PHENOTYPIC CHARACTERIZATION OF SELECTED LOCAL MAIZE LANDRACES FOR DROUGHT TOLERANCE BASED ON FLOWERING STRESS, AND THEIR RESISTANCE TO LARGER GRAIN BORER (*Prostephanus truncatus*) IN KENYA

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DECLARATION AND RECOMMENDATION

DECLARATION

This is my original work and has not been presented in this or any other University for the award of a degree.

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RECOMMENDATION

This work has been submitted with our approval as University Supervisors.

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DEDICATION

This thesis is dedicated to my daughter Ciku for courageously bearing with my absence and remaining steadfast and focused at her own education at such a tender age.

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ABSTRACT

Maize is staple food in Kenya and is grown in almost all agro-ecological zones. The average maize yield in the highlands is about 3.5 t/ha while that for the arid and semi arid (ASALs) low altitude areas is less than 1.3 t/ha. Arid and semi arid areas constitute about 82% of the total land area and supports about 20% of the country's human population. The demand for more food culminating from the population increase and the migration of people from high potential areas to semi arid lowlands has led to maize growing in marginal areas. Kenya's ASALs are home to the very rural poor who practice subsistence farming as a livelihood. Local landraces of maize are an important livelihood resource in these areas. The objective of the study was to characterize selected Kenyan local maize landraces for drought tolerance and resistance to larger grain borer in storage. The characterization for drought tolerance was carried out using secondary traits that exhibit high heritability for drought tolerance such as grain yield, anthesis-silking interval (ASI), tassel size, ears per plant and leaf rolling. The experiment was laid out in a lattice design (unbalanced) each with sixty-four maize genotypes. A second experiment to evaluate drought tolerance was conducted for landraces that exhibited favorable tolerance characteristics. This experiment was laid out in a split plot (RCBD) design with water levels (water stressed and unstressed, at flowering) as the main plots and germplasm as the sub plots. Irrigation was withheld one week to tasseling and resumed forty days later in water stressed plots. The well-watered plots had continuous irrigation. The field experiments were carried out at KARI-Masongaleni field station in Kibwezi district, which falls under agro-ecological zone VI. Among the characters evaluated, a low ASI (1-6 days) was associated with a high level of drought tolerance and low yield losses under moisture stress. Drought stress resulted in 17% to 81% relative grain yield losses. Germplasm GBK-032419, DT/BT/1470.DT and GBK-034659 exhibited lowest grain yield losses of 28%, 22% and 17% while KTL N 70140-4, KTL N 10162-1 and Makueni Dry Land Composite (control) exhibited high grain yield losses of 81%, 70% and 68%, respectively. However, Katumani inbred lines DT/BT/1917.DT and DG/BT/2443.DT, though exhibiting the shortest ASI of about 1 day experienced about 50% grain yield loss under moisture stress. In general, an increase in number of ears per plant, 100-seed weight, increased plant height, high shelling %, reduced leaf rolling and low ASI were associated with yield increases under water stress. Germplasm that exhibited favorable drought tolerance characteristics were CML-492, DT/BT/1917.DT, DT/BT/1470.DT, DG/BT/2443.DT, GBK-044593, GBK-032419, GBK-032423, GBK-34659, KTL N 701104 and GBK-032357. The most susceptible germplasm (ASI between 12-17 days) were KTL N 70133-3, KTL N 10168-1, Katumani Composite B, Makueni Dry Land Composite, KTL N 10168-2, GBK-043227, GBK-034711 and GBK-027054. The germplasm that exhibited drought tolerance characteristics were further evaluated for resistance to larger grain borer (LGB) damage in storage. This experiment was done at CIMMYT field laboratory-Kiboko. Samples were laid out in complete randomized design and replicated three times. Although no absolute resistance existed, most landraces exhibited higher levels of resistance to LGB than the control variety H614. The germplasm with the highest resistance level was CML-492, while GBK-043731 had the lowest level. Germplasm CML-492, DT/BT/1971.DT, DT/BT/1470.DT, DG/BT/2443.DT, GBK-044593, GBK-032419, GBK-032423, GBK-34659 and GBK-032357 exhibited tolerance to drought and also resistance to LGB relative to control H614. Katumani Composite B, though exhibiting susceptibility to drought, had a high level of resistance to LGB than most local landraces. It was concluded that some Kenyan local landraces exhibit drought tolerance characteristics and also resistance to LGB. According to factor analysis, the phenotypic characteristics evaluated for drought tolerance accounted for 68% of the total variation.

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CHAPTER ONE

INTRODUCTION

1.1 Background information

About 82% of Kenya’s landmass is arid and semi arid lands (ASALs) (Government of Kenya, 2004). These areas that are sometimes referred to as ‘dry lands’, make up agro-ecological zones (AEZ) IV, V, VI and VII (Jaetzold and Schmidt, 1983; Government of Kenya, 2004). The bulk of food and cash crop is produced on about 18% of the remaining landmass that is classified as medium to high potential agricultural land. Over the years, production has been decreasing and there have been periodic imbalances between food production and demand as the population increases (Mati, 2000). Kenya’s current human population of about 35 million people, has annual population growth rate of about 2.8% and is expected to reach about 36.5 million people by the year 2010 (Kenya National Bureau of Statistics, 2007). The rapid population increase has led to intensive cultivation of existing farms and movement into previously un-cropped areas (Mugo *et al.*, 1998). Food requirement that is not met by the medium to high potential agricultural areas has to come from previously unused ASALs that are characterized by low and unreliable rainfall and high evapotranspiration rates (Jaetzold and Schmidt, 1983; KARI, 2004). This may explain why production of maize, the country’s staple food, fails completely in 7 out of 10 seasons in ASALs (Jaetzold and Schmidt, 1983).

The rainfall problem in Kenya is not only spatial but also temporal in nature, i.e. amounts vary significantly from year to year and from place to place (Hassan *et al.*, 1998). Paradoxically, even the areas classified as medium to high potential agricultural land also experience periodic transient droughts that affect crop production. The challenge to crop production in dry land areas is compounded by the fact that the occurrence, timing and severity of drought fluctuate from year to year (Ribaut *et al.*, 2002). Overcoming the drought problem is a challenge that can be solved by provision of irrigation water and / or technologies packaged as drought tolerant cultivars with characteristics likely to withstand drought conditions. In Kenya, technologies such as irrigation exist but most growers are resource-poor and cannot afford them. Furthermore, irrigation is becoming a lesser solution as global water demand increases (Boyer and Westgate, 2004). Improvement of ASALs therefore lies strongly in the use of improved genotypes for drought tolerance and yield stability since this can be conveniently packaged and easily adopted. Stress tolerant maize varieties offer a means of stabilizing yields at no additional cost to the farmer (Edmeades *et al*., 1997).

Maize (*Zea mays* L.) is the third ranking cereal crop in the world after wheat and rice and accounts for 20% of the total area under cereals (FAO, 2005). In Kenya, maize is the most important staple food crop grown on about 1.6 million hectares of land (FAO, 2005; Wekesa, 2003). Although maize is a popular crop, the yield realized by farmers (about 1 t/ha) is far below the global yield potential of 8 t/ha (FAO, 2004). The sub-optimal yields realized have been attributed to biotic and abiotic constraints. The most important biotic stresses include diseases and insect pests such as stalk borers and stored grain pests. Among the abiotic factors, drought stress associated with low and unreliable rainfall and low soil fertility are the most important among the abiotic factors (Sallah *et al*., 2002). The mean yield loss associated with drought in maize has been estimated to be 17% per year in the tropics (Edmeades *et al*., 1992).

Crops experience drought stress when water requirements at one or more growth stages exceed the available water in the root zone (Seetharama, 1995). Maize is most susceptible to drought stress during flowering. Water deficits during specific stages of floral development can severely reduce seed set by increasing pollen sterility, abortion of embryos and / or premature end of grain filling (Passioura, 2006). Water stress at flowering can lower grain yield in maize to near zero. The ongoing climatic changes attributable to global warming are likely to increase pressure for food production in water-limited environments (Ribaut *et al.,* 2002). In Kenya although impressive yield increase has been achieved through conventional breeding, potential for genetic improvement of maize production especially under drought conditions still remains high (Hassan *et al.,* 1998; Ribaut *et al.,* 2002). For example, the first hybrid maize in Kenya H621 with a potential yield of 3 t/ha was released in 1964 (Leakey, 1970). The latest hybrid variety H628, with a potential yield of 10 t/ha was released in 2003 (Muasya, personal com). In spite of the existence of high yielding varieties, farmers continue to realize low maize yields. Recent research aimed at finding out reasons for the big and expanding yield gap between zones identified the need for site-specific management (Hassan *et al.*, 1998; Tabu, 2004).

Traditionally, agro-ecological zones for maize production have been classified as lowlands, midlands and highlands and breeding work has used the classification for varietal development (Jaetzold and Schmidt, 1983). Lately, through the maize database project (MDBP), major maize growing areas have been identified, redefined and digitally mapped using geographical information systems (Hassan *et al.,* 1998). The areas are the lowland tropics (3.2%), mid-altitude (19%), transitional (44.5%), highland tropics (29.6%) and extreme water stress zones (3.7%), accounting for 33000ha, 197000ha, 461000ha, 307000ha and 39000ha of total maize area, respectively. In addition to the search for materials with high inherent yielding ability across the diverse maize growing environments, dealing with agro-climatic diversity is crucial for developing a sound maize breeding strategy in Kenya (Hassan *et al.*, 1998). While the maize growing regions have been delineated, crop genotype development has been slow, especially in the dry areas. In many marginal areas farmers use local landraces because they are perceived to perform better under low or no input use (Bellon *et al*., 2006). Participatory analysis for drought tolerance in maize in Eastern Kenya found that farmers preferred maize genotypes that matured early, yielded highly and tolerated drought, pests and diseases (Bett *et al.*, 2000). Some local maize landraces also have other desirable attributes like resistance/tolerance to major diseases and pests, tolerance to drought and productivity under low soil fertility.

In addition to drought stress, crop pests also affect the performance of maize genotypes in the dry areas. Post harvest insect pests have been found to jeopardize food security in Kenya (Gethi, 2002). Among the post harvest insect pests, the weevil (*Sitophilus* spp) and the larger grain borer (LGB) (*Prostephanus truncatus*) are the most important. The pests cause damage by feeding on stored grain and indirectly reduce grain quality when the injury point acts as avenues for fungi development. In recent years, the LGB has acquired the status of a serious pest of stored maize (Tigar *et al*., 1994). In Kenya, LGB attack cause losses of between 9 to 45% depending upon the period of storage and maize genotype. Insecticides such as Pirimiphos methyl 1.6% + Permethrin 0.3% (Actellic Super®) have been recommended for LGB control, but the measures have not checked the losses and spread of this destructive pest. The international grain trade, normal beetle flight activity and the pest's ability to survive and breed outside the storage environment have limited the success of control campaigns (Farrell, 2000). An integrated approach has been proposed to curb the pest and reduce use of pesticides (Hodges, 1994). As a tactic of integrated pest management (IPM), host plant resistance to insects is environmentally safe, economically feasible and socially acceptable.

While the existence of local maize landraces is recognized, their characteristics have not been documented (Chapman *et al.*, 2003). The existence of these highly valuable maize landraces represents a potential wealth of genetic material already adapted to widely varying environments in which maize is produced. Landraces are found growing in Eastern, Western, Coast, Nyanza and Rift valley provinces of Kenya (Gene Bank of Kenya, 2004). In an effort to understand and use the landraces, CIMMYT in conjunction with KARI has collected and stored them.

Phenotypic characterization is the first step in the description and classification of germplasm. Secondary traits are important in maize characterization for drought tolerance as they improve the precision with which drought tolerant germplasm can be identified (Banziger *et al.*, 2000). Further, secondary traits are correlated with yield and demonstrate segregation with high heritability under water-limited conditions (Ribaut *et al.*, 2002). The incorporation of LGB resistant genes into susceptible maize germplasm has been reported to reduce losses to less than 5% (Kumar, 2002). Traditional landraces have not been evaluated for resistance to LGB although biochemical studies have indicated presence of phenolics in maize grains to be correlated with their resistance to LGB (Arnason *et al.*, 1992). Local landraces can be an important source of resistance to LGB damage.

1.2 Statement of the problem

The high population in Kenya (estimated at 35 million) implies that more food has to be produced to achieve self-sufficiency. Since only about 18% of the country is classified as medium to high potential agricultural land, the remaining 82% that is arid to semi arid has to play a major role in providing for livelihoods of many Kenyans. The arid and semi-arid lands are however characterized by low and unreliable rainfall, high temperatures and evapotranspiration rates, pests and diseases. Studies have shown that production of maize, the country's staple food, fails completely in 70% of the cases in ASALs. In a bid to increase maize yield a lot of work has been done to develop hybrid maize varieties for the medium to high potential areas. These hybrid varieties have however failed to produce satisfactorily in the dry areas. Many farmers therefore continue to grow local landraces, which are perceived to perform better under drought stress and low input conditions. In addition to drought, pests such as the larger grain borer continue to inflict heavy losses on maize in the dry areas. The larger grain borer causes direct damage by feeding on stored grain and indirectly cause damage to grain through physical deterioration by encouraging fungal development, thus reducing grain quality. Although conventional control methods using insecticides have been recommended, they are expensive and not environmentally safe. Apart from collection and storage at the Gene Bank of Kenya, the local landraces have not been characterized for tolerance to drought and resistance to the larger grain borer damage. The Kenyan dry areas suffer from perpetual drought stress. Occasionally when a successful harvest is achieved, the larger grain borer damages the grain.

1.3 Objectives

1.3.1 General objective

To improve maize yield through selection of drought tolerant and larger grain borer resistant maize genotypes in the ASALs of Kenya.

1.3.2 Specific objectives

i. Identify drought tolerance phenotypic characteristics of maize landraces grown in Kenya.
ii. Determine the resistance level of local maize landraces grown in Kenya to the larger grain borer damage.
iii. Identify and document the Kenyan maize landraces that are tolerant to drought and also resistant to larger grain borer.

1.4 Hypotheses

i. There are no documented phenotypic characteristics of drought tolerant maize landraces grown in Kenya.
ii. There is no difference in the resistance level to the larger grain borer in local maize landraces grown in Kenya.
iii. There are no Kenyan maize landraces that are tolerant to drought and also resistant to the larger grain borer.

1.5 Justification

The human population in Kenya is expected to reach 36.5 million by 2010 at the current annual growth rate of about 2.8%. Arid and semi-arid areas represent about 82% of Kenya’s landmass.

Achievement of the first Millennium Development Goal (MDG) of eradication of extreme poverty and hunger require increased maize production in the high, medium and marginal areas. Maize is the main staple food in Kenya but most farmers especially in the marginal areas are generally resource-poor and cannot afford the expensive inputs required for its successful production. Although successful hybrids have been developed in Kenya, many farmers especially in the marginal areas continue to grow local landraces for their subsistence and livelihood because of the perception that they tolerate abiotic and biotic stresses. The landraces are an important genetic base for improvement of maize in the face of abiotic and biotic stresses. Stress tolerant maize offer a means of stabilizing yields at relatively less cost to the farmer. While the landraces have been grown for a long time, little has been documented about their specific characteristics. Phenotypic characterization of maize landraces for drought tolerance is a dynamic process in response to changing tools and environments and to study their unique genetic resources. Post harvest insect pests such as the LGB also inflict heavy losses to maize in Kenya. Larger grain borer has developed into a serious pest of stored maize in the dry areas since its accidental introduction into Kenya in 1983. The potential damage of this insect pest threatens the country's food self-sufficiency in this important crop. In Kenya, LGB attack cause losses of between 9 to 45% depending upon the period of storage and the genotype. Though traditional landraces are perceived to be more resistant to major storage pests, they have not been evaluated for resistance to LGB. There is need to evaluate available maize landraces for host plant resistance which can be incorporated in integrated management of LGB. Host plant resistance (HPR) is economical, ecologically sound and compatible with other control tactics. The phenotypic traits associated with drought tolerance and resistance to storage pests such as the LGB will help identify the desired landraces for planting in future and for use in maize breeding programs.

