INHERITANCE AND COMBINING ABILITY STUDY ON DROUGHT TOLERANCE AND GRAIN YIELD AMONG EARLY MATURING INBRED LINES OF MAIZE (*Zea mays L.*)

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(Agronomy Engineer)

NOVEMBER, 2016

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A Thesis Submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana In Partial Fulfilment of the Requirements for the Degree of

MASTER OF PHILOSOPHY IN PLANT BREEDING

By

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NOVEMBER, 2016

DECLARATION

I, Issa Zakai MAHAMAN MOURTALA, do hereby declare that this submission is my own work towards the Master of Philosophy, Plant Breeding and that to the best of my knowledge, it contains no material previously published by another person, nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Utilization of stress tolerant maize is key to sustainable production and food security. Limited knowledge on genetics of drought tolerance hampers development of drought tolerant varieties. The objective of this study was to study inheritance and combining ability of drought tolerance among early inbred lines of maize. Five inbred lines were mated in full diallel in 2015 major season. The resultant 20 hybrids, 5 parents and 2 checks were evaluated under drought stress and well watered conditions in a screen house. Data was collected on days to 50% tasseling (DT 50%), days to 50% silking (DS 50%), anthesis-silking interval (ASI), leaf rolling, leaf senescence, plant aspect (PASP), plant height (PHT), ear height (EHT), ears per plant (EPP), ear weight, hundred grain weight (100 GW) and grain yield per hectare (GY). Drought condition was induced 40 days after planting but watering was continued once per week till maturity. Results from combined ANOVA showed there was high and significant ($p<0.01$) level of genetic variability among parental lines and hybrids used in all the traits studied except DT 50%, PHT, EHT, EPP and 100 GW. There were significant variation in the combining ability of the inbreds under both drought stress and well watered conditions. Both additive and non-additive gene actions were important as well as GCA/SCA ratio variance. Therefore the predominance of GCA over SCA mean squares for DT 50%, DS 50%, ASI, leaf senescence, PHT, EHT, and 100 GW indicates that additive genetic action was more important than non-additive genetic action for inheritance of these traits. Lines TZEI-23 (215.22) and TZEI-25 (76.84) had the highest and highly significant ($p<0.01$) positive GCA effects for GY under drought while TZEI-25 (350.77) and TZEI-124 (237.51) had positive GCA effects under well watered condition. Hybrids TZEI-25 x TZEI-13 showed

the highest positive and highly significant ($p<0.01$) SCA effects for GY (385.74) followed by its reciprocal TZEI-13 x TZEI-25 (311.49) under water stress while under well watered condition TZEI-13 x TZEI-124 (1132.01), TZEI-17 x TZEI-13 (789.01) and TZEI-17 x TZEI-124 (789.01) were the highest and were highly significant ($p<0.01$).

High broad sense heritability was observed for almost all the traits. High narrow sense heritability were observed in only DT 50% (0.69), DS 50% (0.80) and leaf senescence (0.61) under drought condition.

Eighteen hybrids had positive high parent heterosis (HPH) under water stress and ranged from 47.94% (TZEI-124 x TZEI-17) to 364.48% (TZEI-13 x TZEI-25) while 19 hybrids exhibited HPH under well watered condition and ranged from 19.74% (TZEI-13 x TZEI25) to 429.50% (TZEI-124 x TZEI-13) for GY. High parent heterosis were obtained for TZEI-13 x TZEI-25 in GY, ear weight, PAST, leaf senescence, DT 50% and DS 50%, and for TZEI-124 x TZEI-13 in GY, ear weight, PHT, EHT, PAST, DT 50% and DS 50%. Desirable heterotic levels in ASI, DT 50%, DS 50% and PHT are of tremendous advantage in areas with marginal rainfall. Nineteen hybrids scored positive mid-parent heterosis under drought condition as well as under well watered condition for GY and the increase under drought ranged from 5.48% (TZEI-17 x TZEI-13) to 369.90% (TZEI-13 x TZEI-25) and from 58.17% (TZEI-25 x TZEI-23) to 489.76% (TZEI-13 x TZEI-124) under well watered condition.

The lines TZEI-23 and TZEI-25 were identified as the best general combiners respectively under drought and well watered condition. The highest HPH were observed in many traits for TZEI-13 x TZEI-25 and TZEI-124 x TZEI-13. It is recommended these hybrids are further evaluated in different environments for release to farmers to increase yield.

DEDICATION

This thesis is dedicated to my late Dad Elhadji Issa Zakari and my dear Mum Hadjia Nandou Moussa for their support during the whole of my life and my lovely family (my wife Aichatou Jamila and my daughter Mariam) who endured my long absence during this programme.

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ABREVIATIONS, ACRONYMS AND SYMBOLS

>	Greater than
<	Less than
*	Significant at 0.05 probability level
**	Highly significant at 0.01% probability level
%	Percentage

°C	Degree Celcius
ANOVA	Analysis Of Variance
ASI	Anthesis Silking Interval
Ca	Calcium
CIMMYT	International Maize and Wheat Improvement Centre
Cm	Centimeter
CRI	Crop Research Institute
DAP	Day After Planting
DS 50%	Days to 50% Silking
DT 50%	Days to 50% Tasseling
EASP	Ear Aspect
EEP	Ears Per Plant
EHT	Ear Height
ESA	East and Southern Africa
FAO	Food and Agriculture Organization
G	Gram
GCA	General Combing Ability
GEI	Genotype x Environment Interaction
GY	Grain Yield Per Hectare
H_{2b}	Broad-Sense Heritability
H_{2n}	Narrow-Sense Heritability
HPH	High Parent Heterosis
INRAN	Institut National de la Recheche Agronomique du Niger
IITA	International Institute for Tropical Agriculture
K	Potassium
KNUST	Kwame Nkrumah University of Science and Technology
Mg	Magnesium
MPH	Mid-Parent Heterosis
Mn	Minute
MT	Metric Ton
N	Nitrogen

Na	Not Available
Ns	Not Significant
P	Phosphorus
PBT	Plant Breeding Tools
PCA	Principal Component Analysis
PHT	Plant Height
QTL	Quantitative Trait Loci
Rec	Reciprocal
SCA	Specific Combing Ability
SSA	Sub-Sahara Africa
SVP	Singular Value Partitioning
TZEI	Tropical Zea Early Inbred
USA	United States of America
WAP	Week After Planting
WCA	West and Central Africa

