	5.8	60	1.5	19.7	3.4	150.0	0.6	1.0	1.7	242.5	12.5	7.1	4.8	17.5
59	10x5	5.8	59	0.5	6.2	3.0	117.5	0.5	0.9	2.5	220.0	0.0	15.1	1.5	45.0
17	3x5	5.6	62	1.5	6.6	3.8	125.0	0.5	1.1	1.5	232.5	0.0	11.0	6.3	42.5
54	9x6	5.5	58	0.5	29.7	3.3	122.5	0.5	1.1	1.4	230.0	15.9	20.1	5.0	67.5

18	3x6	5.4	59	1.0	7.0	3.6	120.0	0.5	1.2	1.5	225.0	0.0	9.1	1.4	75.0
8	2x2	5.4	59	1.0	3.5	3.1	102.5	0.5	1.0	1.6	217.5	0.0	5.8	0.0	0.0
62	WH507	5.1	64	0.5	8.4	3.1	110.0	0.5	1.0	2.1	222.5	0.0	24.8	0.0	0.0
42	7x6	4.9	58	1.5	14.8	4.2	100.0	0.4	1.1	1.8	225.0	7.0	4.2	10.3	33.3
41	7x5	4.8	61	0.5	38.2	3.6	112.5	0.5	0.9	2.5	222.5	0.0	22.0	6.2	45.0
61	DK8031	4.8	60	1.5	16.7	3.6	120.0	0.5	1.0	1.7	225.0	4.8	3.8	27.1	63.3
45	8x3	4.7	59	0.0	17.3	3.4	110.0	0.5	1.2	1.7	235.0	2.7	2.7	2.4	95.0
14	3x2	4.6	61	2.5	1.5	3.7	102.5	0.5	0.9	1.5	227.5	0.0	0.9	0.0	0.0
43	8x1	4.3	59	0.5	25.6	3.6	127.5	0.6	1.2	1.8	230.0	0.0	25.9	2.3	95.0
Mean		6.5	60	1.1	14.8	3.2	116.0	0.5	1.0	1.7	231.3	2.4	13.6	4.2	44.0
LSD		2.0	2.1	1.6	16.9	0.6	20.9	0.1	0.2	0.5	16.6	7.2	19.2	7.3	0.0
SED		1.0	1.0	0.8	8.3	0.3	10.3	0.0	0.1	0.3	8.2	3.6	9.4	3.6	22.9

†GY,grain yield; AD,days to 50% pollen shed ; ASI,Anthesis Silking Interval; HC,husk Cover ;EA, ear Aspect ; EH,ear height; EPO,ear position; EPP, ears per plant; ET, *ersohilum turcicum*, ,PH,plant height; RL,root lodging; SL,stem lodging; FSE, Fusarium severity; FSI, Fusarium incidence

Appendix 14: Table of means for grain yield, agronomic traits, and fusarium disease parameters at Kakamega under artificial inoculation.

Hybrid	cross	GY†	AD	ASI	HC	EA	EH	EPO	EPP	MOI	GLS	ET	PA	PH	FSI	FSE	FWR
25	5x1	8.2	75	0.5	56.0	2.7	122.5	0.5	1.0	15.5	2.3	2.7	2.0	237.5	23.9	34.4	0.4
35	6x5	7.9	73	0.0	10.0	2.5	135.0	0.5	0.9	17.8	3.0	3.4	3.2	280.0	14.2	61.9	0.3
8	2x2	7.6	71	0.0	0.0	2.8	92.5	0.4	1.0	12.5	1.5	1.7	1.8	230.0	18.3	47.5	0.6
14	3x2	6.8	72	-1.5	3.0	3.0	97.5	0.4	1.0	15.6	1.5	1.6	1.7	247.5	10.9	65.0	0.3
29	5x5	6.5	75	1.5	59.5	2.8	120.0	0.4	1.2	14.0	2.7	2.8	2.8	277.5	15.1	36.3	0.1
23	4x5	6.5	75	1.5	77.5	2.5	130.0	0.5	0.9	15.3	3.3	3.0	2.6	265.0	41.8	19.3	0.0
5	1x5	6.3	76	-1.0	46.5	2.7	137.5	0.5	0.9	18.4	3.7	2.3	3.2	272.5	33.6	8.3	0.0
11	2x5	6.2	74	-1.0	23.0	2.5	117.5	0.5	1.1	16.6	2.3	2.8	2.8	257.5	10.6	15.8	0.5