CHAPTER TWO
LITERATURE REVIEW

2.1 Maize improvement trends

Maize is the staple food crop of Kenyans. It is the third ranking cereal crop worldwide after wheat and rice, and accounts for about 20% of the total area under cereals in the world (FAO, 2005). The average maize yields of highland farmers in Kenya range from 2.8 to 3.5 t/ha though some achieve 7 t/ha while that for low altitude farmers is only 1.0 t/ha (FAO, 2005). The mean yields in national performance trials range from 6.0 to 8.0 t/ ha (FAO, 2005). Kenya produces a total of 1.3 million metric tons from 1.5 million hectares compared to a world production of 720 million metric tons from 150 million hectares. The farmers' average yield of less than 1 t/ha in Kenya is far below the global average yield of 8.0 t/ha (FAO, 2004). The current human population in Kenya is estimated at about 36 million people with a growth rate of 2.8% per year, implying that more food needs to be produced (Kenya National Bureau of Statistics, 2007). Studies have shown that since the mid-1970s there have been imbalances between food production and demand as population increases (Mati, 2000). For example, the total production of maize declined from 3.06 million tons in 1994 to 2.14 million tons in 2004, putting a lot of pressure on already overstretched resources (FAO, 2004). That about 80% of the population live in the rural areas and derive their livelihood largely from agriculture further compounds the problem.

Only 18% of Kenya is classified as medium to high potential agricultural land. The remaining (82%) is arid and semi arid lands (ASALs) and supports about 20% of Kenya's human population and 54% of the livestock population (Government of Kenya, 2004). Arid and semi arid lands have therefore to be used optimally if food security and poverty alleviation goals of MDGs are to be achieved. Unfortunately, ASALs are characterized by low unreliable rainfall (400mm) and high evapotranspiration rates (1650-2300mm) per year that constraints maize production (Jaetzold and Schmidt, 1983; KARI, 2004). In ASALs, production of maize, the country's staple food, has been found to fail completely in 7 out of 10 seasons (Jaetzold and Schmidt, 1983). Overcoming the drought stress problem is a challenge that must be tackled through provision of either irrigation water and / or technologies packaged as drought tolerant germplasm (Kusewa and Guiragossian 1991; Hassan *et al.,* 1998).

Generally, drought in the dry and hot areas also coincides with occurrence of pests such as LGB and weevils (Gethi, 2002). Controlling these pests will ensure that what is harvested is used for food security measures. Larger grain borer was accidentally introduced into Tanzania from where it spread to other parts of Africa (Hodges, 1994). The pest was later accidentally introduced into Kenya from Tanzania in 1983 and is inflicting heavy losses on maize and cassava (Republic of Kenya and GTZ-Kenya, 1993). The incorporation of LGB resistant genes into susceptible maize germplasm has been reported to reduce the losses to less than 5% (Kumar, 2002).

2.2 Maize production zones

In Kenya maize grows best between altitudes of 1200 m and 1800 m above sea level with adequate rainfall during the growing periods. Conventionally, there have been five major maize growing zones defined by both elevation and maturity periods (Mills *et al*., 1995). Using the maize data base project (MDBP) information, different regions have been identified, digitally mapped using geographical information systems (GIS) and classified as lowland tropics (3.2%), mid-altitude zone (19%), transitional zone (44.5%), highland tropics (29.6%) and extreme water stress areas (3.7%). Following the spatial characterization of maize production environments and development of maize agro climatic zones, the need for more work in specific niches such as the transitional and mid altitude zones was apparent (Hassan *et al.,* 1998).

The success story of maize production achieved earlier in Kenya in high potential areas was a result of generation of technology and research development (Hassan *et al.,* 1998). Further improvement has been hampered by pressure that population growth and farm subdivision has placed on effective soil management and more importantly, the expansion of maize production into more marginal environments (Kusewa and Guiragossian, 1991; Mugo *et al*., 1998). While maize growing regions have been delineated, the crop genotype development has been slow in the dry areas. In Kenya the bulk of maize is grown in the 18% of the landmass that represents medium to high potential agricultural land. Many hybrid varieties have been developed for these areas and their adoption is generally higher compared to those developed for marginal areas (Hassan *et al.*, 1998). The poor adoption of improved varieties in marginal areas has partly been attributed to the fact that most farmers in the marginal areas are poorly capitalized and unable to embrace hybrid maize production (Mugo *et al*., 1998).

2.3 The local landraces and variety development

Since the introduction of maize in Kenya, research mainly aimed at developing hybrids for the medium to high potential areas. For example, hybrid maize H621, with a potential yield of 3 t/ha was released in 1964 and the latest hybrid variety H628, with a potential yield of 10 t/ha was released in 2003 (Leakey, 1970; Muasya, personal com). In spite of the high yielding varieties, farmers continue to realize sub-optimal maize yields. Recent research aimed at finding out reasons for the big and expanding yield gap between the different zones identified the need for site-specific management (Hassan *et al*., 1998; Tabu, 2004).

Alongside the hybrids, local maize landraces continue to play an important role especially in the low altitude marginal areas (Bellon *et al*., 1996). In the lowland tropics of Kenya, recommended maize varieties are not popular and 70% of the farmers grow the local landraces (Wekesa *et al.*, 2003). Though maize variety development has been going on in Kenya for the last four decades, the maize data base project (MDBP) recently reported that 84% of farmers in the lowland tropics used local maize genotypes while those in the midland and highland zones used improved varieties. The high use of local genotypes in the lowland tropics could be attributed to several factors which include the farmers' lack of awareness of improved varieties, lack of access to improved varieties, unaffordable cost of improved maize seed, local genotype's resistance to biotic and abiotic stresses and other favorable grain quality characteristics (Hassan *et al.*, 1998). Research has also been slow for variety development in the low to mid altitude areas as compared to the higher potential areas. Most farmers in arid and semi-arid areas of Kenya are subsistence oriented, poorly capitalized and have little or no access to credit facilities that would enable them to acquire necessary inputs for successful hybrid maize production (Kusewa and Guiragossian, 1991). Thus, while many hybrids have been developed, many parts of Kenya where agriculture is practiced by resource-poor farmers with little or no use of external inputs have not benefited from the spectacular yield increases achieved through hybrids and use of inputs. For instance, in the marginal areas, local varieties are still grown, although both Katumani and Makueni Composites have been developed for those areas (Mugo *et al*, 1998). Local landraces perform better than hybrids under low or no fertilizer use (Bellon and Taylor, 1993). Generally, no fertilizer is usually used for maize production in the marginal environments mainly because of lack of finances (Hassan *et al.*, 1998).

Grain quality characteristics of the local and open–pollinated maize populations are also said to be more desirable than those of the highly productive hybrid types (Maziya-Dixon *et al.*, 2000; Bellon *et al*., 2006). Some landraces are more desirable physiologically, possessing such attributes as resistance or tolerance to major diseases of maize, tolerance to drought, and higher productivity under low soil fertility. In Kenya, the Ministry of Agriculture (1986) maize conservation report indicated that the husk cover of hybrid maize was generally inadequate to reduce field and storage damages substantially. The local landraces, selected over centuries for good seed stability, were however covered with a tighter and complete sheath. Local maize landraces possess adequate levels of horizontal resistance to pests and diseases than hybrid maize and are less affected by rot diseases and pest attacks (Robinson, 1996). In Malawi, ear rot due to fungal infections was significantly lower in local varieties both in the field and in storage (Kapindu *et al*., 1999). In Tierra Caliente, South America, some local landraces were comparable or even better than improved varieties in terms of grain and forage yields (Centro Regional Universitario, 1996). Today, landraces are grown under low input as well as high input agricultural technology, in subsistence-oriented and commercialized economies (Bellon and Taylor, 1993).

Genetic erosion undoubtedly occurs with the replacement of landraces by modern cultivars (Brush, 1995). When inbreeding projects began, the adapted landraces served as source of materials for line development (Walden, 1978). Meeting the future demand for increased yields to feed an increasing population requires exploitation of novel genetic resources (Skovmand, 2001). In Kenya local maize landraces have remained an important source of genetic material and diversity. The phenotypic traits associated with drought tolerance will help identify the desirable landraces for cultivation or for use in future breeding programs for maize improvement in the marginal areas.

2.4 Drought stress and plant growth response

Drought stress is defined as a period of months / season of little or no rains leading to yields being reduced by lack of moisture (Tollenaar and Wu, 1999). A crop experiences drought stress when its water requirement at one or more growth stages exceeds the available water in the root zone (Seetharama, 1995). Drought stress is a multi-dimensional process, affecting plants at various levels of their organization over space and time; hence the physiological responses are complex and often unpredictable (Frova *et al.*, 1999). Drought is an important climatic phenomenon, second only to soil fertility in limiting maize production in developing countries (Ribaut *et al.*, 1996). Drought environments are characterized by wide fluctuations in precipitation in quantity and distribution within and across seasons. High temperatures and low precipitation ranging between 200 – 700 mm per annum characterize arid and semi arid areas (Jaetzold and Schmidt, 1983). A majority of soils in the arid and semi-arid areas are low in organic matter and high in sand content and hence drought effect is amplified (CIMMYT, 1983; Kusewa and Guiragossian, 1991). An estimated 40% of maize sown in lowland tropical environments suffers yield reductions because of drought (Bolanos and Edmeades, 1996). Drought is a serious problem that has affected many regions of the world (Saleem *et al*., 2007). It has curtailed productivity of maize in West, Central and East Africa (Sallah *et al*., 2002).

Drought tolerance is the ability of a crop genotype to yield reasonable yield in spite of water stress (Mugo *et al*., 1998). Drought can be either in form of drought escape (where the plant completes critical physiological processes before drought sets in) or drought tolerance (where the presence of physiological mechanisms allows the plant a reasonable level of production despite the presence of drought). One approach to improving crop performance is to select for genotypes that have improved yield in water-limited environments (drought tolerant genotypes). Drought tolerance enables one genotype to be more productive than another under similar condition of drought (Gebrekidan, 1989; Banziger *et al*., 2000). The ability to give high yields in dry environments may be a function of drought avoidance, tolerance or both. Short season (early maturing) cultivars escape drought that occurs at either end of a rainy season, but normally have limited yield potential. Escape through early maturity is however rarely sufficient in Kenya because the occurrence of drought is erratic and often vary in intensity and timing as it occurs at any stage of growth (Mugo *et al*., 1998). In the tropics, loss to drought exceeds 20 million tons of grain per year, reaching up to 60% of expected grain yields in severely affected regions of Africa (Ribaut *et al*., 1996).

Drought stress can reduce maize yields through temporary leaf wilting, leaf rolling, early leaf senescence and reduced leaf area expansion, hence reduced canopy absorption of photosynthetically active radiation (PAR) (Brush, 1995). Drought stress also reduces the efficiency of PAR utilization to produce dry matter (the radiation use efficiency) and limit grain yield by reducing the harvest index (Bassetti and Westgate, 1993). The reduction can occur even in the absence of a strong reduction in total crop dry matter accumulation, if a brief period of stress coincides with the critical developmental stage around silking (Schussler and Westgate, 1995). Developing ovaries are weak sinks, and will fail if there is insufficient photosynthate available for their growth (Bassetti and Westgate, 1993). In wheat, lines from landrace collections have been identified that have very high chlorophyll concentration, which may increase leaf photosynthetic rate at critical times (Skovmand *et al*., 2001). High chlorophyll concentration and high stomatal conductance are associated with heat tolerance.

The risk of drought is usually highest at the start and end of growing season. Maize is however a monoecious plant in which male and female flowers are separated by up to 1 m, hence it is particularly susceptible to drought and high temperature conditions during flowering (Earl and Davis, 2003). Maize is thought to be more susceptible at flowering than other rain fed crops because its female florets develop virtually at the same time and are usually borne on a single ear on a single stem (Banziger *et al*., 2000). Most importantly, silk growth and kernel number depend directly on the flow of photosynthates during the three weeks of extreme sensitivity bracketing flowering. In maize, a major effect in water stress is a delay in silking, which is an important cause of yield failures. This trait has been shown to be highly correlated with kernel number and number of ears per plant and overall grain yield (Frova *et al*., 1999). In maize, when drought stress occurs just before or during the flowering period, a delay in silking is observed, resulting in an increase in the length of anthesis-silking interval (ASI) and a decrease in grain yield (Ribaut *et al*., 1996). Asynchrony between male and female flowering dates is associated strongly with the decrease in grain yield under drought conditions (Mugo *et al*., 1998). When photosynthesis per plant at flowering is reduced by drought, silk growth is delayed leading to an easily measured increase in the anthesis-silking interval (Banziger *et al*., 2000). There are also indications that the stop in embryo growth under limited water conditions is due to a decrease in sucrose flux and an altered carbohydrate metabolism in the ovaries (Frova *et al*., 1999). The low level of reserves coupled with the failure to utilize available sugars at a low ovary water potential severely inhibit assimilate flux to the ears, rendering kernel set highly vulnerable to a water deficit during pollination (Earl and Davis, 2003).

Tolerance to drought stress is largely determined by events that occur at or shortly after flowering. Genetic correlation between grain yield and ASI is weak under well-watered conditions, but strong under severe water stress (Frova *et al*., 1999). The weak correlation indicates that variation in grain yield under stress is due to variation in ear-setting processes related to biomass partitioning at flowering. Selection for tolerance at flowering is for an index of traits that seek to increase grain yield, reduce ASI, increase in number of ears per plant, delay senescence, reduce tassel size, and increase leaf angle while leaving male flowering date unaltered (Mugo *et al.,* 1998). Selection for the reduced ASI in tropical open pollinated varieties is correlated with improved yields under drought stress (Ribaut *et al.,* 1996).

When water is the predominant constraint, overall productivity can be improved by matching the development of the crop to the pattern of water supply. This reduces evaporative and other water losses and fosters a good balance of water-use before and after flowering, which is needed to give a large harvest index (Passioura, 2006). There is also scope for developing genotypes that are able to maintain adequate floret fertility despite any transient severe water deficits during floral development. The high costs of irrigation, the necessity of cultivating in drier areas and the uncertainties posed by world climate change have increasingly required breeders to create drought-adapted cultivars (Sambatti and Caylor, 2007). Landraces that are tolerant to drought could be a source of germplasm for such genotype development. Stress tolerant maize genotypes offer a means of stabilizing yields at no additional cost to the farmer (Edmeades *et al*., 1997). Sources of tolerance are best sought within materials adapted to a region, before introgression of exotic sources (Mugo *et al.,* 1998). Selected materials need to perform well under both water limited and well-watered conditions (Ribaut *et al*., 2002). There is need for drought tolerant maize germplasm in four of the six agro-climatic zones of Kenya (Hassan *et al*., 1998). This can be achieved by exposing breeding materials and segregating progenies to drought stress during periods of crop development (Mugo *et al*., 1998). Managed stress screening approaches provide an opportunity to keep heritability high and adequately representing abiotic stress factors that are relevant in the target environment (Banziger *et al*., 2006). Potential for genetic improvement of maize production under drought conditions therefore remains large. Drought tolerance implies the ability not just to survive physiological effects, but also to grow and yield satisfactorily under such conditions (Ashley, 1993).