CHAPTER ONE

1.0. INTRODUCTION

Maize (*Zea mays L*. 2n = 20) belongs to the family Gramineae, and tribe Maydeae or by others Andropogoneae (Norman *et al.*, 1995). It occupies the second position after wheat in terms of area of production but represents the most important cereal crop in terms of quantity produced worldwide (FAOSTAT, 2015). In terms of consumption and cultivation, maize crop is very adaptable and versatile. In 2014, worldwide production of maize was around 1 billion ton, with America being the largest producer, which produces 51.5% equivalent to 526,449,942 tons and United States of America with 361,091,140 tons (FAO, 2015). Africa produces 7.6% and Nigeria is the largest African producer with 10,790,600 million tons (FAO, 2015). According to Breisinger *et al*. (2008), it is the most important cereal crop in Ghana in terms of consumption and production. In 2014, Ghana produced 1,762,000 tons while the productions in 2012 and 2013 were respectively, 1,949,897 and 1,764,477 tons (FAO, 2015). In developed countries, maize crop is mainly used as an animal feed while it is largely used as a human consumption in developing countries. In Africa, people consume maize as a starchy base in a wide variety of paste, beer, grits and porridge. In sub-Saharan Africa, it is a stable food for around 50% of the total population (USAID, 2010). Maize crop is an important source of protein, minerals, vitamin B, iron, and carbohydrate. It is fast becoming a very important commodity in animal feed, food and beverage industries (USAID, 2010).

Despite the level of adaptation that maize crop displays and its potential in savanna ecology, low yield are still obtained due to biotic and abiotic stresses. According to

Kamara *et al*. (2004), drought and low soil fertility are among the most important stresses threatening food security, maize production and economic growth. In dry savanna zone of West Africa, drought effect on food supplies and maize crop production are most severe (Fajemisin *et al*., 1985), due to the unpredictability of rainfall in the region in terms of establishment, quantity, and distribution (Izge and Dugie., 2011). In addition, recurrent drought is the single most important factor limiting maize production in West and Central Africa, with several billion U.S. dollars in production lost annually to this stress factor (Badu-Apraku *et al.*, 2011). In Ghana, according to Obeng-Antwi *et al*. (1999), frequent drought stress is a major constraint in the largely rain-fed agricultural system that limits the production of maize. Research attention should be directed toward maize hybrids production that can resist drought stressed ecologies. Therefore the need for breeding maize crop tolerant to drought condition for high yield is important.

IITA has developed a wide range of maize germplasm which are adapted to the climate conditions of sub-Saharan African countries (Laouali, 2014). A large number of their inbred lines were developed under stress conditions such as striga, drought and low nitrogen, and some of their early inbreds were used as source of germplasm in this study. However, information on combining abilities, heritability and heterosis of these inbreds is limited. Thus information regarding gene action, combining abilities, heritability and heterosis is essential for selection of suitable parents for hybridization and identification of promising hybrids for the development of improved varieties for a diverse agroecology. Such information is useful in developing stable hybrid with high yield.

Therefore, this study was conducted to estimate heritability, examine combining ability, and determine performance of parents (inbred lines) and hybrids under water stress and well watered conditions among early inbred lines of maize.

The specific objectives were to:

i) Understand genetic control of drought tolerance and grain yield in maize; ii) Examine the combining ability of early inbred lines of maize for drought tolerance and grain yield; iii) Estimate the heritability of drought tolerance and grain yield among early inbred lines of maize; iv) Determine the performance of the inbreds and hybrids under drought condition.

1.1. Hypotheses

Two hypotheses were tested in the study as follows:

i) The genotypes are tolerant to drought stress; ii) The inbred lines are good general combiners for drought tolerance and grain yield.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Origin and Distribution of Maize

Maize (*Zea mays L*.) is a member of the grass family Poaceae. There is some controversy on the origin of maize, though it is generally accepted that its centre of origin is located in Mesoamerica, primarily Mexico and the Caribbean. Maize crop we know nowadays has never domesticated from a wild *teosinte* (*Euchlaena mexicana*), is believed to have begun some 6,000 to 7,500 years ago in the Mexican highlands. The archeological evidence from Mangelsdorf, Revees, MacNeish, and others and supported by radiocarbon dating, have indicated the existence of wild maize ears in Mexico 5200-3400 BC, (Purseglove, 1975)

After several researches, it was agreed that teosinte and maize were fully interfertile, and in essence members of the same biological species. Maize crop is simply a domesticated form of teosinte, and that as few as 5 major genes control the morphological evolution from teosinte (Beadle, 1939)

2.2. Importance and use of Maize

According to FAO (2007), maize crop is cultivated in many countries and is utilized in quite a lot of ways compared to other cereal crops with nearly every fraction of the plant crop having commercial value. The plant is a major source of protein, vitamin B, carbohydrate, iron, and minerals. In developed countries, maize is primarily utilized to feed domestic animals and at the same time as unprocessed material for manufacturing products, but in developing worlds, it is generally utilized for human consumption (IITA, 2009 and Badu-Apraku *et al.*, 2012). In Africa, most people eat maize as a starchy base in a broad mixture of grits, pastes, beer and porridges, while others eat it when roasted, boiled, cob parched or baked. Besides, early maturing maize serves a very significant role in bridging the hunger gap following the dry season (ARC-Grain Crop Institute, 2003).

The tassels, leaves and stalks serve as feed for domestic animals, either in form of fodder or as stover. In some instance, the roots of maize can be incorporated into the soil for physical composition improvement, or used as firewood when dried (Morris, 2002).

2.3. Production

Worldwide production in year 2014 of maize is around 1 billion ton, with America the largest producer, producing 51.5% equivalent to 526,449,942 tons and United States of America with 361,091,140 tons. Africa produces 7.6% and Nigeria is the largest African producer with 10,790,600 tons (FAO, 2015). Maize in Sub-Sahara Africa (SSA) is for the most part the main cereal food crop with more than 50% of all countries apportioning above 50% of their cereal crop production area to maize. Documentation exhibits that maize crop is the main food for an estimated 1,200,000 people in SSA. Global consumption of maize is estimated at 116 million tons with SSA accounting for 21% (IITA, 2012). According to Odogola and Henriksson (1991) and Lyon (2000), in SSA with the exception of South Africa, the bulk of maize produced is mainly by small holder farmers operating as individuals or in groups.