58	10x4	6.0	70	0.0	0.0	2.8	107.5	0.5	0.9	16.7	1.5	3.3	2.0	237.5	29.0	43.1	0.3
26	5x2	5.9	73	-0.5	8.5	3.5	120.0	0.5	1.1	18.4	3.2	2.0	2.2	252.5	26.7	61.4	0.7
34	6x4	5.9	69	-0.5	1.5	2.6	110.0	0.4	0.9	15.8	3.0	3.1	2.1	257.5	15.2	44.3	0.4
63	WH505	5.9	73	-2.0	5.5	3.0	132.5	0.5	1.0	16.9	3.2	2.3	2.6	280.0	47.9	59.8	0.7
46	8x4	5.8	69	-1.0	3.0	2.8	115.0	0.5	0.9	15.6	2.5	1.8	1.5	230.0	53.9	40.4	0.4
16	3x4	5.8	71	1.0	6.5	2.3	95.0	0.5	0.9	16.6	2.3	2.2	2.1	227.5	8.3	26.7	0.2
17	3x5	5.7	72	-0.5	31.5	2.9	112.5	0.5	1.0	15.7	1.8	2.0	2.2	232.5	13.6	73.6	0.0
19	4x1	5.6	74	2.0	56.0	2.8	110.0	0.5	1.0	17.3	2.3	2.7	2.2	235.0	31.3	29.5	0.5
50	9x2	5.5	73	-0.5	0.0	3.1	110.0	0.5	1.0	16.0	2.7	2.3	2.3	240.0	23.0	66.4	0.9
22	4x4	5.5	72	1.0	3.5	3.7	117.5	0.5	1.1	18.5	3.8	2.3	2.3	245.0	21.8	28.8	0.0
3	1x3	5.5	72	0.5	1.5	2.4	115.0	0.5	1.0	15.0	3.2	2.0	2.3	255.0	7.0	31.7	0.4
13	3x1	5.4	72	1.0	43.0	2.5	95.0	0.5	0.9	15.9	2.2	2.6	1.7	215.0	5.7	22.5	0.1
47	8x5	5.3	71	-2.0	74.0	3.3	117.5	0.5	1.3	14.6	2.3	2.3	2.5	255.0	28.3	34.6	0.1
18	3x6	5.3	72	1.0	2.0	2.8	115.0	0.5	1.0	16.7	1.5	2.3	2.0	225.0	7.5	56.3	0.2
31	6x1	5.2	72	0.0	43.0	2.8	120.0	0.5	1.2	16.6	2.0	3.5	2.2	250.0	39.7	36.0	0.5
40	7x4	5.2	72	1.5	0.0	3.0	105.0	0.5	0.8	14.6	3.8	2.4	3.0	222.5	26.4	80.0	0.6
45	8x3	5.2	71	-0.5	13.5	3.5	100.0	0.4	1.5	12.0	2.3	2.7	2.0	242.5	29.6	72.5	0.8
59	10x5	5.2	72	0.0	24.5	3.0	110.0	0.5	1.0	14.5	1.5	4.0	2.6	262.5	10.3	44.2	0.2
2	1x2	5.1	72	0.0	0.0	3.0	102.5	0.5	1.1	15.7	3.5	2.0	1.5	240.0	17.2	34.2	0.2
60	10x6	5.1	71	-1.0	0.0	3.0	97.5	0.5	0.9	12.9	1.5	3.1	2.7	215.0	17.0	58.6	0.4
32	6x2	5.0	70	0.5	0.0	3.1	112.5	0.5	1.0	19.2	2.2	2.5	1.7	235.0	21.8	59.7	0.9
53	9x5	5.0	72	-1.0	14.0	2.7	120.0	0.5	0.9	14.4	4.0	2.1	2.8	270.5	7.5	18.8	0.1
12	2x6	5.0	71	0.0	12.0	2.6	105.0	0.4	1.0	15.7	2.5	2.7	2.7	235.0	24.3	60.0	0.6
30	5x6	4.9	72	0.0	30.5	2.8	110.0	0.5	1.4	16.2	3.0	2.5	2.5	212.5	17.0	37.1	0.3
27	5x3	4.9	75	-1.0	9.0	3.0	110.0	0.5	1.0	13.6	3.0	2.0	2.1	242.5	14.1	47.7	0.5
55	10x1	4.9	73	0.5	22.0	2.5	90.0	0.5	0.8	17.1	1.7	4.6	3.0	220.0	28.2	44.4	0.1
33	6x3	4.8	73	1.0	28.0	2.8	110.0	0.5	1.1	15.9	2.5	2.7	1.7	235.0	10.2	20.8	0.5
62	WH507	4.8	74	1.5	3.5	2.8	127.5	0.5	0.9	15.6	2.5	2.5	2.5	257.5	31.8	57.3	0.7
38	7x2	4.8	71	0.0	0.0	3.5	102.5	0.4	1.1	17.4	3.3	2.5	2.0	262.5	74.5	45.3	1.7
10	2x4	4.8	72	0.5	3.5	2.0	97.5	0.4	0.9	15.3	2.3	2.7	2.5	230.0	3.1	40.0	1.7
9	2x3	4.6	72	-0.5	0.0	2.5	110.0	0.5	0.9	16.3	3.2	3.0	2.7	257.5	7.7	50.5	0.1