2.6 Morphological characterization

Characterization consists of recording drought escape/tolerance characteristics that are highly heritable, can be easily seen by the naked eye, and are expressed in all environments. These are usually represented by the plants morphological traits (Chapman *et al.*, 2003). Characterization can also include more sophisticated attributes generated by chemical, isozyme, restriction fragment length polymorphism (RFLP), and other molecular level analysis (Todorovska *et al*., 2002). These analyses are used by breeders, to study genetic diversity in detail with the aim of identifying differences and interrelationships among living organisms. Characterization is important in drawing linkage maps and identifying gene markers for selection. Such data are however not always available in gene banks, and in many of them even plant morphological characterization data are inadequate or not available (Chapman *et al.*, 2003). The evaluation of germplasm frequently includes comparing traits of agronomic interest, such as resistance to pests and diseases, and tolerance to physiological stresses that are influenced by the environment. In maize drought tolerance trials, secondary traits are most valuable in assessing drought tolerance (Banziger *et al*., 2000). Secondary traits that help to identify drought tolerance in order of decreasing importance are, grain yield, ears per plant, anthesis-silking interval (ASI), leaf senescence, tassel size and leaf rolling. They improve precision in identifying tolerant genotypes, demonstrates the degree to which a crop was stressed and if observed before or at flowering, they can be used for selecting desirable crossing parents in a concurrent running experiment (Banziger *et al*., 2000).

2.7 Secondary traits

Secondary traits are few plant characteristics that are highly heritable and whose variation results in proven genotype x environment interactions for grain yield (Banziger *et al*., 2000). The primary character of interest is grain yield. While tolerance to abiotic stresses is associated with a host of morphological and physiological traits, in testing for drought tolerance, of primary interest are secondary traits that are correlated with yield and demonstrate segregation with high heritability under water limited conditions (Ribaut *et al*., 2002). The use of secondary traits of adaptive value whose genetic variability increases under drought can increase selection efficiency. Because the primary interest is grain yield, secondary traits are also valuable in improving the precision with which drought genotypes are identified and they demonstrate the degree to which a crop was stressed (Banziger *et al*., 2000). Traits to consider in a selection approach must be fast and easy to measure under field conditions, have reasonably high heritability, and be positively correlated with production under drought (Ribaut *et al*., 2002). The secondary traits low correlation with grain yield is an indication that variation in grain yield under moisture stress is dominated by variation in ear-setting processes related to biomass partitioning at flowering, and much less by factors putatively linked to crop water status (Bolanos and Edmeades, 1996). In a maize population selected for drought tolerance traits, flowering was substantially modified i.e., ASI was reduced, and this accounted for most of the variation in grain yield (Bolanos and Edmeades, 1993). The selection increased kernel number, while kernel weight remained unchanged, suggesting that the increase in yield was due solely to an increased partitioning of material assimilated by the ear. Secondary traits that help to identify drought tolerance in order of decreasing importance are, grain yield, ears per plant, anthesis-silking interval (ASI), leaf senescence, tassel size and leaf rolling (Banziger *et al*., 2000). Many other secondary traits that have been evaluated by CIMMYT have low heritability, i.e. leaf and stem elongation rate, canopy temperature, leaf photo-oxidation, leaf chlorophyll concentration, predawn leaf water potential, and seedling survival under drought. Others were heritable but had no relationship with grain yield under drought i.e. osmotic adjustment and leaf erectness.

2.8 Genetic diversity and local landraces

Genetic diversity is the variability that is heritable. Genetic diversity allows farmers and plant breeders to adapt a crop to heterogeneous and changing environments for instance providing resistance to pests and diseases (Bellon, 2002). Genetic diversity helps breeders identify differences and interrelationships within and among populations. Tropical landraces are a good source of germplasm that can be used to broaden the genetic base of modern maize production and improve productivity (Tartar *et al*., 2003). Genetic diversity resulting from interspecific introgression can be evaluated with morphological characteristics (Tatineni *et al*., 1996). For several decades, concern over the loss of crop genetic diversity has grown especially where a few high yielding varieties have replaced genetically valuable crop landraces a process known as crop genetic erosion (Hawkes, 1983). Genetic variability is the lifeblood of any species and the essential raw material used by plant breeders in crop improvement. It is therefore important to know the genetic diversity in maize local landraces in Kenya. This will help avoid duplication of germplasm collection and utilization. Characterization of genetic variation both within and among plant populations is one of the major goals in evolutionary biology and plant breeding programs for rational use of genetic resources (Todorovska *et al*., 2002). Genetic correlation among relatives is important because it is closely related to prepotency, which is the ability of an individual to impress characteristics on its offspring so that they resemble that parent and each other closely than usual (Allard, 1960).

2.9 Resistance to larger grain borer (LGB)

Although many modern maize varieties and hybrids have improved agronomic performance, traits that contribute to improved grain storage have been largely ignored. Post harvest insect pests jeopardize food security throughout the world and losses of between 5-15% are recorded in the developing countries (Bergvinson, 2000). During on-farm storage, maize grain is attacked by a complex of pests consisting primarily of insects, mites and fungi, which contribute to post harvest losses (Gethi, 2002). Among the insects that destroy maize, the weevil (*Sitophilus* spp) and the larger grain borer (*Prostephanus truncatus*) are the most important in Kenya. The larger grain borer was accidentally introduced into Tanzania from where it has spread to other parts of Africa where it is inflicting heavy losses on maize and cassava (Hodges, 1994). The larger grain borer was later accidentally introduced to Kenya from Tanzania in 1983 and is responsible for heavy post harvest losses in maize and cassava (Republic of Kenya and GTZ-Kenya, 1993). In Kenya, the larger grain borer causes losses of between 9 to 45%, depending upon period of storage and genotype (Gethi, 2002). It causes direct damage by feeding on stored grain and indirectly damages the grain through physical deterioration by encouraging fungi development, thus reducing grain quality. Because maize kernels, as in seeds in storage, are in a dormant stage, there is neither growth, nor repair; hence any damage is terminal and costly (Hodges, 1994).

Three types of resistance mechanisms to insect pests have been proposed namely preference, antibiosis and tolerance (Painter, 1951). Preference denotes the group of plant characters and insect responses that lead to or away from the use of a particular plant or variety, for oviposition, food, or shelter, or a combination of the three. Antibiosis denotes plant characters that result in adverse effects on the insect's life history when the insect uses a resistant plant for food, while tolerance denotes a resistance whereby the plant shows an ability to grow and reproduce itself or to repair injury to a marked degree in spite of supporting a population approximately equal to that damaging a susceptible host. According to Howard (1983), evaluation of resistance to stored-grain insect pests should focus on measuring antibiosis and / or non-preference because tolerance, one of the resistance modalities in growing plants does not function in stored grain.

Maize germplasm with improved resistance to storage pests is clearly in high demand among small-scale farmers in the tropical countries (Bergvinson, 2000). In Malawi, improved maize varieties showed increased susceptibility to pests under traditional storage practices than local landraces (Kapindu *et al*., 1999). Traditional landraces have not been evaluated for resistance to LGB although biochemical studies have indicated phenolics in the grains to be correlated with their resistance to LGB (Arnason *et al.,* 1992). Grain characteristics such as testa hardness and biochemical composition may be related to resistance/susceptibility of grain to stored pests (Ogendo, personal com). The structural qualities of the pericarp play a pivotal role in protecting the kernels from oviposition penetration and in hindering emergence. Good correlations between insect resistance and kernel hardness are also correlated with elevated levels of diphenolic acids located within the pericarp of the kernel (Bergvinson, 2000). Kernel hardness as a resistance mechanism is however limited by grain moisture content, with levels above 16% leading to susceptibility in resistant genotypes. Some results suggest that phenolic acids toughen the outer layers of the maize kernel, making it less palatable for the borer.

The international grain trade, normal beetle flight activity and the pest's ability to survive and breed outside the storage environment have limited the success of control campaigns (Farrell, 2000). The survival mechanisms have made it likely that the pest would continue to spread in Africa, wherever agro-climatic conditions and food sources were favorable. Despite concerted efforts by national programs and international agencies, using quarantine, chemical control and biological control that have slowed the rate of dispersal, its advance in Africa has been relentless. A number of storage insecticides have been tested and recommended for LGB control, but the measures have not checked the losses. An integrated approach has been proposed to curb the pest and to reduce use of pesticides (Hodges, 1994). Host plant resistance in maize can be a useful component of Integrated Pest Management (IPM) of the larger grain borer (Kumar, 2002). Host plant resistance is environmentally safe, economically feasible and socially acceptable. Grain weight loss is the best economic indicator, rated well as a resistance measurement where the level of resistance is indicated by the amount of powder (chewed uneaten maize plus feces) produced during feeding or by the small size of adult populations (Kumar, 2002).

Laboratory tests suggested that hot and humid conditions favored LGB abundance, but models forecasted higher LGB numbers in hot and dry environments. A model based on climatic factors from data collected at Kiboko-Kenya had predicted LGB abundance in dry and hot areas (500mm rainfall and 24˚C) (Giles *et al*., 1995). Using climate data from Kenya, a Mexico model accurately predicted that LGB numbers were likely to be higher in dry regions (Farrel, 2000). The larger grain borer is mainly a serious pest in the hot and dry areas of Kenya. It is envisaged that drought tolerant and larger grain borer resistant Kenyan maize landraces could be identified.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experiment I – Phenotypic Characteristics of Local Maize Germplasm in Kenya

3.1.1 Site description

The experiment was carried out at the Kenya Agricultural Research Institute (KARI) Masongaleni farm, Kibwezi division, Makueni district, Kenya. The farm is located at latitude 2˚ 21.6' South and longitude 38˚ 7.3' East, at an elevation of about 650 meters above sea level. The area falls under the dry lowland zones of Kenya. The farm is within the semi-arid areas of Kenya, agro-ecological zone VI and receives approximately 400mm of rainfall per year with an annual evapotranspiration potential of between 1650-2300mm per year (Jaetzold and Schmidt, 1983). Average maximum temperature is between 28˚ and 36˚C described as fairly hot to very hot. The soils are rhodic and orthic *Ferrasols* (Jaetzold and Schmidt, 1983).

3.1.2 Maize germplasm

The experimental materials consisted of 64 maize germplasm that included 37 local maize landraces from the Gene Bank of Kenya, Muguga. The landraces had been collected by CIMMYT / Gene Bank of Kenya from different environmental niches in Western, Eastern, Coast and Nyanza provinces. The rest included 10 inbred lines from KARI-Kitale, 7 from KARI-Katumani and another 7 from CIMMYT-Nairobi. Katumani Composite B was used as a control as it is the recommended genotype for dry areas. A brief description of the landraces used in the study is given in Table 1.

3.1.3 Experimental design

The 64 landraces were planted in an 8x8 lattice design, replicated three times on the 4/02/06. The treatments were randomly allocated to the lattices and each of the eight blocks carried eight treatments. The crop was grown under normal rain supplemented with irrigation. The crop was protected against pests and weeds so that characters could be expressed well. Diammonium Phosphate (DAP) fertilizer at the rate of 40kg/ha N and 102 kg/ha P_2O_5 was applied at planting (Ministry of Agriculture, 1987). Bifenthrin 25g/L (Brigade) insecticide was sprayed three days after seedlings emergence to protect against insect pests' damage. The crop was top dressed with Calcium Ammonium Nitrate (CAN) at the rate of 48kg N per ha 30 days after planting. Trichlorfon 2.5% (Dipterex) granules were applied when seedlings were about 45cm high to protect against stalk borer attacks. Each experimental plot consisted of ten plants in a row spaced 30 cm apart with a row spacing of 75cm (0.75mx0.3m). A one-meter path was provided between the replications and a 0.5m path between the plots. Data was collected from the six middle plants of each row (1.35m^2 area).

3.1.4 Parameters measured

Days to emergence after sowing, days from sowing to 50% plants tassel anthesis (AD), days to 50% plants silking (SD), anthesis-silking interval (ASI) (calculated as ASI = SD-AD), tassel size measured on a scale of 1 to 5 scale (where 1 = few branches, small tassel; 3 = medium size tassel; 5 = many branches, large tassel), grain yield in t/ha, number of ears per plant harvested at physiological maturity (counted as the number of ears with at least one fully developed grain, divided by the number of harvested plants) (Banziger *et al*., 2000).

Table 1. Maize germplasm used in Experiment I and their source

Entry No.	Variety code	Source	District of collection
1	032422	GBK	Kilifi
2	045385	”	Meru central
3	027054	”	Machakos
4	045385	”	Meru central
5	027017	”	Kitui
6	045386	”	Meru central
7	043227	”	Meru
8	027016	”	Kitui
9	043731	”	Bungoma
10	027061	”	Machakos
11	032423	”	Kilifi
12	034711	”	Makueni
13	045381	”	Meru central
14	DG/BT/144 IR	KARI-Katumani	Not known
15	043042	GBK	Kakamega
16	045383	”	Meru central
17	DG/BT/47 IR	KARI-Katumani	Not known
18	026961	GBK	Kitui
19	032418	”	Kilifi
20	032420	”	”
21	032404	”	”
22	034660	”	Taita Taveta
23	044591	”	Siaya
24	045366	”	Meru central
25	044676	”	Suba
26	044655	”	”
27	034619	GBK	Taita Taveta
28	044628	’’	Homa Bay
29	032419	”	Kilifi
30	044593	”	Siaya
31	034659	”	Taita Taveta
32	044611	”	Bondo
33	044627	”	Homa Bay
34	044674	”	Suba
35	044592	”	Siaya
36	044654	”	Migori
37	034661	”	Taita Taveta
38	032357	”	Kwale
39	044659	”	Suba
40	Katumani Composite B	Kenya Seed Company	Not known
41	KTL N 70133-3	KARI-Kitale	’’
42	KTL N 10162-1	”	’’
43	KTL N 10139-3	”	’’
44	KTL N 10168-2	”	’’
45	KTLT N 10150-1	”	’’
46	KTL N 701110-2	”	’’
47	KTL N 70188-2	”	’’
48	KTL N 70140-4	”	’’
49	KTL N701104	”	’’
50	KTL N 10148-3	”	’’
51	IR-KIB-04B-9-27	CIMMYT-NBI	’’
52	IR-KIB-04B-9-19	”	’’
53	IR-KIB-04B-9-2	”	
55	CML-492	CIMMYT-NBI	Not known
56	CML-312	”	’’
57	CML-265	”	’’
58	DG/BT/1470.DT	KARI-Katumani	’’
59	DG/BT/2443.DT	”	’’
60	DT/BT/1917.DT	”	’’
61	DT/BT/1849.DT	”	’’
62	KTL Inbred A	KARI-Kitale	’’
63	DT/BT/101 IR	KARI-Katumani	’’
64	DT/BT/111	’’	”

3.2 Experiment II - Effects of Moisture Stress on Phenotypic Characters of Maize Local Landraces at Flowering

3.2.1 Site description

The same site as described in 3.1.1 was used.

3.2.2 Maize germplasm and design of experiment

Twenty-five germplasm selected on the basis of ASI duration from Experiment I were planted in a split plot randomized complete block design (RCBD) replicated three times. They included eleven germplasm with a short anthesis-silking interval (1-5 days) as recommended by CIMMYT (Banziger *et al*., 2000). Others were seven germplasm with medium ASI (6-11 days) and five with long ASI (12-17 days) for comparison purposes. Two dry land Composites (Katumani Composite B (KCB) and Makueni Dry Land Composite (DLC)) were included as controls. The main plots were the water status (water stressed and the well watered), while the sub plots were the local maize landraces. Landraces with close or equal days to tassel anthesis were grouped together for synchronized planting for easier management of stress conditions during flowering (irrigation withdrawal at flowering stage). All the germplasm were, therefore, expected to reach tassel anthesis at approximately the same time. Treatments were randomly allocated to the plots. Each experimental plot was 6.075m^2 (2.25mx2.7m). Fertilization and pests control was done as indicated earlier in Experiment I. In the drought stressed plots irrigation continued until one week to male flowering (tassel anthesis), then irrigation was withdrawn. Moisture application resumed forty days later when at least 80% male flowering had been achieved. The well-watered plots had sufficient water throughout growth to ensure normal maize growth. The selected germplasm and their ASI are given in Table 2.