Maize plant is grown in Ghana, almost everywhere, from the coastal belt across the forest savanna, transition, Guinea savanna to the north east corner (NARP, 1993). However, for maize, the forest-savanna transition zone is largest agro-ecological area, which has a bimodal rainfall regime. In this production area, maize fields usually range from one to two hectare (GGDP, 1990). According to FAOSTAT (2013), in Ghana the area of maize planted stands at approximately 1,000,000 ha.

2.4. Ecological requirements for maize

2.4.1. Temperature

Maize crop requires a warm temperature and is not grown in regions where the average daily temperature is < 19 ºC or the average months summer < 23 ºC. For germination, 10 ºC is the minimum temperature and this germination will be faster and less variable at soil temperature between 16 and 18 ºC. Within 5 to 6 days, maize should emerge at 20 ºC, while 32 ºC is a critical temperature which could detrimentally affect yield. Frost can also damage maize crop at all periods. Frost easily damages leaves of mature plants and affects grain filling (ARC-Grain Crops Institute, 2003).

2.4.2. Precipitation and water requirements

During the growing season, maize needs in general 500-700 mm of rainfall. Even that quantity of rain can be insufficient, if the soil moisture cannot be retained because of shallow soil depth or runoff or if the evaporative require is great due to low relative humidity and high temperatures. A yield of 3152 kg/ha demands 350-450 mm of rain per annum and 10-16 kg of maize grain are produced for every mm of water applied. In the absence of moisture stress, 250 liters of water will have been applied to each plant at maturity (ARC-Grain Crops Institute, 2003).

2.4.3. Soil requirements

The most suitable soil for maize plant is one with a good internal drainage, good effective depth, favorable morphological properties, an optimal moisture regime, sufficient and balanced amounts of plant nutrients and chemical properties (Obeng, 1971). Although large scale maize crop production takes place on soils with a clay content of < 10 % (sandy soils) or in excess of 30 % (clay and clay-loam soils), the texture classes between 10-30 % have moisture regimes and air that are optimal for healthy maize production (IITA, 1997).

2.5. Constraints to maize production in Sub-Sahara Africa

2.5.1. Abiotic constraints

Maize crop exhibits a wide genetic base for abiotic stress tolerance, which is mirrored by its capability to grow in diverse environments, although it is essentially a warm climates crop with adequate moisture (Purseglove, 1972). Water deficiency, temperature, waterlogging and nutrient deficiencies are some of the abiotic factors that affect maize production. Symptoms such as stunted plants, leaf yellowing, delayed flowering, crop lodging, poorly filled ears and sometimes death of plants can occur when nutrients are in excess or when they are limiting (Hughes, 2006). Rainfall is a limiting factor to dryland production of commercial maize crop and irrigation is essential in regions with a winter dominant rainfall pattern or where the quantity of summer dominant rain is highly variable. Maize plant is particularly susceptible to drought at the flowering stage when yield potential is being set especially as this coincides with the high evapotranspiration rates of mid-summer (Farnham *et al*., 2003). Temperatures below 8 ˚C or above 40 ˚C causes cessation of development because factors such as translocation, photosynthesis and pollen viability are negatively affected (Birch *et al.*, 2003). Srinivasan *et al*. (2004) reported that plant growing for prolonged periods in waterlogged soils exhibit reduced leaf area growth, stomatal closure, reduced root growth, root death, chlorosis, and ultimately plant mortality.

2.5.2. Biotic constraints

Weeds, pests and diseases are some biotic constraints to maize production. Maize is susceptible to competition from weeds, particularly at the early stages. The large spacing within and between rows provides opportunity for weed establishment. Weeds may directly lead to grain yield reduction by competing with the maize plants for water and nutrients supplied and need to be controlled within three weeks of crop emergence (Morris, 2008). Pests and diseases are other factors that affect maize production. Beckingham (2007) reported that some of the pests and diseases that cause damage to maize during germination and maturity are false wireworms, maize stem borer, black field earwigs, cutworms, Africa black beetle, fusarium cob rot and stalk rot, soft rot, downy mildew, head smut, common rust, maize dwarf mosaic and boil smut.

2.6. Effects of climate change on maize production in the tropics

According to FAOSTAT (2010), maize is produced on nearly 100,000,000 ha in developing worlds, with almost 70 % of the maize production in the developing countries coming from low and lower middle income countries. Maize grain yields remain variable between years across SSA at 1,600 kg per ha, only just enough to reach self-sufficiency in many areas (Bänziger and Diallo, 2001 and FAOSTAT, 2010). By 2050, the world population is expected to exceed 9,000,000 people, with population growth highest within developing countries. Projection of climate change will further exacerbate the capacity to ensure foster economic growth and food security within several areas of maize production.

In the tropic, biotic and abiotic stress are factors that accounts for the decline in maize production. Some of these factors are waterlogging, heat, insects pests and diseases.

2.7. Water and high temperature stress effects on maize production

In SSA, high temperature and water stress are regarded as severe constraints to maize production even under conditions where the soil profile is fully recharged at the beginning of the growing season. As reported by Tweneboa (2000), experience in many countries have shown that soil moisture deficiency that causes wilting for one-two days during tasseling stage can reduce yield by up to 28 % and six-eight days wilting can cause 50 % yield reduction, which cannot be made up by later irrigation or precipitation.

High temperatures affect pollen grain viability directly, even when the crop showed no visible symptoms of drought stress, (Herrero and Johnson, 1980). Carberry *et al*. (1989) and Johnson and Herrero (1981) added that, at temperatures greater than 38 °C, poor seed set in maize has been attributed to direct effect of high temperature. Madhivazhagan *et al.* (2004) corroborated the idea by saying, grain numbers, low grain yields and harvest index were observed in the sowing treatment where high air temperatures (>38°C) coincided with anthesis.

2.8. Drought concept

Plants adapt to stresses using different mechanisms such as tolerance (which stabilize and protect cellular integrity under conditions of tissue desiccation), escape (which allows a plant to grow and complete its life cycle before soil moisture becomes limiting) and avoidance (which enables plants to maintain positive tissue water relations even under water stress) (Ludlow and Muchow, 1990).