44	8x2	4.5	71	-1.0	3.5	3.2	97.5	0.4	1.3	16.3	2.0	1.9	1.5	240.0	38.3	68.5	0.9
48	8x6	4.4	70	-1.0	24.0	3.2	110.0	0.5	1.2	15.1	2.5	2.0	2.3	215.0	63.9	45.1	0.6
15	3x3	4.4	72	0.0	0.0	2.5	100.0	0.4	1.0	14.6	3.0	2.0	2.2	237.5	28.8	66.7	0.6
24	4x6	4.4	73	0.0	58.5	2.4	117.5	0.5	1.1	14.6	3.0	2.7	2.5	230.0	15.6	61.6	0.4
39	7x3	4.3	73	0.0	2.0	4.0	117.5	0.5	1.1	13.0	4.3	2.4	2.5	252.5	49.4	66.9	0.5
41	7x5	4.2	73	0.0	26.5	3.1	110.0	0.5	0.9	14.1	2.8	3.0	2.3	250.0	14.5	33.2	0.5
61	DK8031	4.2	70	-1.0	11.5	4.0	105.0	0.5	0.9	14.6	2.2	2.0	3.3	210.0	69.5	38.3	0.9
21	4x3	4.1	75	1.5	20.5	3.1	105.0	0.5	1.0	15.0	3.2	2.2	2.0	247.5	36.5	57.6	0.4
28	5x4	4.1	72	1.0	22.0	2.9	102.5	0.5	1.3	13.8	4.0	2.3	2.5	227.5	49.0	33.7	0.1
36	6x6	4.1	70	0.5	1.5	2.5	127.5	0.5	1.2	18.2	3.0	3.0	2.8	260.0	27.3	76.4	1.1
1	1x1	4.0	77	0.0	61.0	2.9	117.5	0.5	1.2	13.4	2.8	2.7	2.4	237.5	25.3	55.0	0.7
56	10x2	3.9	74	-1.0	0.0	3.3	110.0	0.5	1.0	16.7	1.5	3.0	2.2	247.5	32.0	65.4	0.9
37	7x1	3.8	72	0.0	29.5	3.9	115.0	0.5	0.8	14.3	3.3	3.5	3.0	237.5	30.4	40.3	0.6
4	1x4	3.7	72	0.5	7.0	2.9	107.5	0.5	1.1	14.7	4.0	2.2	2.5	235.0	43.8	27.8	0.7
7	2x1	3.7	73	1.5	4.5	2.5	117.5	0.5	1.1	14.7	3.0	2.8	2.8	247.5	14.5	35.6	0.3
52	9x4	3.6	71	-1.0	4.0	3.7	95.0	0.4	1.0	16.0	4.5	2.0	3.0	215.0	63.5	35.0	0.4
43	8x1	3.5	72	-0.5	66.5	3.3	115.0	0.5	1.1	15.5	2.0	2.6	2.5	232.5	24.0	37.5	0.1
57	10x3	3.5	75	-1.0	0.0	2.5	115.0	0.5	0.9	14.7	1.7	4.0	1.9	262.5	12.0	86.3	0.6
6	1x6	3.4	72	1.0	13.0	3.3	110.0	0.5	1.2	15.2	3.5	2.3	2.0	245.0	14.8	45.8	0.8
20	4x2	3.4	74	1.0	1.5	3.2	107.5	0.4	1.0	16.4	2.5	1.7	2.0	247.5	20.2	68.3	0.5
64	H513	3.3	71	-1.0	2.5	2.9	122.5	0.6	1.0	14.8	4.2	2.8	3.5	227.5	56.4	41.1	0.7
51	9x3	2.6	73	0.0	0.0	3.8	100.0	0.4	0.9	14.6	4.5	2.5	3.0	235.0	11.3	53.3	0.3
42	7x6	2.6	71	0.0	9.0	3.7	95.0	0.5	0.9	14.2	3.5	3.2	3.0	212.5	42.3	62.4	1.0
54	9x6	2.4	70	0.0	9.0	3.0	115.0	0.5	0.9	15.7	4.0	2.0	3.6	225.0	42.5	51.6	0.6
49	9x1	1.8	74	1.5	21.0	3.0	102.5	0.5	1.1	16.3	3.7	2.5	3.0	217.5	3.7	40.0	0.2
Mean		4.9	72	0.0	17.4	2.9	110.8	0.5	1.0	15.5	2.8	2.6	2.4	241.3	26.5	47.0	0.5
LSD		2.9	2.5	2.7	28.6	0.6	25.1	0.1	0.3	4.1	0.7	0.5	0.8	25.7	27.7	43.0	0.9
SED		1.4	1.2	1.3	14.0	0.3	12.3	0.1	0.2	2.0	0.3	0.2	0.4	12.6	13.6	21.1	0.5