Table 2. Selected germplasm for drought tolerance evaluation

Entry No.	Serial No.	Germplasm code	ASI period (in days)
Short ASI			
1	59	DT/BT/2443.DT	1
2	60	DT/BT/1917.DT	’’
3	29	GBK-032419	3
4	58	DT/BT/1470.DT	4
5	38	GBK-032357	’’
6	11	GBK-032423	’’
7	5	GBK-027017	5
8	31	GBK-034659	’’
9	55	CML-492	’’
10	49	KTL N 701104	
11	30	GBK-044593	6
Medium ASI			
12	47	KTL N 70188-2	9
13	48	KTL N 70140-4	10
14	2	GBK-045385	’’
15	9	GBK-043731	’’
16	32	GBK-044611	’’
17	12	GBK-034711	11
18	3	GBK-027054	12
19	40	Katumani Composite B (control)	’’
20	65	Makueni Dry Land Composite (control)	’’
Long ASI			
21	57	CML-265	13
22	44	KTL N 10168-2	’’
23	7	GBK-043227	14
24	45	KTL N 70133-3	15
25	42	KTL N 10162-1	16

3.2.3 Parameters measured

Days from sowing to 50% tassel anthesis (AD), days from sowing to 50% silking (SD), anthesis-silking interval (ASI) (counts of plants anthesed and silked were taken in each plot daily during the flowering period, and the interval between 50% anthesis and 50% silking was calculated to give the (ASI) i.e. ASI = SD - AD), leaf rolling measured on a scale of 1-5 just before flowering (1 = unrolled (turgid), 2 = leaf rim starts to roll, 3 = leaf has a v-shape, 4 = rolled leaf rim covers part of the leaf blade and to 5 = leaf is rolled to the shape of an onion leaf) (visual scores of leaf rolling were taken on two occasions during stress period), tassel size measured on a scale of 1-5 (1 = few branches (small tassel), 3 = medium tassel and 5 = many branches (large tassel), plant height in meters measured from the ground to the point of flag leaf insertion, grain yield in t/ha (all harvested ears were hand shelled and grain weight determined at 13% moisture content), (moisture content was determined using Dickey John® moisture tester), number of ears per plant (number of ears with at least one fully developed grain divided by the number of harvested plants), shelling % (percentage of grain weight to harvested cob), 100-seed weight in grams .

3.2.4 Data analysis

Data was tested for normality using $\log_e\sqrt{}$ (ASI + 10) and subjected to Analysis of variance (ANOVA) using the general linear model (SAS Version 7). Treatments found to be statistically significant at ($P \leq 0.05$), according to the F-test were subjected to mean separation, using Duncan's Multiple Range Test. Correlation analysis was done using Pearson's partial correlation. Factor analysis, a variant of Principal component analysis (PCA) was used to summarize data and investigate inter-variable relationships. In this procedure, the variables (some of which were correlated) were transformed to a new set of uncorrelated variables (Principal components). The analysis was important because of removing multicollinearity.

3.3 Experiment III-Evaluation for Larger Grain Borer (LGB) Resistance

3.3.1 Maize Germplasm

The experiment consisted of the 25 germplasm evaluated for drought tolerance in the second experiment in section 3.2.2. Hybrid maize H614 was used as check for the laboratory experiment because CIMMYT has listed it as most susceptible to LGB.

3.3.2 Site description

The experiment was carried out at KARI-Kiboko field laboratory located at 37.75˚ East and 2.15˚ South, at an elevation of 975 m above sea level with a minimum daily temperature of 14.3˚C and maximum temperatures of 35.1˚C. The area falls under mid-altitude dry agro-ecological zone VI and receives about 530mm rainfall per annum. The soils are rhodic and orthic *Ferrasols* (Jaetzold and Schmidt, 1983).

3.3.3 Larger grain borer (LGB) culturing procedure

Hybrid maize H614 was used for culturing LGB as it records the highest reproduction rates. Four hundred grams of dry maize grain was introduced into a sterilized 1-kilogram Kliner jar. One hundred and fifty adult larger grain borers (LGBs) were then introduced into each Kliner jar at a female male ratio of 75:75. In 45 days, there were over 500 adults in each jar. At the rate of 50 insects per 100 grams of grains, the 25 germplasm replicated three times required 3750 insects. Eight (8) jars of this culture were made for this experiment and the needed number of adult insects achieved. The forty-five days' duration of culturing gave a minimum of 2 generations of the insect. All equipment used was sterilized to keep off contaminants that could contaminate the insect culture (CIMMYT, 1998).

3.3.4 Experimental procedure

The grains were introduced into glass jars, closed tightly using two rubber bands between glass cover and the cover lid to ensure no air left the jar during sterilization procedure. Grain was then sterilized in the oven for 2 hours at 60^{o} C to get rid of any field infestation threat or risk. The grains were left to cool overnight and reabsorb any moisture that may have escaped into the airspace in the glass jar. One hundred grams of each grain genotype at 13% moisture content was introduced into sterilized glass jars and infested with 50 adult larger grain borers from 3.3.3. Improvised stone weights (100g) were placed on top of the grain in the jar to enable LGB feeding as in natural conditions in a column of sack. The jars of infested maize were then placed on wooden shelves at room temperature for ninety days. The experiment was set up in a complete randomized design (CRD) and replicated three times. The procedure was carried out under sterilized conditions to avoid contaminants i.e. fungi (CIMMYT, 1998).

3.3.5 Parameters measured

Grain weight before larger grain borer damage, grain and powder weight after three months of LGB damage. After 90 days, grains were separated from the insects and powder using sieves. Powder and grain weight was recorded. Damage was calculated on weight loss in the grains and the weight of powder produced after 90 days of LGB feeding. Germplasm recording less damage (less weight) than the susceptible control H614 were considered resistant.

3.3.6 Data analysis

Data in percentages were transformed using angular transformation before statistical analysis. Analysis of variance was carried out using the general linear model (SAS, version 7) and means separated by Duncan’s Multiple Range Test where the F-test was significant. Data was tested at 5% level of significance.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Experiment I - Phenotypic Characteristics of Local Maize Germplasm in Kenya

The maize germplasm collected from all over Kenya varied significantly in the phenotypic characteristics (Table 3). The variation was expected because of the different agro-ecological zones they grow. Banziger and Diallo (2001) similarly found large variations in phenotypic characteristics of maize genotypes growing in moist mid-altitudes zones of East Africa.

Table 3. Phenotypic characteristics of maize germplasm

Characteristic	Mean	Range	Pr >F	CV
Days to50% tassel anthesis	50	35-64	0.0001	2.48
Days to 50% silking	58	47-74	0.0001	0
ASI in days	8	1-16	0.0001	18.94
Tassel size	3	1-5	0.0001	23.8
Ears per plant	1	0.5-1.6	0.0598^{ns}	27.72
Yield in t/ha	4.33	1.0-8.0	0.0001	40
Plant height in meters	2.0	1-3.0	0.0001	4.2

Pr= Probability; CV=Coefficient of variation; ns=not significant

4.1.1 Correlation and factor analysis of phenotypic characteristics

Days to tassel anthesis were significantly and positively correlated with days to silking but negatively correlated with plant height, anthesis-silking interval, ears per plant and grain yield. Days to silking was positively correlated with ASI but negatively correlated with plant height and grain yield. Plant height was positively correlated with ears per plant and grain yield (Table 4). Anthesis-silking interval had no correlation with yield and yield components under well-watered conditions. Bolanos and Edmeades (1996) similarly reported that correlations between grain yield and ASI and ears per plant were weak under well-watered conditions.

Table 4. Pearson's Correlation Coefficients (r) of the phenotypic characteristics of maize germplasm in Kenya

	Variety	DT	DS	ASI	Plt ht	Ears/plt	Grain yield
Variety	1.000						
DT	0.467***	1.000					
DS	0.423***	0.829***	1.000				
ASI	-0.925NS	-0.155***	0.423***	1.000			
Plt ht	-0.658***	-0.353***	-0.372***	-0.087NS	1.000		
Ears/plt	-0.148**	-0.631NS	-0.085NS	-0.445NS	0.228***	1.000	
Yield	-0.199**	-0.228***	-0.233***	-0.04NS	0.377***	0.922NS	1.000

** Significant at 5%, *** significant at 1%, NS; Not Significant

DT, days to 50% tassel anthesis; DS, days to 50% silking; ASI, anthesis-silking interval; Yield, grain yield (t/ha); Ears/plt, number of ears per plant; Plt Ht; plant height in meters.

Factor analysis

Three out of seven principal components accounted for 72% of the total variation in the characters affecting grain yield under optimal conditions (Table 5). Days to flowering is one of the most important characteristics of a maize plant accounting for 40% of the variation in yield while yield and yield components accounted for 17% of the variation. Anthesis-silking interval signifies the synchronization between male and female flowers in maize (Mugo *et al*., 1998). It accounted for 15% of the variation in the germplasm.

Table 5. Factor patterns of variables under optimum conditions

	Factor loading		
Variable/statistic	Factor 1	Factor 2	Factor 3
Days to tasseling	**0.93**[*]	**-0.93**	-0.11
Days to silking	**0.86**	-0.12	0.45
ASI	0.01	-0.05	**0.98**
Plant height	-0.43	**0.73**	0.00
Ears/plant	0.20	**0.73**	-0.11
Grain yield	-0.22	**0.51**	-0.02
Eigen value	2.79	1.19	1.08
Proportion of variance	0.40	0.17	0.15
Cumulative variance	0.40	0.57	0.72

[*] Figures in bold represent significant contribution to variable ($P \leq 0.05$)

Factor loading 1 can be described as flowering time characteristics, factor 2 as yield and yield components and factor 3 as ASI effects

4.1.2 Days to 50% tassel anthesis and silk emergence

The germplasm varied significantly in the number of days to 50% tassel anthesis. Days to tassel anthesis ranged from 35 days in the Katumani Composite B (control), to 64 days in genotype KTL N 10139-3, an inbred line from KARI-Kitale. Other genotypes that tasseled early included GBK-027054 (39 days), IR-KIB-04B-9-19 (41 days), GBK-043227 (42 days) and GBK-044591 (43 days). Genotypes that took longest to reach tassel anthesis were KTL N 10139-3 (59 days), KTL N 10162-1 (58 days) and CML-492 and KTL N 10168-2 (57 days), respectively. Generally, genotypes from KARI-Kitale took longer to tassel than those from KARI-Katumani and the local landraces.

The germplasm also varied significantly in the number of days to 50% silk emergence. The days to silking ranged from 47 days in genotype DT/BT/47 IR, an inbred line from KARI-Katumani to 74 days in genotype KTL N 10162-1, an inbred line from KARI-Kitale. Genotypes with the highest number of days to silking were inbred lines from Kitale and included KTL N 10162-1

(74 days), KTL N 10139-3 (73 days), KTL N 10148-3 (72 days), KTL N 10150-1 (71 days) and KTL N 10168-2 (70 days). Germplawm DG/BT/47 IR (47 days), Katumani Composite B (48 days), GBK-026961 (49 days), GBK-044591 (50 days) and GBK-032404 (51 days) had the shortest number of days to silking after sowing. Katumani Composite B control was among the earliest germplasm to silk at 48 days after sowing. Early silking in Katumani Composite B was expected because the genotype is recommended for dry areas because of its drought escape strategy (Diallo and Banziger, 2001). Gerrmplasm from Kitale took longer to silk than the local landraces and those from Katumani. Days to silking is a highly heritable character and hence least affected by the environment (replications).

4.1.3 Anthesis-silking interval (ASI)

Germplasm varied significantly in the ASI. The anthesis-silking interval (ASI) ranged from 16 days in KTL N10162-1, a KARI-Kitale inbred line to 1 day in DG/BT/2443.DT, a KARI-Katumani drought tolerant inbred line. Some germplasm exhibited a short ASI (1-6 days), indicating potential for drought tolerance. Some of the germplasm exhibiting a short ASI (1-6 days) included local landraces i.e. GBK-032419, GBK-032357, GBK-032423, GBK-027017, GBK-034659 and GBK-044593. Other germplasm that exhibited a short ASI were DG/BT/2443.DT, DT/BT/1917.DT, DG/BT/1470.DT, CML-492, and KTL N 701104. Within the group of short ASI germplasm, local landraces had higher mean grain yield (6.7 t/ha) than the inbred lines (2.8 t/ha). Inbred lines from KARI-Katumani exhibited ASI as low as 1 day (DG/BT/2443.DT and DT/BT/1917.DT), while the lowest ASI in the landraces was 3 days for landrace GBK-032419 from Kilifi. Under optimum moisture conditions, ASI had a moderate negative correlation (R^2 = -0.52) with grain yield (Figure 1). Bolanos and Edmeades (1996) reported that anthesis-silking interval has a strong and consistent genetic correlation with grain yield and is the most important among the drought tolerance traits. Germplasm that had long ASI were mainly inbred lines from Kitale and included KTL N 10162-1, KTL N 10150-1, KTL N 10148-3, KTL N 10139-3 and KTL N 10168-2. Others were CIMMYT inbred line CML-265 and landraces GBK-027054 and GBK-043227, both landraces from Machakos and Meru districts, respectively. The control genotype Katumani Composite B had an ASI of 12 days.

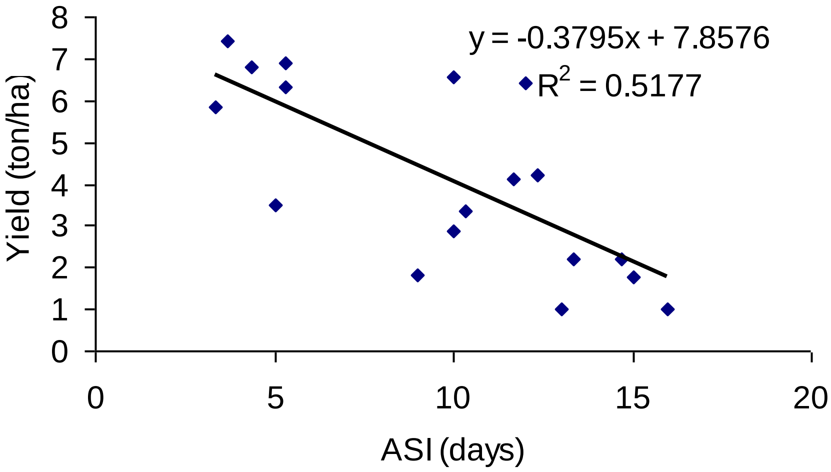


Figure 1. Relationship between maize grain yield (t/ha) and ASI (days) of germplasm grown in Kenya

4.1.4 Tassel size

The germplasm varied significantly in the tassel sizes. Tassel size score ranged from 1 (small) in CML-312 to 5 (large) in landraces like GBK-032419, GBK-044659, GBK-045383, and GBK-043227. A small tassel is a favored criterion for selection of drought tolerance in a well-watered experiment. It is also the only trait that can be measured under well-watered conditions but is indicative of drought tolerance at flowering stage (Banziger *et al*., 2000). Germplasm DG/BT/2443.DT, DT/BT/1917.DT, DT/BT/1470.DT and CML-492, inbred lines selected for drought tolerance by CIMMYT and / KARI-Katumani had small tassels (few branches). Local landraces GBK-032357, GBK-032423, GBK-034659, GBK-032419 and GBK-027017 had medium to large tassels (many branches). Chapman and Edmeades (1999) reported that selection for a reduced tassel size increased ear size at flowering due to reduced competition for assimilates between organs.

4.1.5 Plant height (m)

The germplasm differed significantly in the plant height (Table 3). Plant height ranged from 1m in DTBT/111 IR, a KARI-Katumani inbred line to 3m in GBK-027054, a local landrace from Machakos district. Generally, local landraces were taller and more vigorous in growth than the inbred lines. The lack of vigor in the inbred lines was expected because of their narrow genetic base (inbreeding depression). Germplasm GBK-044655 gave the highest grain yield of 8 t/ha and had a height of 2.59m. However, Richards (2006) however reported that under optimum moisture conditions, reduced plant height may contribute to higher yields as it increases the allocation of assimilates to grain and reproductive organs rather than to the stem.