Drought is an imbalance between water uptake and water lost through transpiration (Yoshida, 1981). Larcher (1995) reported that drought denotes a period without appreciable precipitation, during which the soil water content is reduced to such an extent that plants suffer from lack of water. On a large scale, drought results from both combination of low precipitation and high evapotranspiration caused by dryness of the air and high levels of radiation (Larcher, 1995). Nevertheless, plants may experience transient drought stress during noon hours of hot days even with adequate rainfall or irrigation (McKersie and Lesshem, 1994). Turner (1997) indicated that if plants are to survive this imbalance they must have a range of both morphological and biochemical mechanisms that enable them to grow and reproduce despite water limitations. Events of drought can be classified according to their cause, (i) agricultural drought when water supplies used directly for agriculture are scarce resulting in a consistently high soil moisture deficit over the growing season; (ii) meteorological drought occurs when precipitation is significantly below expectations for the year and location. The threshold for agriculture drought may be influenced by shifting to another crop because different crops have different water requirements (Ashley, 1993).

2.8.1. Impact of drought on crop production

For many households, drought stress is a major problem of food insecurity. Its estimation has found out that in the developing countries it causes annual maize yield loss of 24,000,000 tons. The estimated losses are about 10-75 % in Asia (Logrono and Lothrop, 1997); 15 % or 1,200,000 tons annually in Indonesia (Dahlan *et al*., 1997); 1,200,000 tons in Argentina (Eyherabide *et al*., 1997), and 1.69 t/ha or 37 % in the large-scale commercial sector in Zimbabwe (Machida, 1997). In Ghana, drought stress is also the major factor that limits maize productivity (SARI, 1995 and Obeng-Antwi *et al*., 1999). Drought stress has often been cited by farmers in Ghana as one of the major constraints to high maize productivity. According to Agrama and Moussa (1996), drought is second only to poor soil fertility in reducing maize yield in the developing worlds, leading to a 15 % overall reduction in grain yield in these countries, and in a bad year can be the major constraint on yield in developed countries as well.

2.8.2. Effect of drought on seedling establishment

If drought occurs at seedling stage, it enhanced root growth and adaptation of maize hybrids to drought stress. Aslam *et al*. (2013) reported that maize seedlings adapt to low water potential by making the walls in the apical part of root further extensible. Drought stress caused meristematic cells to be long and cell division reduced along with per unit length of tissues and cell in all the meristem as concluded by Sacks *et al*. (1997). Many authors such as Anjum *et al*. (2003); Kusaka *et al*. (2005); Bhatt and Rao (2005) and Shao *et al*. (2008) concluded that the cessation of elongation and cell expansion stops growth of seedlings.

2.8.3. Effect of drought on vegetative growth

Drought can kill young maize plants during the crop establishment, thereby reducing the plant density. According to Prabhu and Shivaji (2000), the main effects of drought stress in the vegetative stage are to induce leaf rolling and reduce leaf and stem growth, so that the crop intercepts less sunlight. Besides, Vianello and Sobrado (1991) reported that drought during the maize vegetative period provides diminution of the stem and leaves growth and Aslam *et al*. (2013) concluded that stem elongation in maize under water stress was reduced during vegetative period. Edmeades and Gallaher (1992) reported that plant height of fullsib maize plant families were higher in the irrigated compared to the rain fed site.

2.8.4. Effect of drought on root growth

Drought stress reduced fresh and dry shoot and root weight by 40 and 58 %, respectively. Ramadan *et al*. (1985) found that drought stress reduced shoots and root growth in maize production. The enhancement in ratio was due to the fact that comparatively roots are less susceptible to drought stress than shoots growth. Studies of Anderson (1987) clarified that rapid development of root occurs during the first 8 WAP and it can assist the plant till maturity. It was found out that the most drought resistant varieties had maximum root fresh weight that was the best characteristic to identify drought resistant crop plants (Aslam *et al*., 2013).

2.8.5. Effect of drought on photosynthetic activity

Studies showed that drought diminished the photosynthesis and that grain growth during endosperm cell division was more sensitive to drought as compared to deposition of starch in the seed. Under drought stress, activity of enzymes reduces, hence formation of starch from sucrose in grain decrease as the ability of acid invertase diminishes (Aslam *et al*., 2013).

Carotenoids are the compound which support the plants to resist against drought stress. Photosynthesis directly depends on leaf water potential and relative water contents. The study of Lawlor and Cornic (2002) found that decreases in relative water contents and leaf water potential decreases the speed of photosynthesis.

2.8.6. Effect of drought on maize at flowering

Although drought stress can strike maize crop at any time of development stage, during flowering the plants are most susceptible to damage due to limited water. This is supported by Classman and Shaw (1970) who reported that drought stress affects maize grain yield at almost all growth stages, but the crop is most susceptible at flowering.

Abortion of ovules, kernels and ears may occur within the period from 1 week before silking to 2 weeks after silking. Water deficit stress decrease carbon availability and dry mater partitioning to ear at the critical periods and these factors determine the number of grain (Andrade *et al.*, 2000). It is a fact that during the reproductive stage, the plant reduces the demand of carbon by decreasing the sink size when drought stress begins to affect the plant. As a consequence, tillers degenerate, pollen may die, flower may drop and ovule may abort (Blum, 1996). Limited water at pollen shedding period does not restrict the pollination but due to the lack of photosynthesis, it prevents the development of embryo (Westgate and Boyer, 1986).

On pre-anthesis stage, as reported by Denmead and Shaw (1960) and Classman and Shaw (1970) drought stress before 1 week to silking and 2 weeks after silking decreased the grain yield by 53 % of the well watered.

On anthesis-silking interval (ASI), the study of Fiedrick *et al*. (1989) showed that drought stress increase ASI, which reduced grain filling duration of all the hybrids. The sensitive stages of vegetative and reproductive growth in maize plant are silking, flowering, pollination and grain filling. Ear growth and silk appearance reduction may be caused by continued drought stress during flowering. This results in expansion of ASI gap (Aslam *et al*., 2013). The studies on maize hybrids conducted by Bassetti and Westgate (1994) show that effect of reduced number of pollen on the number of grain occur when pollen quantity reduced to 80 % or more or when ASI reached to eight days or more. ASI is a good indicator of movement of recently produced assimilates to the ear, number of grains, ear growth, and also the water potential of plant (Edmeades *et al*., 2000).