†GY,grain yield; AD,days to 50% pollen shed ; ASI,Anthesis Silking Interval; HC,husk Cover ; EA, ear Aspect ; EH,ear height; EPO,ear position; EPP, ears per plant; MOI,moisture; GLS,grey leaf spot; ET,*exserohilum turcicum*; PA,plant aspect; PH,plant height; FSI, Fusarium incidence ; FSE, Fusarium severity

Appendix 15: Table of means for grain yield, agronomic traits, and fusarium disease parameters at Kakamega under natural disease pressure.

Hybrid	Cross	GY†	AD	ASI	HC	EA	EH	EPO	EPP	GLS	ET	PA	PH	FSI	FSE	FWR
		t/ha	d	d	%	1-5	cm	0-1	#	1-5	1-5	1-5	cm	%	%	t/ha
8	2x2	7.9	70	0.5	0.0	2.2	117.5	0.5	1.1	1.6	1.5	2.0	257.5	8.6	48.7	1.2
17	3x5	7.7	74	0.0	7.2	2.6	120.0	0.5	1.1	1.5	2.1	2.5	255.0	9.5	58.4	0.8
5	1x5	7.1	74	0.0	20.7	2.7	135.0	0.5	0.9	3.0	3.3	3.0	267.5	22.2	13.5	0.5
38	7x2	6.2	72	0.0	0.0	3.4	100.0	0.4	1.1	2.3	2.8	1.8	242.5	42.2	49.7	1.4
23	4x5	6.0	72	0.0	15.5	2.8	125.0	0.5	1.1	3.1	3.2	3.0	262.5	25.1	38.9	0.4
59	10x5	5.9	73	0.0	3.1	2.6	100.0	0.4	1.0	1.8	2.8	2.5	250.0	12.0	39.2	0.5
13	3x1	5.9	72	0.0	28.3	2.6	107.5	0.5	1.1	1.5	1.8	2.3	232.5	9.7	40.8	0.3
36	6x6	5.8	70	0.5	3.5	2.5	110.0	0.5	1.3	2.7	2.8	2.0	235.0	18.0	66.6	0.6
29	5x5	5.8	73	0.0	36.1	2.5	127.5	0.5	1.2	2.9	2.9	2.8	260.0	15.7	54.9	0.8
58	10x4	5.7	72	-0.5	0.0	2.5	107.5	0.5	0.9	2.5	2.5	2.3	232.5	17.5	49.4	0.7
32	6x2	5.7	71	0.0	0.0	3.1	117.5	0.4	1.2	1.8	2.0	1.5	267.5	7.2	79.3	1.6
34	6x4	5.6	71	0.5	0.0	2.5	110.0	0.5	1.2	2.6	2.9	2.0	240.0	11.1	50.0	0.7
14	3x2	5.6	72	0.0	0.0	2.8	102.5	0.5	1.0	1.7	1.8	1.5	230.0	26.9	52.5	0.3
47	8x5	5.6	72	0.5	3.0	2.8	105.0	0.5	1.6	2.3	2.3	2.3	225.0	20.0	25.2	0.3
44	8x2	5.4	71	0.5	0.0	3.3	97.5	0.4	1.1	1.8	2.1	1.5	222.5	39.1	64.0	1.3
26	5x2	5.4	71	0.0	5.7	3.0	102.5	0.4	1.1	2.4	2.3	1.8	247.5	18.7	40.1	1.6
20	4x2	5.3	73	-1.5	15.1	2.7	105.0	0.4	1.0	2.3	2.3	1.5	255.0	22.2	57.3	0.7
35	6x5	5.1	74	0.0	5.0	2.5	140.0	0.5	0.9	2.6	2.7	3.0	295.0	12.7	38.7	0.2
16	3x4	5.0	70	0.5	0.0	2.5	112.5	0.5	1.0	2.8	2.7	3.3	245.0	6.1	48.7	0.6
30	5x6	4.9	70	0.5	6.3	3.0	107.5	0.5	1.3	3.3	3.3	2.8	215.0	21.0	30.4	0.8
56	10x2	4.8	70	0.5	0.0	2.8	100.0	0.4	1.0	2.2	2.7	1.5	252.5	27.1	65.0	0.9
62	WH507	4.7	73	0.0	0.0	2.5	95.0	0.4	1.1	2.1	2.5	3.3	222.5	28.7	61.1	1.5
27	5x3	4.7	74	-1.0	12.0	3.1	100.0	0.4	1.1	2.6	2.7	2.0	227.5	16.5	52.6	0.7
2	1x2	4.7	71	0.5	0.0	2.8	107.5	0.4	1.0	3.2	3.5	1.5	252.5	9.3	30.3	0.7
11	2x5	4.7	73	-0.5	5.0	3.0	125.0	0.5	1.4	1.8	2.0	3.0	260.0	6.5	27.8	0.0