4.1.6 Yield (t/ha) and yield components

The germplasm varied significantly in grain yield and the associated components. Germplasm IR-KIB-04B-9-19, a stalk borer resistant inbred line from CIMMYT had the lowest yield (1.0 t/ha) while a landrace from Suba district GBK-044655 had a yield of 8.0 t/ha. When compared to local landraces, inbred lines were less vigorous in growth and recorded lower grain yields. There was a difference of 4 t/ha between the highest yielding landrace GBK-044655 (7.9 t/ha) and the highest yielding inbred line DG/BT/2443.DT (3.6 t/ha). Inbred lines from Katumani had a mean yield of 2.8 t/ha compared to 1.8 t/ha in that from Kitale. This was expected as they were adapted to higher altitudes and cooler temperatures. Even within the landraces there were variations in yields.

The number of ears per plant ranged from 0.5 ears per plant in CIMMYT inbred line CML-265 (1.0 t/ha) to1.6 ears per plant in GBK-027054 (6.4 t/ha) a local landrace from Machakos district. The number of ears per plant was highly and positively correlated to the grain yield ($R^2 = 0.7$) (Figure 2). Monneveux *et al*. (2006) similarly reported that genetic yield improvement is attributable to an increase in partitioning of dry matter to the ear during the critical period bracketing silking. The greater the number of ears per plant under stress, the higher the grain yield.

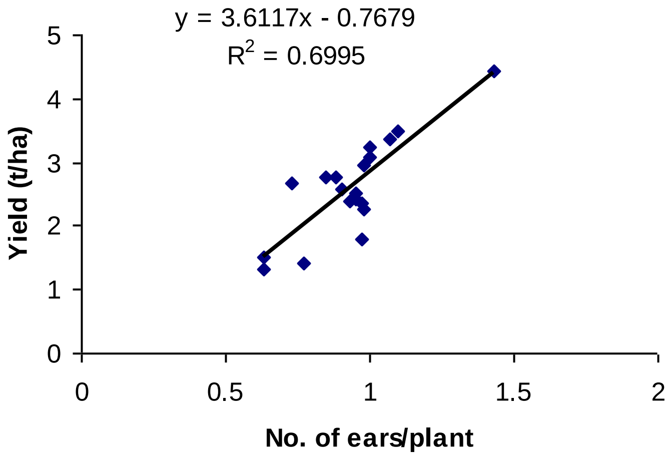


Figure 2. Relationship between grain yield (t/ha) and number of ears per plant in germplasm grown in Kenya

4.2 Experiment II – Effects of Moisture Stress on Phenotypic Characters of Maize Local Landraces at Flowering

Germplasm differed significantly in variables evaluated for drought tolerance (Table 6). Under moisture stress (WS) conditions, days to tassel anthesis, days to silking, leaf roll intensity and ASI increased while tassel size, number of ears per plant, plant height, a 100-seed grain weight and grain yield decreased significantly. The high coefficient of variation (CV) in ASI, leaf rolling, tassel size ears/plant and grain yield was indicative of the variability of the sources of the germplasm.

Table 6. Effects of water stress on the phenotypic characteristics of local maize germplasm grown in Kenya

	Moisture regimes					
	Water stressed (WS)		Well watered (WW)			
Traits	Mean	Range	Mean	Range	Pr>F	CV
Days to tasseling	63.6	43.0-78.0	62.9	40.0-74.0	0.0001	3.81
Days to silking	71.7	53.3-85.0	69.1	48.7-80.7	0.0001	4.86
ASI (days)	7.9	-1.3-12.3	6.3	-1.0-12.3	0.0001	42.6
Leaf rolling (1-5)	3.0	1.7-4.3	1.0	1.0-1.0	0.0001	20.7
Tassel size (1-5)	2.9	1-5	3.3	1-5	0.0001	23.6
Shelling %	68.4	50-83	75	56.7-81.7	0.0001	9.8
Grain yield (t/ha)	1.7	0.4-3.7	3.6	1.8-5.9	0.0001	30.8
Ears/plant	0.9	0.5-1.1	1.1	0.7-1.7	0.0001	19.17
100-seed wt (g)	27.2	15.7-42.1	31.1	19.7-44.6	0.0001	12.92
Plant height (m)	1.7	1.3-2.3	2.1	1.6-2.5	0.0001	14.32

Pr= Probability; CV=coefficient of variation

Water stress reduced the grain yield of genotypes by between 17% and 81% (Table 7, Figure 3). Relative yield loss was calculated as follows;

Relative yield loss = 100x [1-(Grain yield under moisture stress/Grain yield under WW)]

Table 7. Relative yield loss of maize germplasm under moisture stress conditions

Germplasm code	Yield (t/ha) WW	Yield (t/ha) WS	Yield loss (%)
DT/BT/2443.DT	4.6 (±0.28)	2.2 (±0.95)	52
DT/BT/1917.DT	3.7 (±0.46)	1.7 (±0.43)	54
GBK-032419	5.1 (±2.21)	3.7 (±0.54)	28
DT/BT/1470.DT	3.9 (±2.2)	3.1 (±0.68)	21
GBK-032357	4.7 (±0.69)	1.8 (±0.26)	62
GBK-032423	2.9 (±0.26)	1.6 (±0.49)	45
GBK-027017	3.7 (±0.91)	1.7 (±1.4)	54
GBK-034659	2.9 (±1.15)	2.4 (±0.39)	17
CML-492	2.5 (±0.47)	1.3 (±0.4)	49
KTL N 701104	4.1 (±0.67)	2.0 (±0.55)	51
GBK-044593	3.0 (±0.78)	1.8 (±0.66)	40
KTL N 70188-2	1.8 (±0.75)	1.0 (±0.16)	44
KTL N 70140-4	2.2 (0±.37)	0.4 (±0.36)	81
GBK-045385	4.0 (±0.92)	1.6 (±0.5)	60
GBK-043731	5.9 (±1.7)	1.8 (±0.74)	70
GBK-044611	4.5 (±0.99)	1.0 (±0.53)	77
GBK-034711	3.3 (±0.53)	1.5 (±0.62)	55
GBK-027054	2.0 (±0.64)	1.0 (±0.4)	50
Katumani Composite B	3.7 (±1)	1.4 (±0.43)	62
Dry Land Composite	3.6 (±0.22)	1.1 (±0.97)	68
CML-265	2.2 (±0.29)	1.4 (±0.3)	36
KTL N 10168-2	3.1 (±0.62)	1.3 (±0.7)	54
GBK-043227	4.3 (±0.91)	2.1 (±0.14)	51
KTL N 10150-1	4.2 (±0.9)	1.7 (±0.97)	60
KTL N 70133-3	3.9 (±1)	1.2 (±0.35)	69

Numbers in brackets represent the standard error of the mean

4.2.1 Correlation and factor analysis of phenotypic characteristics for drought tolerance

The correlations between drought tolerance characters under moisture stress varied. Moisture stress positively and significantly correlated with days to silking, ASI and leaf rolling score but negatively and significantly correlated with the shelling %, grain yield, tassel size, ears per plant and plant height (Table 8). Monneveux *et al*. (2005) and Bolanos and Edmeades (1996), found similar correlations under moisture stress in ears per plant, days to silking, ASI, leaf rolling, tassel size and plant height.

Factor analysis

Three out of eleven principal components accounted for 68% of the total variation in the characters explaining drought tolerance in maize (Table 9). Factor 1, consisted of leaf rolling, shelling %, grain yield, ears per plant and plant height and accounted for 35% of the variation in drought tolerance among maize genotypes. The ASI, 100-seed weight and tassel size represented factor 2 and accounted for 18% of the variation in drought tolerance. The days to tassel anthesis and days to silking represented factor 3 and accounted for 15% of the variation in drought tolerance attributed to duration to flowering after sowing.

Banziger (2000) recommended the use of secondary traits like ASI, leaf rolling, grain yield and ears per plant as a measure for drought tolerance in maize. This emphasizes the importance of synchronization of the male and female flowers for improved tolerance to drought. Mugo *et al*. (1998) found that asynchrony between male and female flowering time is associated strongly with the decrease in grain yield under drought conditions.

Table 8. Pearson's Correlation Coefficients (r) for variables under moisture stress

	Moisture stress	DT	DS	ASI	LR	Shelling %	Yield (t/ha)	Tsize	Ears/plt	Plt Ht
Moisture stress	1.000									
DT	0.046 NS	1.000								
DS	0.144*	0.877***	1.000							
ASI	0.192***	0.198***	0.286***	1.000						
LR	0.837 ***	0.021 NS	0.125 NS	0.203***	1.000					
Shelling%	-0.339***	-0.234***	-0.375***	-0.328***	-0.377***	1.000				
Yield (t/ha)	-0.661 ***	-0.071 NS	-0.218**	-0.311***	-0.642***	0.537***	1.000			
Tsize	-0.186**	-0.0645 NS	0.069 NS	-0.268***	-0.144*	-0.062 NS	0.079 NS	1.000		
Ears/plt	-0.643***	-0.038 NS	-0.126 NS	-0.345***	-0.676 ***	0.475***	0.677***	-0.030 NS	1.000	
Plant height	-0.457 ***	-0.141*	-0.142*	-0.009 NS	-0.444***	0.184**	0.455***	0.420***	0.340***	1.000

*significant at 10%, ** significant at 5%, *** significant at 1%, NS; Not Significant

WS, water stress; DT, days to 50% tassel anthesis; DS, days to 50% silking; ASI, anthesis-silking interval; LR, leaf rolling score (1-5); Yield (t/ha), Tsize, tassel size score (1-5); Ears/plt, number of ears per plant; and plant height in meters.

Table 9. Factor pattern of variables affecting drought tolerance

	Factor loading		
Variable	Factor 1	Factor 2	Factor 3
Moisture stress	**-0.92***	-0.01	0.17
Days to tassel anthesis	-0.01	-0.15	**0.91**
Days to silking	-0.16	0.15	**0.94**
Athesis-silking interval	-0.31	**0.59**	0.17
Leaf rolling	**-0.87**	0.03	-0.21
Shelling %	**0.57**	-.032	-0.35
100-seed weight	0.44	**0.54**	-0.37
Grain yield	**0.84**	-0.11	-0.52
Tassel size	0.23	**-0.73**	0.1
Ears per plant	**0.62**	0.44	0.02
Plant height	**0.91**	-0.37	0.11
Eigen value	4.87	2.55	2.16
Proportion of variance explained	0.35	0.18	0.15
Cumulative variance explained	0.35	0.53	0.68

*Figures in bold represent significant contribution to variable ($P \leq 0.05$)

Factor loading 1 stands for yield and yield components, 2 for ASI and 3 for flowering time characteristics

4.2.2 Morphological responses to drought

i) Days to tassel anthesis

Days to tassel anthesis were positively correlated with days to silking and ASI. Maize is a monoecious plant, hence the positive association between male-female flowers and the ASI. Tassel anthesis was however negatively correlated with shelling % and plant height (Table 8). Frova *et al*. (1999) similarly found no correlation between days to anthesis and grain yield. In 65% of the genotypes, water stress increased days to tassel anthesis by between 1 and 5 days. In similar findings, Monneveux *et al*. (2005) reported that severe stress prior to flowering induces leaf rolling and reduces stomatal conductance which affects photosynthates partitioning to the male inflorescence (tassel) and hence promotes delayed tassel anthesis. In the composite controls, Katumani Composite B (KCB) and Makueni Dry Land Composite (DLC) water stress increased the days to tassel anthesis by 3 days and 4 days, respectively (Table 6). Water stress did not affect days to tassel anthesis in KTL N 70188-2 and GBK-044593. Richards (2006) noted that drought that occurs from mid to late vegetative stage onwards does not affect the timing of tassel anthesis

The control genotypes KCB and DLC exhibited the lowest number of days to tassel anthesis (40–45 days) under both moisture regimes. This indicated that these checks have ability to escape drought. Kitale inbreed lines KTL N 10162-1, KTL N 70133-3 and KTL N 10168-2 had the highest number of days to tassel anthesis (73-78 days) under both moisture regimes. Days to tassel anthesis in the germplasm selected for drought tolerance traits ranged from 57 days in GBK-044593 to 71 days in CML-492, implying that the composites were superior drought escapers than the other germplasm tested.

ii) Days to silking

Germplasm varied significantly in days to silk emergence. Water stress increased the mean days to silking from 69 days to 72 days, i.e. stress caused a delay in silking by 3 days. Richards (2006) similarly found that drought that occurs from the mid to late vegetative stage onwards in maize delayed the process of ear silking. Days to silking was negatively correlated with shelling %, grain yield, and plant height but positively correlated with ASI, moisture stress and days to tassel anthesis. It had no correlation to leaf rolling tassel size and ears per plant (Table 8). Days to silking for the composite controls ranged from 52 to 54 days in KCB and 49 to 53 in DLC. Inbred lines KTL N 10162-1, KTL N 70133-3, KTL N 10168-2, KTL N 70188-2, KTL N 70140-4, all from Kitale and CML-265 from CIMMYT had highest number of days to silking (76 to 82 days). Mugo *et al*. (1998) found that delayed silking was associated with barrenness, and reflected on reduced partitioning of assimilates to the developing ear at flowering, thus reducing yields. Richards (2006) reported that the reason for silk delay is that the drought-susceptible genotypes allocate less assimilates to ear growth when the ears are quite small. Frova *et al*. (1999) noted that under water stress conditions during flowering, changes such as accelerated leaf senescence, leaf rolling and reduced stomatal conductance, results in reduced photosynthates flow to the ear. The effects led to higher grain yield loss in genotypes that exhibited extended delay to silking under moisture stress conditions.

iii) Anthesis-silking interval (ASI)

Germplasm varied significantly in the anthesis-silking interval (ASI). Under moisture stress, ASI increased by 2 days. Anthesis-silking interval is one of the most important traits that can be used to indicate maize genotype's tolerance to stress (Mugo *et al*., 1998; Richards, 2005). Anthesis-silking interval was positively correlated with moisture stress, days to tassel anthesis, days to silking, leaf rolling but negatively correlated with shelling %, grain yield, tassel size and ears per plant (Table 8). Richards (2006) reported that under moisture stress the ASI period was negatively correlated with grain yield. Frova *et al*. (1999) noted that genetic correlation between grain yield and ASI was weak under well watered conditions, but negative and strong under severe stress, indicating that variation in grain yield under stress is due to variation in ear setting processes related to biomass partitioning at flowering. The results were consistent with findings of Frova *et al*. (1999) that in maize, a major effect of water stress at flowering is an increase in the ASI duration. Bolanos and Edmeades (1996) linked a high grain yield under stress to a short ASI. Mugo *et al*. (1998) and Frova *et al*. (1999) similarly found that when drought stress occurs just before or during the flowering period in maize, a delay in silk emergence is observed resulting in an increase in the length of the ASI.

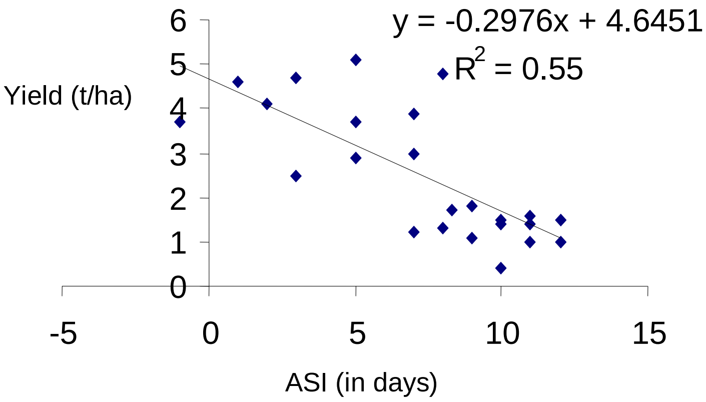


Figure 3. Relationship between ASI and grain yield (t/ha) under moisture stress

Under both water stress and well-watered regimes, the following germplasm exhibited a favorable ASI of between -1 to 5 days, DT/BT/1917.DT, DG/BT/2443.DT, GBK-032423, GBK-032419 and GBK-032357. Among these germplasm, the last three were local landraces. Katumani inbred lines DT/BT/1917.DT and DG/BT/2443.DT exhibited the lowest ASI duration of -1 day under both moisture regimes (Photo 1, silking before tasseling).