2.8.7. Effect of drought on grain yield

Maize grain yield reduced due to shortage of water if water deficit occurs during the critical growth period from tasseling to grain filling. Bergamaschi *et al*. (2004) studied that during 1998/'99 a long period drought, 48.8 mm rainfall produces 4.8 t/ha of grain yield. On the other hand during the year 2002-2003 a short duration drought that occurred during critical growth period reduced the grain yield up to 2 t/ha. Grain yield is a highly complex character through which resulting grain production is affected by plant phenotypic characteristics and regulatory pathways (Ribaut *et al*., 1997).

Variation in yield among maize inbreds and hybrids increases with the intensity of water deficit stress, (Betran *et al*., 2003).

2.9. Combining ability

2.9.1. Combining ability in relation to diallel crossing systems

The terms general and specific combining ability (GCA and SCA) were originally defined by Sprague and Tatum (1942). The authors defined the terms as follows: the term "general combining ability" is used to designate the average performance of a line in hybrid combination and the term "specific combining ability" is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved."

There are four possible experimental methods: (1) parents, one set of F_1's and reciprocal F_1's are included (all p^2 combinations); (2) parents and one set of F_1's are included but reciprocal F_1's are not ($1/2p(p+1)$ combinations); (3) one set of F_1's and reciprocals are included but not the parents *(p(p-l)* combinations); and (4) one set of F_1's but neither parents nor reciprocal F_1's is included ($1/2P(P-1)$ combinations). Each method necessitates a different form of analysis (Griffing, 1956).

With regard to the sampling assumptions it is necessary to distinguish between (1) the situations in which the parental lines are assumed to be a random sample and (2) the situations in which the lines are deliberately chosen and cannot be regarded as a random sample from any population. These two different assumptions give rise to different estimation problems and different tests of hypotheses regarding combining ability effects.

2.9.2. General combining ability and specific combining ability of some agronomic traits under drought stress

Reports on the gene action conditioning grain yield of tropical maize under water stress are available but many are contradictory. In the study of Guei and Wassom (1992), in two maize populations, greater dominance deviation ears per plant and grain yield were recorded even though additive genetic variance was more important than non-additive genetic variance in the expression of flowering characters. In contrast, Badu-Apraku *et al.* (2004) reported moderate-to-large additive genetic variance and narrow sense heritability estimates for grain yield and other traits studied in the early maturating population, Pool

16 DT, after eight cycle of recurrent selection for improved grain yield under stress. Effect of both GCA and SCA were significant for 24 late maturing tropical maize inbred lines evaluated in line x tester crosses under well watered and controlled moisture stress conditions. In the study, GCA accounted for > 50% of total variation for all traits, except ears per plant under well-watered conditions.

Besides, Badu-Abraku *et al.* (2011) reported significance of entries mean squares for all the studied traits (DS 50%, ASI, ear aspect, PHT, EPP, leaf death score and grain yield), indicating that there is potential genetic variability among the inbred lines to allow good progress from selection for improvements in the traits. Mean squares for GCA and SCA were significantly different for all the measured traits except ASI, DS 50% and ear aspect for which only general combining ability was significant. The significant of entry and general combining ability mean squares indicated that there was scope for the improvement of these characters through selection. For the remaining traits like PHT, EPP and grain yield; GCA and SCA mean squares were both significant under water stress and well-watered conditions.

A study by Aminu *et al.* (2014a) indicated that the mean squares due to lines were significant for DT 50%, DS 50% and EHT and significant to testers for DT 50% and DS 50% and keep saying yet that the analysis of variance for combing ability showed that the mean squares due to line x tester interaction were significant ($p<0.05$) in DT 50%, DS 50%, ASI, PHT and EHT. The result shows that additive and dominance gene actions are important and responsible in the genetic expression. These results are in agreement with those of Kadams *et al*. (1999), Badu-Apraku (2011), Aminu and Izge, (2013). The explanation of that fact is that there is the existence of tremendous amount of variability in the genetic materials evaluated, confirming the results of Olaoye *et al*. (2005) and Izge *et al*. (2007). Even though, both additive and dominance gene actions play an important role in the genetic control of most traits under water stress and non-drought stress, the estimates of variance components indicated that the GCA/SCA ratio variance shows the importance and predominance of non-additive genetic effects because the specific combining ability variance was higher than the general combining ability except number of stand per plot, dehusked ears, number of ears per plot, and grain yield. However the results were in agreement with that of Sharma *et al*. (2004), Badu-Apraku *et al*. (2011) and Aminu and Igze (2013) who found preponderance of additive genetic effects in control of maize traits.

2.10. Heritability

2.10.1. Concept of heritability

According to Falconer and Mackay (1996), heritability is defined as the expression of the proportion of total variation that is attributable to differences of breeding values, and this is what determines the degree of resemblance between relatives. It indicates the degree to which variation in a quantitative trait can be passed from parent to offspring; how well parent's trait predicts offspring's trait.

Heritability can be expressed in narrow sense and broad sense. Narrow sense heritability (h^2_n) is a ratio of the additive genetic variance of the phenotypic variance; σ^2_A/σ^2_P. Heritability in the narrow sense is the more useful concept because it measures the relative importance of the additive portion of the genetic variance that can be transmitted to offspring. Thus, breeders and scientists use narrow sense heritability as a measure of heritability and call it “breeding value”. Heritability in broad-sense (h^2_b) is a ratio of the total genotypic variance (σ^2g) to the phenotypic variance (σ^2_P); σ^2_G/σ^2_P, where:

$$\sigma^2_G = \sigma^2_A + \sigma^2_D + \sigma^2_I$$

$$\sigma^2_P = \sigma^2_G + \sigma^2_E = \sigma^2_A + \sigma^2_D + \sigma^2_I + \sigma^2_E + \sigma^2_{GE}$$

σ^2_P = phenotypic variance; σ^2_G = genotypic variance; σ^2_E = environmental variance; σ^2_A = additive variance; σ^2_D = dominance variance; σ^2_I = interaction variance; σ^2_{GE} = interaction between genotypes and environment.

The heritability of a character is not a constant value. The magnitude of heritability and the amount of genetic improvement obtained from selection can be influenced by breeder. An understanding of the factors that contribute to heritability allows the breeder to develop a breeding program that maximizes genetic improvement with available resources. Because many factors can influence heritability, estimates of them should be interpreted with regard to the conditions under which they were obtained (Fehr, 1987).