41	7x5	4.6	72	0.5	15.1	2.9	127.5	0.5	1.2	2.8	3.2	2.0	247.5	21.3	49.9	0.4
50	9x2	4.6	70	0.5	0.0	2.8	105.0	0.4	1.0	2.7	2.7	2.0	245.0	31.0	62.9	1.4
10	2x4	4.5	72	0.5	0.0	2.3	127.5	0.5	0.9	2.1	2.3	3.0	250.0	10.4	53.8	1.0
12	2x6	4.5	71	0.5	13.7	2.5	85.0	0.4	1.3	2.3	2.5	2.5	195.0	21.0	56.4	0.6
3	1x3	4.4	74	0.5	0.0	2.7	100.0	0.4	0.9	3.5	3.5	1.8	242.5	7.7	63.1	0.4
53	9x5	4.4	72	0.0	0.0	2.5	112.5	0.5	1.0	3.2	3.3	2.8	247.5	10.1	68.7	0.8
9	2x3	4.4	71	0.0	0.0	2.5	125.0	0.5	1.0	2.9	3.3	3.0	257.5	9.4	70.5	0.7
63	WH505	4.4	73	0.5	1.5	2.9	120.0	0.5	1.0	2.3	2.9	3.0	240.0	34.3	55.8	1.1
25	5x1	4.3	74	0.5	21.6	3.3	112.5	0.5	1.0	1.8	2.1	2.3	237.5	29.6	31.4	2.4
60	10x6	4.2	70	0.5	19.6	3.0	107.5	0.5	1.1	1.7	2.3	2.3	222.5	41.5	56.5	1.3
61	DK8031	4.2	71	0.0	7.7	4.0	105.0	0.5	1.0	2.0	2.5	3.0	227.5	45.1	48.5	0.8
15	3x3	4.2	73	0.0	9.1	2.5	102.5	0.4	1.0	2.5	2.7	2.3	240.0	23.3	35.1	0.8
19	4x1	4.2	75	1.0	16.9	3.0	105.0	0.5	0.9	1.8	2.0	2.5	237.5	25.8	43.5	0.4
7	2x1	4.0	72	-1.0	5.4	2.5	115.0	0.5	0.8	2.8	3.0	2.8	247.5	14.8	42.6	0.8
18	3x6	4.0	72	0.0	0.0	2.6	102.5	0.4	1.1	1.7	2.1	2.3	237.5	6.2	65.2	0.6
31	6x1	4.0	73	0.5	0.0	2.5	95.0	0.4	0.9	1.9	2.7	2.5	222.5	29.5	26.1	0.4
1	1x1	3.8	75	0.5	21.1	2.8	122.5	0.5	1.1	2.1	3.0	3.0	245.0	22.3	27.1	1.1
48	8x6	3.5	69	0.5	22.0	3.0	117.5	0.5	1.3	1.9	2.7	2.3	247.5	41.1	65.3	1.1
46	8x4	3.5	70	0.5	0.0	3.3	102.5	0.5	1.1	2.0	2.5	2.0	225.0	52.8	50.9	1.5
22	4x4	3.4	71	0.0	4.2	2.8	120.0	0.5	1.1	3.6	3.6	2.0	242.5	11.7	46.8	0.6
52	9x4	3.4	70	1.0	0.0	3.0	105.0	0.5	1.0	3.3	3.7	3.5	222.5	14.4	44.6	0.2
21	4x3	3.4	74	1.5	3.4	3.1	102.5	0.4	0.9	3.0	3.1	2.3	245.0	17.1	44.0	0.5
37	7x1	3.2	72	0.0	7.4	3.3	110.0	0.5	1.1	2.7	2.7	3.0	227.5	27.8	39.9	0.9
24	4x6	3.0	74	0.5	25.0	3.0	127.5	0.5	1.2	2.5	3.1	3.0	242.5	7.4	71.3	0.6
33	6x3	3.0	73	0.0	5.6	2.8	125.0	0.5	1.4	3.1	3.5	2.3	277.5	7.4	25.0	0.3
28	5x4	2.9	72	0.0	9.6	3.5	112.5	0.5	0.9	3.3	3.3	2.5	222.5	37.2	30.2	1.2
43	8x1	2.8	69	0.0	25.0	3.0	112.5	0.5	1.4	2.2	2.7	2.8	227.5	20.8	3.8	0.3
57	10x3	2.8	73	0.0	3.6	3.1	100.0	0.4	0.8	2.2	3.0	2.3	235.0	4.1	44.8	0.3
55	10x1	2.8	73	0.0	16.0	3.1	112.5	0.5	1.1	2.0	3.0	3.5	230.0	28.0	40.1	0.7
64	H513	2.7	70	0.5	4.6	3.3	127.5	0.5	1.0	3.6	3.5	3.3	267.5	17.3	54.0	0.9
4	1x4	2.7	73	0.5	0.0	3.1	110.0	0.5	0.7	3.3	3.2	2.5	237.5	29.4	34.9	1.3