Other germplasm exhibiting drought tolerance characteristics i.e. KTL N 701104 and CML-492 increased the ASI period by 5 days under moisture stress (3 to 8 days). The greatest increase in ASI period under moisture stress was in germplasm KTL N 70140-4 (5 days) which also recorded the highest grain yield loss of 81% (Table 7). Bolanos and Edmeades (1993) attributed 76% of variation in grain yield loss across a range of cultivars and watering regimes to ASI. Frova *et al*. (1999) noted that a long ASI duration was an important cause of yield losses and was highly correlated with grain yield, kernel number and number of ears per plant. Chapman and Edmeades (1999) and Richards (2006) further reported that a lengthening of the ASI period is an indicator of poor performance under drought and is negatively correlated with grain yield.

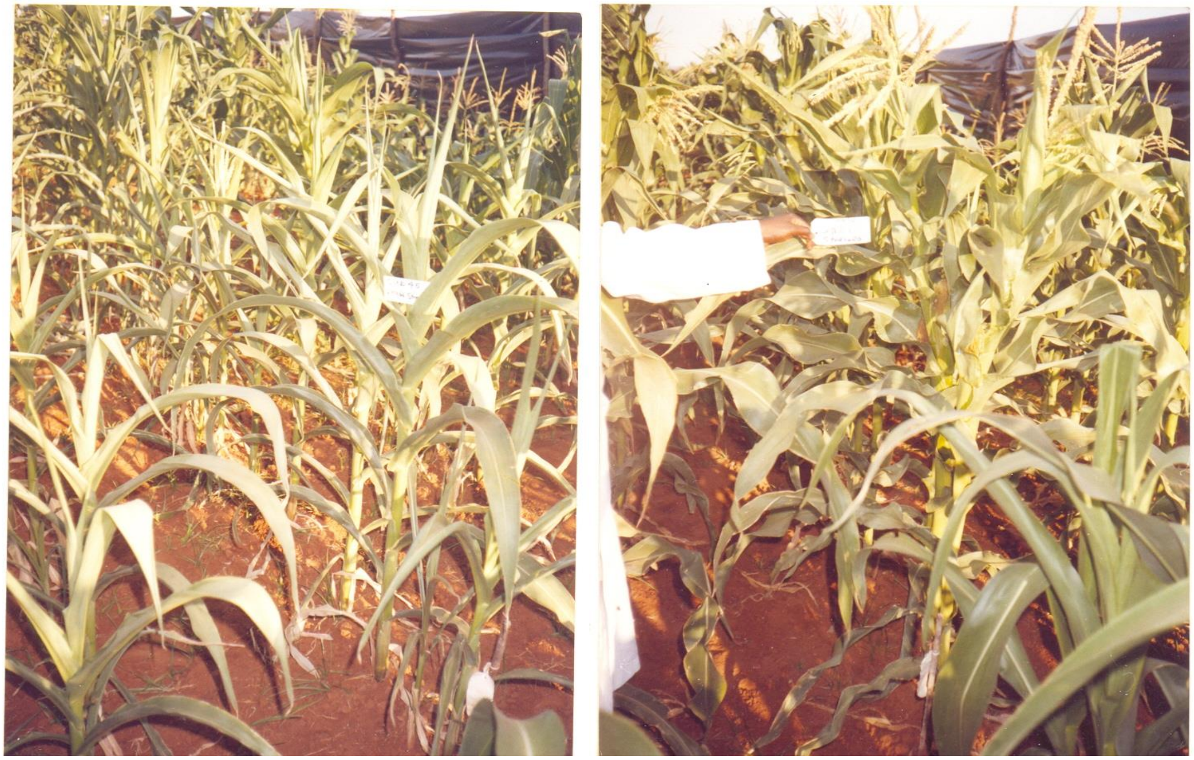
Plate 1. Silking before tasseling in germplasm DT/BT/1917.DT

Similarly, Passioura (2006) reported that water deficit in maize could contribute to a mismatch between time of anthesis and silking leading to lack of fertilization and ultimately increased grain yield losses. Monneveux *et al*. (2005) noted that the ovule abortion rate at anthesis was positively correlated with ASI period. Bruce *et al*. (2002) reported that the delay in silking in relation to pollen shed under drought led to the anthesis-silking interval that was highly correlated with kernel set. Under such conditions of delayed silking, pollen can arrive after it has desiccated, when silks have withered or senesced or after ovaries have exhausted their starch reserves.

iv) Leaf rolling

Germplasm varied significantly in the leaf rolling score. Leaf roll was positively correlated with moisture stress and ASI but negatively correlated with shelling %, grain yield, tassel size, ears per plant and plant height. It however had no correlation with days to tassel anthesis and days to silking (Table 8). Monneveux *et al*. (2005) associated leaf rolling with a reduction in photosynthesis due to a decrease in radiation interception. Bolanos and Edmeades (1993) attributed the reduction in photosynthesis to a decrease in radiation interception associated with leaf rolling and reduced leaf expansion. Leaf rolling under moisture stress was more prominent in the control DLC, KTL N 70133-3, KTL N 10162-1, GBK-027054 and Kitale inbred KTL N 70140-4 with score of 4 and lowest in DG/BT/2443.DT, DT/BT/1470.DT, CML-492 and CML-265 with a score of 2 (Photo 2). Germplasm with high leaf roll score were associated with higher yield losses. Mugo *et al.* (1998) attributed low grain yield to strong leaf rolling and high abscisic acid (ABA) concentration when plants were under stress. Abscisic acid is present in all flowering plants and when they wilt, ABA levels typically rise as a result of an increase in the rate of synthesis (Mugo *et al.* 1998; Bruce *et al.*, 2002). The high level of abscisic acid throughout a droughted plant inhibits leaf expansion, thus reducing radiation interception. Bruce *et al.* (2002) reported that the accumulation of ABA may enhance survival but reduces productivity.

Turner (1986) noted that leaf roll increases water use efficiency by reducing water loss at critical times of the day when the vapor pressure deficits are large, but allow photosynthesis to continue in the early morning or late afternoon when vapor pressure deficits are less severe. The reduction in water loss postpones dehydration of leaf tissue and delays the development of soil water deficit. Bolanos and Edmeades (1996) found out that leaf rolling is a drought adaptive trait, while Julianno and Kelly (2007) noted ecological, morphological and physiological trade-offs associated with drought adaptation traits. For example, in selection for reduced stomatal conductance, plants will avoid drought by saving water when it is scarce, however when water is available, growth will be limited by the same mechanism, by limiting carbon dioxide intake.



(a) (b)

Plate 2. Leaf rolling under moisture stresses for two different germplasm two weeks after irrigation withdrawal (a) drought susceptible KTL N10150-1 (b) drought tolerant DG/BT/2443.DT

v) Tassel size

Selection for a small tassel is often associated with improved partitioning to the ear. Germplasm differed significantly in their tassel sizes. Water stress significantly reduced tassel size score from a 3.2 to 2.9. Tassel size had no correlation with grain yield, shelling %, days to tassel anthesis and days to silking. It was however negatively correlated with moisture stress, ASI and leaf rolling and positively correlated with plant height (Table 8). Bolanos and Edmeades (1996) observed a small but significant negative phenotypic correlation between tassel branch number and grain yield, while Ribaut *et al*. (2002) noted negative correlation between tassel weight and ear at tassel anthesis. The smallest tassel score (1) was recorded in inbred lines KTL N701104, DG/BT/2443.DT and DT/BT/1917.DT where a loss of about 50% of grain yield was observed (Table 7). Landraces GBK-043227, GBK-27054 and GBK-034659, had the largest tassel score of 5 and recorded yield losses of 51%, 47%, and 17%, respectively. Both KCB and DLC controls had medium sized tassels and grain yield losses of 62% and 68%, respectively when exposed to moisture stress. Monneveux *et al*. *(*2005) reported that recurrent selection for small tassels resulted in substantial increase in partitioning to early ear growth and successful grain set. Chapman and Edmeades (1999) observed that selection for a reduced tassel size increased ear size at flowering as competition for assimilates between competing organs at flowering affects ear growth and grain number. Some germplasm such as Katumani inbred lines DG/BT/2443.DT and DT/BT/1917.DT that exhibited small tassels (few branches) had good tolerance to drought. According to Banziger *et al*. (2000), such genotypes demand less allocation of the little assimilates during times of drought, thus more can be channeled to the developing ear for grain production. Mounneveux *et al*. (2005) noted that reduction in tassel size resulted in an increase in ear and husk weight, thus improved grain yield under stress. Further, most gains in ear growth were attributable to decreases in tassel and stem weight, i.e. to successful competition between the ear at flowering and other organs for available carbon products. Selection for reduced tassel size may also increase canopy photosynthesis through reduced shading.

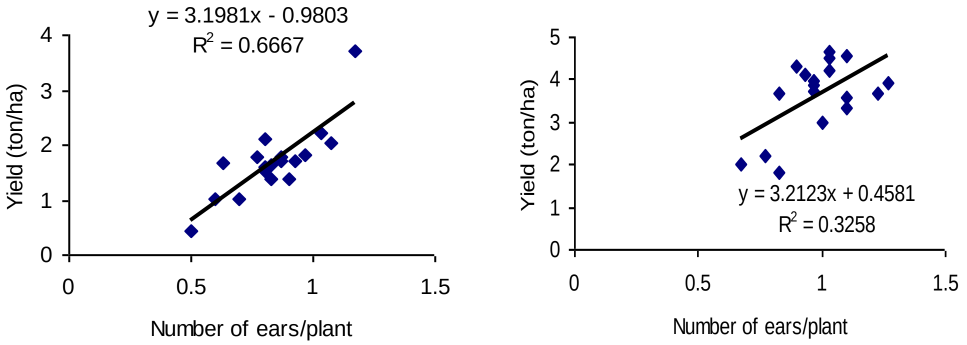
vi) Plant height (m)

Germplasm differed significantly in plant height. Moisture stress reduced the plant height from 2.1m to 1.7m (Table 6). Monneveux *et al*. (2005) however reported that plant height was unaffected by selection under stress. Plant height was negatively correlated with stress, days to tassel anthesis, days to silking and leaf rolling but positively and significantly correlated with shelling %, grain yield, ears per plant and tassel size (Table 8). The tallest germplasm under both moisture regimes was landrace GBK-032419 with a mean height of 2.4m. The germplasm recorded the highest yields under both moisture regimes, i.e. 5.1 t/ha under WW and 3.7 t/ha under moisture stress (28% yield loss) (Table 7). The shortest germplasm under moisture stress was CIMMYT inbred line CML-492 at 1.3m, it lost 50% grain yield under moisture stress. Bolanos and Edmeades (1996) similarly found a moderate association between yield and plant height under moisture stressed conditions ($r^2 = 0.28$). The KCB and DLC controls both had a height of 1.5m under moisture stress and 1.9m under WW conditions and lost 62% and 68 % in grain yield, respectively. Most of the highest yielding landraces were taller than the composite controls. Julianno and Kelly (2007) reported that plant growth rate could be used as a measure of performance because plants that grow fast end up showing greater biomass, resulting in more harvestable products. Mounneveux *et al*. (2005) similarly reported that taller progenies were able to capture additional radiation. Richards (2006) however noted that selection for optimal plant height was important so as to avoid lodging and to maximize harvest index (HI) in favorable environments. Selection for reduced height has contributed to higher yields as it has increased the partitioning of assimilates to the grain and reproductive organs rather than to the stem. Selection for reduced growth of stems (plant height) may reduce competition for assimilates at flowering and thereby decrease kernel abortion. Reducing plant height may also reduce competition for assimilates between the developing grains and other organs whose demands coincides with kernel set. Sergio *et al*. (2006) observed that improved radiation use efficiency around flowering is associated with a significant increase in mean plant growth rate.

4.2.3 Effect of drought on yield and yield components

i) Number of ears per plant

Number of ears per plant is one of the most important yield components of maize. Germplasm varied significantly in the number of ears per plant. Moisture stress reduced mean number of ears per plant from 1.1 to 0.9. Severe stress causes complete abortion of the ear. Monneveux *et al.* (2005) found that the number of ears per plant varied with moisture regimes. The number of ears per plant was positively correlated with grain yield and shelling % but negatively correlated with ASI and leaf rolling (Table 8). The relationship in number of ears per plant was positive and weak under well-watered conditions ($R^2 = 0.33$) than under moisture stress ($R^2 = 0.67$) (Figure 5). Under moisture stress, the number of ears per plant ranged from 0.5 in germplasm KTL N 70140-4 (80% yield loss) to 1.2 (28% yield loss) in germplasm GBK-032419. Under well-watered conditions, it ranged from 0.7 in GBK-027054 to 1.7 in GBK-032419. The mean number of ears per plant under moisture stress was 0.8 and 1.2 under WW conditions. Germplasm GBK-032419, GBK-034659, GBK-032357, KTL N 10168-2, KTL N 701104, CML-492, CML-265, DT/BT/1470.DT and DT/BT/2443.DT had the highest number of ears per plant under moisture stress. The better performance in some of the germplasm under moisture stress may be a result of the allocation of more assimilates to ear formation at the critical stage.



(a) **(b)**

Figure 4. Relationship between number of ears per plant and grain yield (t/ha); (a) under moisture stress (b) under well watered conditions

The higher correlation between number of ears per plant and grain yield under moisture stress than under well-watered conditions indicates the dependence of grain yield on ears per plant. Chapman and Edmeades (1999) and Monneveux *et al*. (2005) similarly attributed marked grain yield losses with decreasing number of ears per plant under moisture stress. Bolanos and Edmeades (1993a), Chapman and Edmeades (1999) and Monneveux *et al*. (2005) further associated grain yield gains with increase in number of ear per plant under stress. Bolanos and Edmeades (1996) attributed more than 75% of variation in grain yield under drought to variation in number of ears and kernels per plant. The number of ears per plant under moisture stress for controls KCB and DLC was 0.8; they lost 62% and 68% grain yield, respectively. Mugo *et al*. (1998) noted that grain yield and numbers of ears per plant were inherently smaller in composites because of the high level of barrenness and floret and kernel abortion.