2.10.2. Heritability of some agronomic traits under drought stress

In the study of heritability, years and location can play an important role in modifying the heritability estimates for different traits and Wannows *et al*. (2010) reported that heritability estimated is important in choosing the suitable segregation generations for exhibiting the best expression of gene of different studied traits. Aminu and Izge (2012) reported high broad-sense heritability (h^2_b) estimates were detected 61.54%, 60.78%, 60.16%, 67.44% and 60.73% respectively for number of stands per plot, ASI, PHT, ears weight and grain yield. However the study shows again moderate broad-sense heritability estimates for DT 50% 47.91%, DS 50% 50.03%, EHT 58.45% and dehusked cobs

55.06%; while low heritability estimates were obtained for EPP (37.21%), number of ears per plot (43.62%) and hundred seeds weight (31.99%). These results are in agreement with Amer and Mosa (2004). Also, Hasib (2005) found highest heritability estimates with 0.99 % for grain yield and 0.90% for plant height, and Bello *et al*. (2012) found too high magnitude of this heritability in all maize traits (seedling emergence, DT 50%, DS 50%, ASI, PHT, EHT, ear weight, number of grain per ear, and grain yield) except days to 50% pollen shed 8.54%. This implied better opportunities for selection regarding these traits and these were in line with results obtained by Swati and Ramesh (2004), Saleem *et al*., (2008) and Aminu and Izge (2012) who reported that high estimates of h^2_b for most of the traits revealed that variations were transmitted to the progeny and indicated potential for developing high yielding varieties through selection of desirable plants in succeeding generations.

2.11. Heterosis

2.11.1. Concept of heterosis

Hybrid cultivars that result from inbred lines crossing; typically two inbred lines in the case of two-way/single-cross hybrid and they are used for the commercial production of a number of plant species. Inbred lines are chosen for their combing ability to achieve maximum hybrid vigor and this is a desirable type of cultivar because of their ability for maximum heterosis (Fehr, 1987). The superior performance of hybrid progenies over their parents is called heterosis. Heterosis can be expressed: (i) High-Parent Heterosis (HPH) or Better-Parent Heterosis (BPH) which is a comparison of the performance of the hybrid with that of the best parent in the cross; and (ii) Mid-Parent Heterosis (MPH) which is the performance of a hybrid compared with the average performance of its parents (Fehr 1987). Two methods are used:

$$\text{High-Parent Heterosis (\%)} = \frac{F_1 - HP}{HP} \times 100$$

$$\text{Mid-Parent Heterosis (\%)} = \frac{F_1 - MP}{MP} \times 100$$

Where: HPH = High-Parent Heterosis

MPH = Mid-Parent Heterosis

F_1 = Performance of hybrid

HP = Performance of best parent

MP = Average performance of parents per se (parent 1 + parent 2)/2

Heterosis can be expressed when the parents of a hybrid have different alleles at a locus and there is some level of dominance among those alleles (Falconer, 1981). Extensive debate about the genetic mechanisms behind the expression of heterosis still persist among researchers. Therefore dominance hypothesis and the over dominance hypothesis are the two hypothesis that received the most attention. According to the dominance hypothesis, heterosis is caused by complete or partial dominance. In the over dominance hypothesis, the value of the heterozygote is considered superior to the value of either homozygote (Fehr, 1987).

2.11.2. Heterosis of some agronomic traits in maize under drought stress

A study by Aminu *et al*. (2014a) indicated that positive high value heterosis is actually desirable for ASI, which mean that the hybrid could tolerate drought. This corroborates with the findings of Grant *et al*. (1989) that drought stress is more detrimental on maize crop during tasseling. Izge *et al*. (2007) and Izge and Dugje (2011) reported that hybrids which tassel and produce silks early in the season will be of utmost advantage in a drought endemic environments because they could escape drought. Aminu *et al*. (2014a) found out that hybrids with negative heterosis for PHT and EHT will mature early and can escape drought.

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Experimental site

The experiment was conducted on the research field of the Department of Crop and Soil Sciences, KNUST during the major season of 2015 (from April to July).

The evaluation of the twenty diallel single crosses, the five inbreds parents and two checks for drought tolerance was carried out in the screen house of the Department of Horticulture, KNUST, Kumasi (Ghana) during the major season of 2016 (from March to June). The site is located geographically on latitude 01º; 36º and 01º; 43º West of the Greenwich meridian.

3.2. Genetic materials

Five early maturing tropical yellow-grained IITA maize inbreds were used in this study. Most of these inbreds were developed under environmental stresses such as drought, low N and *Striga* but information about their combining ability is limited. The characteristics of these inbreds are given in Table 3.1.

Table 3.1. Characteristics of the maize inbred lines used in full diallel to develop hybrids for the study

Entry	**Origin**	**Parentage**	**Reaction to Striga**	**Reaction to Drought**
TZEI-13	IITA	TZE Comp5-Y C6 S6 Inbred 12	Resistant	Susceptible

TZEI-17	IITA	TZE Comp5-Y C6 S6 Inbred 35	Tolerant	Tolerant
TZEI-23	IITA	TZE-Y Pop STR C0 S6 Inbred 62-2-3	Tolerant	Tolerant
TZEI-25	IITA			
TZEI-124	IITA	TZE-Y Pop STR Co S6 Inbred 3-1-3	Tolerant	Susceptible

Source: Laouali (2014)

The five inbred lines were crossed in a 5 x 5 full diallel at the research field of the Department of Crop and Soil Sciences. Twenty single cross hybrids were generated. The twenty diallel single crosses, the 5 inbred parents and two checks [one open-pollinated variety (OPV) OMANKWA and one triple ways hybrids MAMABA from Crop Research Institute (CRI) Maize Program] were used for the evaluations (Appendix 1).

3.3. Experimental design

A Completely Randomized Design (CRD) was used for the evaluation of the 27 genotypes under managed drought and well watered conditions. The treatments were replicated three times. Each plot contained three pots. Therefore a total of 486 potted plants were evaluated. The water stress and the well-watered experiments were planted in the same plant house in two adjacent blocks.

A software [Plant Breeding Tools (PBT) version 1.4, 2014] was used to randomize the treatments.