6	1x6	2.6	74	0.5	2.8	3.2	107.5	0.5	0.9	2.6	2.6	2.5	232.5	17.4	42.7	0.4
51	9x3	2.5	71	0.5	6.9	3.5	102.5	0.5	1.1	3.4	3.5	2.5	232.5	16.2	54.6	0.5
39	7x3	2.5	71	1.0	0.0	4.3	120.0	0.5	1.1	3.6	3.6	2.8	255.0	66.2	33.3	1.5
45	8x3	2.4	72	-0.5	7.2	3.5	102.5	0.4	1.0	2.3	2.2	2.0	247.5	36.1	58.1	0.5
40	7x4	2.3	69	0.0	0.0	3.5	97.5	0.5	1.1	3.3	3.3	2.8	215.0	37.0	56.3	0.9
49	9x1	2.1	73	-0.5	19.1	3.0	102.5	0.5	1.0	3.3	3.5	2.8	215.0	18.2	45.1	0.4
42	7x6	2.1	72	0.0	17.4	3.9	95.0	0.5	1.0	3.2	3.1	3.5	202.5	47.7	53.0	0.6
54	9x6	1.8	70	0.0	12.9	4.0	112.5	0.5	0.7	3.3	3.2	3.3	235.0	52.3	51.2	1.4
Mean		4.3	72	0.2	7.7	2.9	110.5	0.5	1.1	2.5	2.8	2.5	240.3	22.6	47.3	0.8
LSD		2	2.3	1.4	22	0.54	22	0.1	0.4	0.7	0.6	0.8	25.3	19	40	0.9
SED		1	1.2	0.7	11	0.26	10.8	0	0.2	0.3	0.3	0.4	12.4	9.5	20	0.5

† GY, grain yield; AD, days to 50% pollen shed ; ASI, Anthesis Silking Interval; HC,husk Cover ; EA, ear Aspect ; EH,ear height; EPO,ear position; EPP, ears per plant; GLS,grey leaf spot; ET, *ersohilum turcicum*; PA,plant aspect; PH,plant height; FSI, Fusarium incidence; FSE, Fusarium severity; FWR, weight of rotten ears.