Under moisture stress, a low number of ears per plant could have indicated increased ear barrenness in the genotypes, thus low grain yields. Mugo *et al.* (1998) reported that as stress increased, the dependence of grain yield on ears per plant increased more than on kernels per ear. Mounneveux *et al*. (2005) similarly reported that 85% of kernel abortion under moisture stress occurred during the first 20 days after female flowering and was associated with a significant level of barrenness. Banziger *et al.* (2000) proposed that on the basis of consideration of heritability and correlation with yield under stress, barrenness should be considered as a useful secondary trait for improving maize yields in drought prone environments. Tollenaar and Wu

(1999) noted that grain abortion occurs during the first 2 to 3 weeks after silking and is worsened by stress that reduces canopy photosynthesis and the flux of assimilates to the developing ear.

ii) 100-seed weight (gm)

Germplasm differed significantly in the 100-seed weight. Water stress reduced the mean 100-seed weight from 31.1gm to 27.2gm (Table 6). Under water stress, the 100-seed weight ranged from 15.73gm in germplasm CML-265, a CIMMYT inbred line to 39.3gm in GBK-043731, a landrace from Bungoma district. Under WW conditions, the 100-seed weight was 19.7gm in CML-492 and 44.6gm in GBK-043731. The grain yields of these germplasm under moisture stress were 1.4 and 1.8 t/ha, respectively, and 2.2 and 5.9 t/ha, respectively under WW conditions (Table 7). Under both regimes, CIMMYT inbred line CML-492 had lowest 100-seed weight while landrace GBK-043731 had the highest seed weight. Bolanos and Edmeades, (1996) associated low grain yield with a reduced grain weight under moisture stress environments. Saleem *et al*. (2007) reported that under WW conditions, maize grain yield could be improved by selecting for increased grain weight. Boyer and Westgate (2004) noted that water deficit later in development tends to reduce kernel size rather than the number, and seems to be largely determined by the available photosynthetic reserves that can be moved to the grain.

iii) Grain yield

The grain yield of the germplasm varied significantly. Yield reduction under moisture stress ranged from 17% in GBK-034659, landrace from Taita Taveta to 81% in KTL N 70140-4, Kitale inbred line (Table 7). Grain yield was negatively correlated with moisture stress, days to silking, ASI and leaf rolling (Table 8). It was however positively correlated with shelling %, ears per plant and plant height. The mean grain yield under moisture stress was 1.7 t/ha and 3.6 t/ha under WW, i.e. over 50% yield loss under moisture stress. A large fraction of the yield potential was thus not realized in many germplasm under moisture stress. Under WW conditions, grain yield ranged from 1.8 t/ha in inbred line KTL N 70188-2 to 5.9 t/ha in GBK-043731, landrace from Bungoma district (Table 6). Under moisture stress yield ranged from 0.4 t/ha in Kitale inbred line KTL N 70140-4 to 3.7 t/ha in GBK-032419, a landrace from Kilifi district. Germplasm GBK-032419, DT/BT/1470.DT and GBK-034659 had the lowest grain yield losses of 28% 22% and 17% under moisture stress, respectively (Table 7). Inbred lines

DT/BT/2443.DT from Katumani and KTL N 701104 from Kitale were the highest grain yielding inbred lines under WW at 4.6 and 4.1 t/ha, respectively. Both recorded yield losses of about 50% under moisture stress. Inbred line DT/BT/1470.DT from Katumani had low yield (3.9 t/ha) under WW conditions, but also gave lowest yield loss (21%) among inbred lines. The KCB and DLC controls had 3.7 and 3.6 t/ha, under WW conditions, but recorded grain yield losses of 62% and 68%, respectively under moisture stress (Table 7). Germplasm DT/BT/2443.DT, DT/BT/1917.DT, GBK-032419, GBK-034659, DT/BT/1470.DT, GBK-032423, GBK-032357, GBK-027017, CML-492, GBK-044593 and KTL N 701104 lower grain yield losses under moisture stress than the composite controls, thus better tolerance to drought. They recorded grain yield losses ranging from 17% in landrace GBK-034659 from Taita Taveta, to 54% in inbred line DT/BT/1917.DT from Katumani.

Banziger *et al*. (2000) reported that a drought tolerant genotype should perform well under both well watered and water stress conditions. Ouk *et al*. (2006) noted that the practical approach for selection of a drought tolerant parent is to use a measure or an index of the relative grain yield of genotypes under stress to that under well watered conditions as an integrative measure of the complex of traits that provide drought tolerance. Boyer and Westgate (2004) reported that in early phases of ovary development, the maize plant is unable to access plant reserves to sufficiently maintain reproductive development when current photosynthesis is inhibited by limited water. Water stress significantly reduced grain yield by negatively influencing the number of ears per plant, plant height, tassel size, 100-seed weight and the shelling percent.

Bolanos and Edmeades (1996) reported that high correlation between grain yield and its components are normally found because of lack of independence among them. Focusing on traits which are indicative of partitioning in the plant at flowering (ears per plant and ASI) would result in higher harvest index and grain yield in all water regimes. Ribaut *et al*. (2002) noted that selection for low ASI, high fertile ear number per plant and small tassels resulted in substantial increase in partitioning to early ear growth and successful grain set. Germplasm DT/BT/1917.DT and DG/BT/2443.DT had the lowest and unchanged ASI duration of -1 day and 1 day under both watering regimes had grain yield losses of 55 and 52%, respectively. Bolanos and Edmeades (1993) reported that ASI accounted for 76% of variation in grain yield across a range of cultivars and watering regimes, with yield reductions of almost 10% per day increase in ASI. Frova *et al*.

(1999) and Passioura (2006) similarly noted that moisture stress prolonged the ASI and ultimately reduced the grain yield.

Richards (2006) noted that yield reduction was associated with the fact that recurrent selection for low ASI, results in substantial increase in partitioning to early ear growth and successful grain set. Increased number of ears per plant under moisture stress was positively associated with grain yield gains. Boyer and Westgate (2004) similarly attributed the effects of water stress to constrained partitioning of photosynthates to the ear and observed that the largest response to grain yield loss reduction in maize is during ear development. Banziger *et al*. (2000) noted that on the basis of heritability and correlation with yield under stress, ear barrenness is a useful secondary trait for improving maize yields in drought-prone environments. Richards (2006) reported that direct selection for yield in dry environments is inefficient due to large seasonal variation in weather and a large genotype x environment interaction, resulting in low heritability for yield.

4.3 Experiment III - Evaluation for Larger Grain Borer (LGB) Resistance

Germplasm varied significantly in their grain weight loss and dust weight percentages (Table 10). A low (%) grain weight loss and dust weight was an indicator for higher levels of resistance. Dust weight ranged from 14.4% in CIMMYT inbred line CML-492 to 33.8% in germplasm GBK-043731, a Bungoma landrace. The mean dust weight was 26.1%. Grain weight loss ranged from 22.8% in CIMMYT inbred line CML-492 to 55.4% in Kitale inbred line KTL N 70140-4 with a mean grain weight loss of 40.6% (Table 11).

Table 10. Effects of LGB damage on stored local maize germplasm

Variables	Mean	Range	CV	Pr>F
Dust weight (%)	26.19	14.4-33.8	19.58	0.0002
Grain weight loss (%)	40.69	22.8-55.4	19.58	0.0004

Pr= Probability; CV=coefficient of variation

The lowest level of LGB damage was recorded in CML-492, a CIMMYT inbred line which recorded the least grain weight loss and the least dust weight produced. Grain weight loss and dust weight of 23% and 14%, respectively were observed in the genotype after 3 months of storage signifying highest resistance level among genotypes. Kumar (2002) reported that resistance in maize against LGB could be expressed in terms of grain damage, powder production, and the number of LGB recovered, because these parameters are highly correlated with one another. Makundi (1991) reported that LGB could destroy a whole grain and covert it into powder. Bergvinson (2000) similarly reported that LGB could reduce grain to powder in five months. Highest damage levels were recorded in germplasm GBK-043731, a landrace from Bungoma and KTL N 70140-4 a Kitale inbred line. Kumar (2002) reported that grains that showed a high level of resistance had a low powder production relative to a susceptible control and less grain weight loss. Both had equal dust weights of 33.5% but differed in grain weight losses which were 51% in GBK-043731 and 55% in KTL N 70140-4. This was an indication of the extensive feeding by LGB relative to the susceptible control. The control hybrid H614 had a 44% grain weight loss and 28% dust weight (Table 11). None of the tested genotypes experienced total grain destruction during the three months' period of storage, indicating that each germplasm had a certain level of resistance. Grain damage, i.e. weight loss which signified consumed grain and powder production were highly related with one another ($R^2 = 0.98$) (Figure 6).

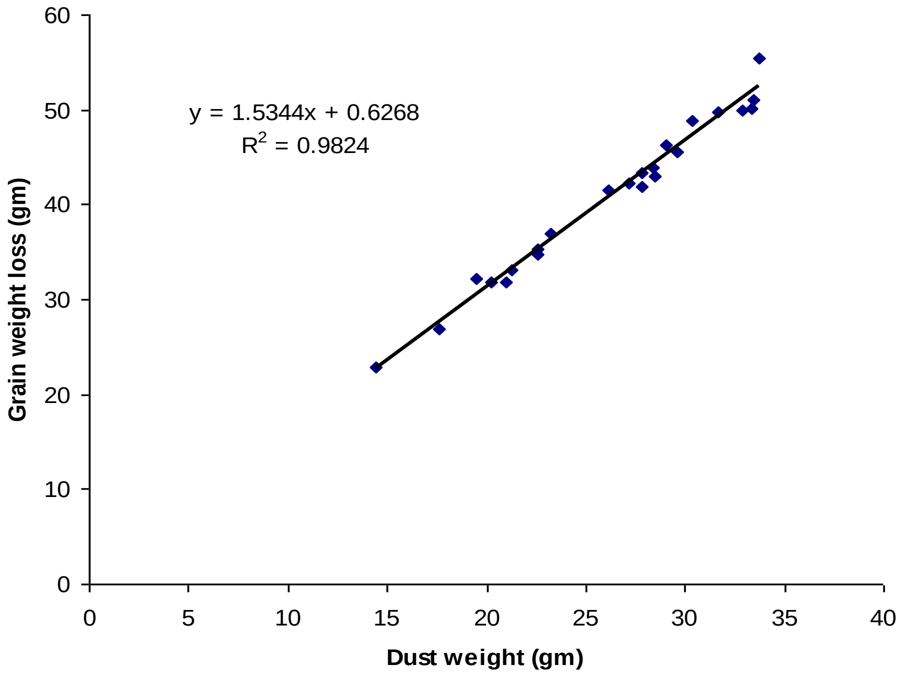


Figure 5. Relationship between grain weight loss and dust weight (gm)

Except GBK-027017 which was poorer in performance than H614, other germplasm classified and evaluated as drought tolerant exhibited high levels of resistance to LGB compared to the hybrid control. Germplasm CML-492, DT/BT/1971.DT, DT/BT/1470.DT, DG/DT/2443.DT, KTL N 10168-2 and KTL N 701104, were the inbred lines exhibiting highest resistance levels. Their grain weight losses ranged from 22.78 to 42.27% and dust weight ranged from 14.43 to 27.13%. Germplasm GBK-044593, GBK- 032419, GBK-032423, GBK-034659 and GBK-032357 gave the highest resistance level among landraces. They recorded grain weight losses of between 31.9 and 43.42% and dust weight of between 20.25 and 27.82% (Table 11).

Table 11. Germplasm percentage grain weight loss and dust weight after storage

Serial No.	Germplasm code	Dust weight (%)	Grain weight loss (%)
1	GBK-043731	33.75^{a}	51.0^{ab}
2	KTL N 70140-4	33.45^{ab}	55.38^{a}
3	GBK-027054	33.32^{ab}	50.19^{abc}
4	GBK043227	32.92^{abc}	49.9^{abc}
5	GBK-045385	31.69^{abcd}	49.72^{abc}
6	KTL N10150-1	30.31^{abcde}	48.79abcd
7	KTL N70188-2	29.60^{abcdef}	45.64^{abcde}
8	GBK-027017	29.0^{abcdef}	46.29^{abcde}
9	GBK-034711	28.45^{abcdef}	42.93^{abcde}
10	HYBRID 614-control	28.42^{abcdef}	43.88^{abcdef}
11	GBK-032357	$27.82^{abcdefg}$	$43.4^{abcdefg}$
12	GBK-034659	$27.83^{abcdefg}$	41.9^{abcdef}
13	KTL N 10168-2	$27.19^{abcdefg}$	$42.27^{abcdefg}$
14	KTL N 701104	$26.1^{abcdefg}$	41.55^{abcdef}
15	DG/DT/2443.DT	$23.26^{bcdefgh}$	36.99^{bcdefg}
16	GBK-044611	22.62^{cdefgh}	35.29^{cdefg}
17	GBK-032423	22.62^{defgh}	34.78^{cdefg}
18	GBK-032419	21.25^{efgh}	$33.14d^{efg}$
19	Katumani Comp B	21.03^{efgh}	31.88^{efg}
20	GBK-044593	20.2^{efgh}	31.90^{efg}
21	DT/BT/1470.DT	19.53^{fgh}	32.22^{efg}
22	DT/BT/1971.DT	17.61^{gh}	26.85^{fg}
23	CML-492	14.43^{h}	22.78^{g}

Germplasm followed by same letter are not significantly different at 5% level

Katumani Composite B was the fifth best in resistance level, performing better than all landraces with a weight loss of 31.9% and dust weight of 21.03%. No germplasm had total resistance, but all showed varying degrees of resistance to LGB. This agrees with Kumar (2002) who similarly found varying degrees of resistance to LGB in landraces, with susceptible germplasam demonstrating extensive feeding and reproduction by LGB. Arnason *et al.*, (1992) reported that biochemical studies had indicated presence of phenolics in the grains to be correlated with resistance to LGB. Bergvinson (2000) similarly noted that good correlations between insect resistance and kernel hardness were correlated with elevated levels of diphenolic acids located within the pericarp of the kernel. In CIMMYT (1998) maize storage report, phenolic acids in maize toughen the outer layers of the kernel, making it less palatable for LGB and the weevil (*Sitophilus zeamais*). The substances bind to cell wall carbohydrates and then to each other, strengthening the tissue and providing a first layer of defense to storage pests.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Based on the evaluations carried out, the following conclusions are made:

- Higher level of tolerance to drought under moisture stress at flowering was exhibited in germplasm that had higher number of ears per plant, plant height (improved growth rate), a short ASI, less leaf rolling, a small tassel and a high shelling % (indices). The composite controls flowered and reached physiological maturity earlier than all germplasm evaluated thus were superior drought escapers.
- The most tolerant germplasm to drought stress in terms of low yield losses and low ASI included GBK-034659, DT/BT/1470.DT, GBK-032419, CML-265, DG/BT/2443.DT, DT/BT/1917.DT, KTL N 701104, CML-492, GBK-032357 and GBK-044593. Notable in this category was a highland germplasm; Kitale inbred KTL N 701104. The most drought susceptible germplasm were: KTL N 70140-4, KTL N 10162-1, GBK-043731 and Makueni Dry Land Composite. The germplasm experienced about 70% yield losses and exhibited highest ASI of above 6 days.
- Based on grain weight loss and dust weight, the most resistant germplasm to LGB were, CML-492, DT/BT/1917.DT, DT/BT/1470.DT, GBK-044593, Katumani Composite B, GBK-032419, GBK-032423, GBK-044611, DG/BT/2443.DT, KTL N 701104, KTL N 10168-2, GBK-34659 and GBK-032357. All exhibited higher levels of resistance than the control H614. The germplasm most susceptible to LGB included GBK-043731, KTL N 70140-4, GBK-027054, GBK-043227, GBK-045385, KTL N 10150-1, KTL N 70188-2, GBK-027017 and GBK-034711.
- Few germplasm exhibited both drought tolerance and resistance to LGB. These were CML-492, DT/BT/1971.DT, DT/BT/1470.DT, DG/BT/2443.DT, GBK-044593, GBK-032419, GBK-032423, GBK-034659 and GBK-032357. Katumani Composite B though exhibiting susceptibility to drought, had a high level of resistance to LGB than most local landraces and the control H614.

Based on the findings of the study, the following recommendations are made:

- Since phenotypic characterization of the germplasm has been done, molecular characterization of local landraces identified as drought tolerant and LGB resistant should be carried out for the development of improved maize varieties for dry areas in future breeding programs. Laboratory screening and genomic research is needed to ascertain whether any genetic correlation exists between drought tolerance and larger grain borer resistance in maize germplasm.
- Local landraces exhibiting superior drought tolerance traits and LGB resistance may be evaluated for performance at farmers’ level in the ASAL areas, so that the best landraces could be distributed for production.