3.4. Crop management practices

3.4.1. Stress management and quantity of water applied

The number of the pots was divided into two in the same plant house; the water stress and the well-watered conditions. For the whole experimental time, plants received water twice or thrice each week (interval three-four days before flowering and two-three days during flowering) depending on the temperature and soil moisture. However, water was withdrawn at 40 DAP (one week before tasseling) from the water stress regime but watering continued once in a week, while irrigation was kept normally till eleventh week after planting for the non-water stress which coincided with end of grain filling. Five liters of water was applied (Appendix 2) each week to each plastic pot to regain the initial soil moisture but this quantity was increased during flowering stage.

3.4.2. Evaluation substratum

3.4.2.1. Soil sampling

Soil samples were collected from Kotai area specifically at "Donyina" which is in the rain forest agro-ecological zone of Ghana from a depth of 0-100.00 cm in March, 2016. The bulk sample was air-dried. A sample was taken and stored in polythene bag for analysis. The pots (buckets) of 18 liters were used and each was filled with 18 kg of soil samples.

3.4.2.2. Soil chemical analysis

The bulk sample was taken to KNUST Soil Science Laboratory where it was analyzed for routine parameters by standard laboratory procedures.

3.4.2.2.1. Soil pH

The determination of hydrogen ion activity (pH) of soil was done using a model MK2 pH meter (with a glass electrode) with soil to water ratio of 1: 2.5. The method described by Landen (1991) followed to determine soil pH.

3.4.2.2.2. Organic carbon

The procedure used to calculate the quantity of organic carbon in the soil was the wet combustion method described by Walkley and Black (1934). The following formula was used to calculate percentage carbon in the soil sample:

$$\%C = \frac{M \times (a-b) \times 0.39 \times Mcf}{W}$$

Where: W = weight of the soil sample used

a = volume of ferrous sulphate needed for blank titration

b = Volume of ferrous sulphate needed for sample

M = Molarity of ferrous sulfate solution

Mcf = Moisture correlation factor

0.39 = 3 x 0.001 x 100% x 1.3 (3 = equivalent weight of C, 1.3 = compensation factor for incomplete oxidation of C)

3.4.2.2.3. Percent Organic Matter (O.M)

As described by Landen (1991), percentage organic matter was determined by multiplying the organic carbon value by a factor of 1.72 to convert it to percent organic matter.

3.4.2.2.4. Total nitrogen

Macro-Kjeldahl method was used to determine the total N. This was in agreement with the method described by Bremmer and Mulvaney (1982). The percentage of total nitrogen in the soil was calculated as follows, according to the basis that, 14 g of N is contained in one equivalent weight of NH_3.

$$\%N = \frac{14 \times (A-B) \times N \times 100}{1000}$$

Where: A = Volume of standard acid (HCl) used in the sample titration

B = Volume of standard acid (HCl) used in the blank titration

N = Normality of standard acid (HCl)

3.4.2.2.5. Available phosphorus

The Bray P method (Bray and Kurtz, 1645) was used to obtain the available phosphorus in the soil. Bausch and lamb Spectrophotometer were used to determine the phosphorus content of the soil.

3.4.2.2.6. Exchangeable bases (K, Ca, Mg, and Na)

These (K, Ca, Mg and Na) were obtained using ammonium acetate (1.0 M NH_4 OAC) at a pH 7.0. K and Na were detained by the flame photometer while Ca and Mg by the EDTA titration method (Black, 1986).

3.4.2.2.7. Effective cation exchange capacity (E.C.E.C)

ECEC was obtained by adding all the exchangeable cations namely K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+} and H^+.

3.4.2.2.8. Percentage base saturation (B.S)

It was determined by dividing the total exchangeable bases (TEB) by the ECEC, and the result multiplied by 100.

$$B.S\ (\%) = \frac{\text{Total Exchangeable Bases}}{\text{Effective Cation Exchange Capacity}}\ x\ 100$$

3.4.2.3. Soil physical analysis

The soil particle size was analyzed using the hydrometer method (Day, 1953).

Calculation: % sand = 100 – [(A / W) x 100]

% Clay = 100 x (B / W)

% Silt = 100 – (% sand + % clay)

Where A = corrected hydrometer reading at 40 seconds

B = corrected hydrometer reading at 3 hours

W = weight of dry soil

The textural class of the soil analyzed was then obtained from the textural triangle.

3.5. Planting

During planting, two or three seeds of each of the twenty seven genotypes were sown per pot and were thinned to one healthy plant per pot 15 DAP. Therefore a total of four hundred and eighty six plants were obtained for the two water regimes. Planting was done on 13th March, 2016. Refilling was done on 18th March, 2016.

3.6. Fertilizer application

N: P_2O_5: K_2O (15-15-15) and urea were applied as fertilizers. NPK was applied at a rate of five grams to each pot at twelfth DAP followed by urea also the same rate (five grams) at thirty second DAP.

The diameter of bucket used in the study is 34cm, therefore:

Surface area of the bucket, $S = 2 \times \Pi \times r^2$

Where: S = Surface area of the bucket, Π = Pi approximately 3.142 and r = radius.

$S = 2 \times 3.142 \times (17)^2 = 0.1816 = 1816\ cm^2 = 0.1816\ m^2$

The number of plants per hectare are $10000\ m^2/0.1816m^2 = 55066$ plants.

So 5 g x 55066 = 275330 g = 275 kg/ha of NPK and Urea each were applied.

3.7. Pest and weed control

Systematic insecticide and nematicide, fulan 3% G (furadan) was applied to the soil before sowing at a rate of five grams per pot. It was used to control not only stem borers and other insect pests but also all soil insects and nematodes affecting agricultural crop. It is a powerful insecticide/nematicide and also acts as contact pesticide.

Hand weeding was done at tenth, twentieth and thirtieth DAP to control weeds. Weeding was done one or two days before fertilizer application.

3.8. Data collection

3.8.1. Days to 50% tasseling (DT 50%)

It was taken as a number of days that 50% of plant showed tassels.

3.8.2. Days to 50% silking (DS 50%)

It was taken as the number of days that 50% of plants showed silks.

3.8.3. Anthesis-silking interval (ASI)

This is the difference between days to 50% silking and days to 50% anthesis. The formula is ASI = DS 50% – DA 50%. The days to 50% silking determine the number of days from sowing until 50% of the plants show silks, and the days to 50% anthesis is the number of days from sowing till 50% of the plants showed anthers.