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APPENDICES

Appendix 1. Duncan's Multiple Range Test for drought tolerance characterization in maize landraces - Experiment I

Maize Genotype	Days to silking	ASI	Yields (t//ha)	Ears/plant
GBK-032422	60.33^{n}	$6^{nopqrst}$	$5.6^{abcdefghijkl}$	1.59^{ab}
GBK-045385	53.67^{c}	8.67^{ijklmn}op	$5.4^{abcdefghijklm}$	0.81^{de}
GBK-027054	51.00^{i}	$12b^{cdefgh}$	$6.4^{abcdefg}$	16^{a}
GBK-045385	73.33^{b}	$7.67^{jklmnopq}$	$5.9^{abcdefghij}$	1.36^{abcd}
GBK-027017	58.67^{p}	5rstq	$3.5^{cdefghijklmno}$	1.2^{abcd}
GBK-045386	73.33^{b}	$9.33^{ghijklmn}$	6.5^{abcdef}	1^{abcde}
GBK-043227	73.33^{b}	$12b^{cdefgh}$	$5.9^{abcdefghi}$	0.93^{abcde}
GBK-027016	-	-	-	-
GBK-043731	59.33^{o}	$10.33^{efghijk}$	$3.3^{defghijklmno}$	0.87cde
GBK-027061	71.33^{d}	$9^{hijklmno}$	$4.^{6abcdefghijklmno}$	1.33^{abcd}
GBK-032423	66^{f}	4.33^{rstu}	6.8^{abcde}	1.23^{abcd}
GBK-034711	65^{g}	$11.67^{cdefghi}$	$4.1^{bcdefghijklmno}$	1.1^{abcde}
GBK-045381	56.33^{v}	$8.33^{jklmnop}$	$5.4^{abcdefghijklm}$	1.03^{abcde}
DG/BT/144 IR	57^{t}	$8^{jklmnopq}$	$3.3^{defghijklmno}$	1^{bcdae}
GBK-043042	70^{e}	$8.33^{jklmnop}$	6.8^{abcde}	1.33^{abcd}
GBK-045383	56.33^{v}	8jklmnopq	$6^{abcdefghi}$	1.11^{abcde}
DG/BT/47 IR	60.33^{n}	2^{uv}	$2.2^{ijklmno}$	1^{abcde}
GBK-026961	62^{l}	$6.67^{mnopqrs}$	$3.9^{bcdefghijklmno}$	1.05^{abcde}
GBK-032418	58.67^{p}	$6.33^{mnopqrst}$	$3.7^{bcdefghijklmno}$	0.95^{abcde}
GBK-032420	56^{w}	$6.33^{mnopqrst}$	$5^{abcdefghijklmn}$	1.02^{abcde}
GBK-032404	62.67^{j}	$8^{jklmnopq}$	$5.9^{abcdefghi}$	1.13^{abcde}
GBK-34660	48^{m}	$6.33^{mnopqrst}$	6.9^{abcde}	1.22^{abcd}
GBK-044591	50^{k}	$7^{lmnopqr}$	6.8^{abcde}	1.15^{abcd}
GBK-45366	51.67^{g}	$8^{jklmnopq}$	$5.3^{abcdefghijklm}$	1.13^{abcde}
GBK-044676	54^{b}	$8.33^{jklmnop}$	$5.6^{abcdefghijk}$	1.07^{abcde}
GBK-044655	57^{t}	$8.67^{ijklmnop}$	7.9^{a}	$1.^{27abcd}$
GBK-034619	56^{w}	$6.33^{mnopqrst}$	$5^{abcdefghijklmn}$	1.17^{abcd}
GBK-44628	54.33^{a}	$7.33^{klmnopqr}$	$3.9^{bcdefghijklmno}$	1.1^{abcde}
GBK-032419	58.67^{p}	3.3^{tuv}	$5.9^{abcdefghij}$	1.39^{abcd}
GBK-044593	71.33^{d}	5.67^{opqrst}	$6.3^{abcdefg}$	1.52^{abc}
GBK-034659	57.57^{r}	5.33^{prstq}	6.9^{abcd}	1.34^{abcd}
GBK-044611	64.33^{h}	$10.33^{efghijk}$	$5.8^{abcdefghij}$	0.95^{abcde}
GBK-044627	56.33^{v}	$8.67^{ijklmnop}$	$5.5^{abcdefghijklm}$	1^{abcde}
GBK-044674	57.33^{s}	$8.33^{jklmnop}$	7.3^{abc}	0.93^{abcde}
GBK-044592	56^{w}	$8.33^{jklmnop}$	$5.6^{abcdefghijk}$	1.1^{abcde}
GBK-044654	56.33^{v}	$10^{efghijk}$	6.6^{abcdef}	1.09^{abcde}
GBK-034661	53.67^{c}	$7.33^{klmnopqr}$	7.1^{abcd}	1.22^{abcd}
GBK- 032357	57.33^{s}	3.67^{stuv}	7.4^{ab}	1.42^{abcd}
GBK- 044659	57^{t}	$8.67^{ijklmnop}$	$6.1^{abcdefgh}$	1.13^{abcde}
Katumani Comp B	48^{m}	12.33^{bcdefg}	$4.2^{abcdefghijklmno}$	1.54^{abc}

Continued

KTL N10162-1	74.33^{a}	16^{a}	1^{o}	1.22^{abcd}
KTL N10139-3	73.33^{b}	13.67^{abcd}	1.3^{no}	0.96^{abcde}
KTL N10168-2	70^{e}	13.33^{abcde}	$2.2^{ijklmno}$	1.15^{abcd}
KTLT N10150-1	71.33^{d}	15^{ab}	1.8^{mno}	1.47^{abcd}
KTL N701110-2	62.67^{j}	5.33^{prstq}	1.2^{no}	0.94^{abcde}
KTL N70188-2	65^{g}	$9^{hijklmno}$	1.8^{lmno}	0.87^{cde}
KTL N70140-4	64.33^{h}	$10^{fghijkl}$	$2.9^{fghijklmno}$	0.89^{cde}
KTL N701104	55.33^{y}	5.33^{prstq}	$2.5^{hijklmno}$	1.25^{abcd}
KTL N10148-3	71.67^{c}	14.67^{abc}	$2.2^{ijklmno}$	1.3^{abcd}
IR-KIB-04B-9-27	62.33^{k}	$9.67^{ghijklm}$	$2.2^{ijklmno}$	0.93^{abcde}
IR-KIB-04B-9-19	51^{i}	$10.33^{efghijk}$	1^{o}	1.06^{abcde}
IR-KIB-04B-9-2	58^{q}	5.67^{opqrst}	$2.7^{ghijklmno}$	1.42^{abcd}
IR-KIB-04B-9-8	58.67^{p}	$7^{klmnopqr}$	1^{o}	0.79^{de}
CML-492	62.33^{k}	5.33^{prstq}	1.9^{lmno}	1^{abcde}
CML-312	65^{g}	$9^{hijklmno}$	$3.6^{cdefghijklmno}$	1^{abcde}
CML-265	62.67^{j}	13^{bcdef}	1^{o}	0.47^{e}
DG/BT/1470.DT	55.6^{x}	3.5^{stuv}	$2.7^{ghijklmno}$	1.5^{abc}
DG/BT/2443.DT	55^{z}	1^{v}	$3.6^{bcdefghijklmno}$	1^{abcde}
DT/BT/1917.DT	56.67^{u}	1.3^{v}	2.1^{klmno}	1.15^{abcd}
DT/BT/1849.DT	57^{t}	$6.67^{mnopqrs}$	2.1^{jklmno}	1.06^{abcde}
KTL Inbred A	66^{f}	$7.67^{jklmnopq}$	$3^{efghijklmno}$	0.92^{bcde}
DT/BT/101 IR	62.33^{k}	$10.67^{defghij}$	$5^{abcdefghijklmn}$	0.92^{bcde}
DT/BT/111 IR	62^{l}	$7^{klmnopqr}$	1.3^{no}	1^{abcde}

Germplasm followed by same letter are not significantly different at 5% level

Appendix 2. Analysis of variance for drought tolerance traits – Experiment I

		Drought tolerance selection variables											
		Day to tasseling		Days to Silking		ASI		Tassel size		Ears/plant		Grain yield	
Source	DF	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F
Variety	62	**57.53**	0.0001	**Infty**	0.0001	**11.86**	0.0001	**6.99**	0.0001	1.43	0.0598	**3.91**	0.0001
Block	21	**23.45**	0.0001	**Infty**	0.0001	**8.17**	0.0001	1.59	0.0683	**1.85**	0.0237	1.31	0.1910

Numbers in bold are significantly different

Appendix 3. Duncan's Multiple Range Test for variables - Experiment II

S/no	Genotype code	Days to anthesis		Days to silking		Leaf rolling		Ears/plant		Grain yield (t/ha)	
		Stressed	Watered	Stressed	Watered	Stressed	Watered	Stressed	Watered	Stressed	Watered
59	DT/BT/2443.DT	63^{e}	64^{cd}	64.33^{j}	64.67^{hijkl}	1.67^{g}	1^{a}	1.03^{abc}	1.1^{bc}	2.2^{bcd}	4.57^{abcd}
60	DT/BT/1917.DT	66.67^{bcde}	64.33^{cde}	65.33^{j}	63.33^{kl}	2.67^{def}	1^{a}	0.87^{abcdef}	1.2^{b}	1.7^{bcde}	3.67^{bcdefg}
29	GBK032419	65.67^{cde}	64.67^{cde}	70gh^{j}	70^{efghij}	2.33^{efg}	1^{a}	1.17^{a}	1.7^{a}	3.7^{a}	5.13^{ab}
58	DT/BT/1470.DT	66.33^{bcde}	67^{bcd}	76.33^{defg}	74.33^{abcde}	1.67^{g}	1^{a}	0.93^{abcdef}	1.27^{b}	3.07^{ab}	3.93^{bcdef}
38	GBK032357	66^{bcde}	64.67^{cde}	73.33^{fghi}	67.67^{fghijkl}	2.67^{def}	1^{a}	0.97^{abcde}	1.03^{bc}	1.83^{bcde}	4.67^{abc}

11	GBK032423	62.33^{e}	61^{efg}	64.67^{j}	65.67^{ghijkl}	3^{cde}	1^{a}
	$0.83^{abcdefg}$	1.13^{bc}	1.63^{bcde}	2.87^{efgh}			
5	GBK027017	65.33^{de}	66^{cd}	73^{fghi}	70.67^{efgh}	3^{cde}	1^{a}
	0.63^{efg}	0.83^{cd}	1.67^{bcde}	3.67^{bcdef}			
31	GBK034659	66.67^{bcde}	63.67^{cdef}	74.33^{efgh}	71.67^{defg}	3^{cde}	1^{a}
	1.07^{abc}	1.1^{bc}	4^{abc}	4.88^{efgh}			

Continued

Appendix 3. Continued

55	CML492	67.67^{bcd}	70.67^{ab}	75^{efgh}	73.33^{bcdef}	2^{fg}	1^{a}
	1.13^{ab}	1.6^{a}	1.27^{de}	2.5^{fgh}			
30	GBK-044593	57^{fg}	56.67^{hi}	65.33^{j}	63.67^{jkl}	3^{cde}	1^{a}
	$0.87^{abcdefg}$	1^{bcd}	1.8^{bcde}	3^{defgh}			
49	KTL N 701104	64^{de}	62.33^{defg}	70.33^{ghij}	64.67^{hijkl}	3.33^{bcd}	1^{a}
	0.9^{abc}	1.07^{bcd}	2.03^{bcde}	4.13bcde			
45	KTL N 70133-3	75^{a}	71^{ab}	83.33^{abc}	78^{abcd}	4^{ab}	1^{a}
	0.93^{abcdef}	1.03^{bc}	1.7^{bcde}	4.23^{bcde}			
42	KTL N 10162-1	78^{a}	73.67^{a}	85^{a}	80.67^{a}	4ab	1^{a}
	0.93^{abcdef}	0.97^{bcd}	1.2^{de}	3.87^{bcdef}			
7	GBK-043227	57f^{g}	59.33^{fgh}	67.33^{ij}	$69.67^{efghijk}$	3^{cde}	1^{a}
	0.8^{bcdefg}	0.9^{bcd}	2.1^{bcd}	4.3^{bcde}			
44	KTL N 10168-2	76^{a}	74^{a}	84^{ab}	79.33^{ab}	3.33^{bcd}	1^{a}
	0.83^{abcd}	1.23^{b}	1.33^{cde}	3.13^{cdefgh}			
57	CML265	67.67^{bcd}	63.67^{cdef}	78^{bcdef}	76^{abcde}	2^{fg}	1^{a}
	0.9^{abcdef}	1.03^{bc}	1.4^{cde}	2.2^{gh}			
40	KCB (control)	43^{h}	40^{j}	53.67^{k}	51.67^{m}	3.33^{bcd}	1^{a}
	$0.83^{abcdefg}$	0.97^{bcd}	1.4^{cde}	3.73^{bcdefg}			
65	DLC (control)	44.67^{h}	40.33^{j}	53.33^{k}	48.67^{m}	4.33^{bcd}	1^{a}
	0.83^{ab}	0.93^{bc}	1.33^{de}	3.57^{bcdefg}			

9	GBK043731	68.33^{bcd}	63.67^{cdef}	77^{def}	$69.67^{efghijk}$	3.33^{bcd}	1^{a}	0.77^{bcdefg}	0.97^{bcd}	3.7^{bcde}	5.13^{a}
32	GBK044611	58.33^{f}	59^{ghi}	69.33^{hij}	64^{ijkl}	3^{cde}	1^{a}	0.67^{def}	1.03^{bc}	1.03^{de}	4.5^{abcd}
12	GBK-034711	65^{de}	63.33^{cdef}	73.33^{fghi}	$67.67^{fghijkl}$	3.33^{bcd}	1^{a}	0.8^{bcdefg}	1.1^{bc}	1.53^{bcde}	3.33^{cdefgh}
48	KTL N 70140-4	70.33^{b}	68^{bc}	80^{abcde}	72.67^{cdef}	3.67^{abc}	1^{a}	0.5^{g}	0.77^{cd}		
2	GBK-045385	53^{g}	55^{i}	64.33j	62^{l}	2.67^{def}	1^{a}	0.8^{bcdef}	0.97^{bcd}	1.6^{bcde}	3.97^{bcdef}
3	GBK-027054	54^{g}	65^{cde}	64.67^{j}	77.33^{abcd}	3.67^{abc}	1^{a}	0.6^{fg}	0.67^{b}		
47	KTL N 70188-2	70^{bc}	70.33^{ab}	82^{abcd}	78.33^{abc}	3.33^{bcd}	1^{a}	0.7^{cdef}	0.83^{cd}	1.03^{de}	1.83^{gh}

Means followed by same letter are not significantly different ($p<0.05$)

Appendix 4. Analysis of variance for drought tolerance evaluation traits – Experiment II

		Drought tolerance evaluation variables									
		Day to anthesis		Days to silk		Anthesis-Silking Interval		Tassel size		Shelling %	
Source	DF	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F
Moisture regime	1	**4.00**	0.0483	**20.58**	0.0001	**10.52**	0.0016	**9.92**	0.0022	**32.94**	0.0001
Genotype	24	**71.76**	0.0001	**33.03**	0.0001	**6.30**	0.0001	**5.68**	0.0001	**4.17**	0.0001
Moisture regime by Genotype	24	**2.71**	0.0003	**2.11**	0.0058	1.1	0.3445	1.58	0.0627	**2.39**	0.0015

Numbers in bold are significantly different

Continued

		Drought tolerance evaluation variables									
		Leaf rolling		100-seed weight		Plant height		Ears/plant		Grain yield	
Source	DF	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F	F-value	Pr.>F
Moisture regime	1	**878.37**	0.0001	**40.76**	0.0001	**77.25**	0.0001	**206.62**	0.0001	**201.16**	0.0001
Genotype	24	**4.29**	0.0001	**12.73**	0.0001	**7.16**	0.0001	**6.04**	0.0001	**4.96**	0.0001
Moisture regime by Genotype	24	**4.13**	0.0001	1.52	0.0787	0.93	0.5606	1.96	0.5606	**1.79**	0.0252

Numbers in bold are significantly different