3.8.4. Leaf rolling

As described by Bänziger *et al*. (2000), the scores on leaf rolling were done by using a scale from 1 to 5 as shown in Plate 3.1.

1 = unrolled, turgid

2 = leaf rim stars to roll

3 = leaf has the shape of V

4 = rolled leaf rim covers part of leaf blade 5 = leaf is rolled like an onion.

Data were collected during the first time of flowering because Bänziger *et al*. (2000) indicated that at that time, leaves are still more upright but after flowering leaves are less likely to roll because they become more lax and thicker. The score was done at 47 DAP which correspond to seven (7) days after imposing drought stress. Data were collected once and on sunny days between 12:00 and 2:00 pm and the set of leaves of each plant was considered to score this character.

Plate 3.1: Pictures leaf rolling score from 1 to 5.

3.8.5. Plant aspect

Data on plant aspect was taken at 70 DAP, date on which it is assumed that genotypic tolerant to drought could show their capacity by displaying a good growth and development of plant and ear especially in drought stress. Plant aspect (PASP) was recorded on a scale of 1 to 5 based on overall plant type.

Where: 1 = excellent plant type (desirable plant and ear characteristics)

2 = Very good plant type

3 = good plant type

4 = tolerable plant type and

5 = poor plant type (undesirable plant and ear characteristics).

3.8.6. Leaf senescence

The score was taken on ear leaf on the scale from 1 to 10 by dividing the percentage of estimated total dead leaf area by 10 (Bänziger *et al*., 2000).

1 = 0-10% dead leaf	6 = 50-60% dead leaf
2 = 10-20% dead leaf	7 = 60-70% dead leaf
3 = 20-30% dead leaf	8 = 70-80% dead leaf
4 = 30-40% dead leaf	9 = 80-90% dead leaf
5 = 40-50% dead leaf	10 = 90-100% dead leaf

Plate 3.2: Pictures of leaf senescence for the scores 1, 5 and 10

Leaf senescence was scored at 73 DAP as suggested by Bänziger *et al*. (2000) that it should be scored 7-10 days apart during the latter part of grain filling.

3.8.7. Plant height

Plant height was recorded at 74 DAP, at which elongation of stem was completed. It was measured from the base of the maize plant to the top of the largest leaf using a measuring tape. The score was given in centimeter (cm).

3.8.8. Ear height

It was measured at 74 DAP from the base of plant to the ear leaf using measuring tape. The score was given in centimeter (cm).

3.8.9. Ears per plant

It was recorded as the total number of ears which developed at least one full grain and divided by the total number of all the plants harvested in the plot.

3.8.10. Ear weight

Ear weight was recorded by dividing the weight of total ears in the plot that at least exists one fully grain by number of harvested ears. SARTORIUS scale was used to weight the sample (g).

3.8.11. Hundred grains weight

After bulking the grain results of all plants within the plot, hundred grains were counted and weighted. The results were given in gram (g) by using SARTORIUS scale.

3.8.12. Grain yield per hectare

After shelling (by using hand), all grains from all ears of each plot were weighted. This was adjusted to actual moisture level of grain to compute GY per hectare. The conversion of grain yield to grain moisture-standardized yield was calculated as follows (BaduApraku *et al*., 2012).

$$\text{Yield (at 15\% grain moisture)} = \frac{\text{Grain yield x (100 − actual grain moisture \%)}}{85}$$

AQUA-BOY, KPM (moister tester) was used to determine moisture level of each sample.

3.9. Statistical analysis

Combined ANOVA was performed across all research conditions (drought and nondrought stress) for DT 50%, DS 50%, ASI, leaf rolling, leaf senescence, PASP, PHT, EHT, EPP, ear weight, 100-seeds weight and GY per hectare using a software Plant Breeding Tools version 1.4 (Griffing's 1956) method 1 model 1. Mean squares and error were also computed.

The GCA effects of inbreds and SCA effects of the hybrids as well as their mean squares in each environment, were estimated on the 5 x 5 diallel mating design, excluding the checks, following Griffing's method 1 model 1 (fixed model), Griffing (1956) (Table 3.2) using a software Plant Breeding Tools version 1.4. Standard errors for each parent and cross were computed. The programme also computed genetic variance components (V_A and V_D).

Also, GCA effects of inbreds and SCA effects of the hybrids as well as their mean squares were performed using Diallel SAS program developed by Zhang *et al.* (2005) modifier in 2009 adopted to SAS software version 9.0.

Means and coefficient of variation (CV) of all genotypes (parents, crosses and checks) were performed using GenStat (2009). Pearson correlation between grain yield and other characters were computed.

High-parent heterosis (HPH) and mid-parent heterosis (MPH) were estimated according to the formulae given by Fehr (1987) as described in 2.11.1.

Table 3.2. Form of analysis of variance for method 1 given expectations of mean squares for the assumptions of model 1.

Source of variance	**Degrees of freedom**	**Sum of squares**	**Mean squares**	**Expected mean squares/model 1**
GCA	p - 1	Sg	Mg	$\sigma^2+2p(\frac{1}{p-1})\sum gi2$
SCA	p(p - 1)/2	Ss	Ms	$\sigma^2+2\ (\frac{2}{p(p-1)}\ \sum_i \sum_j Sij2$
Reciprocal effects	p(p - 1)/2	Sr	Mr	$\sigma^2 + 2(\frac{2}{p(p-1)})\ \sum_i \sum_j rij2$
Error	M	Se	Me	σ^2

Where:

$$Sg = \frac{1}{2p}\sum_{i}(Xi.+X.i)^2 - \frac{2}{p2}X..^2$$

$$Ss = \frac{1}{2}\sum_{i}\sum_{j}xij(xij+xji) - \frac{1}{2p}\sum_{i}(X.i+Xi.)^2 + \frac{1}{p2}X..^2$$

Also, the estimate of genetic variability parameters and heritability were computed as follow:

(i) Genotypic and phenotypic variance as well as heritability in broad sense were computed using the formulae given by Singh and Chaudhary (1985) in case of one location.

Broad sense heritability (h^2_b) = $\sigma^2_g / \sigma^2_{ph}$

For individual location, variance components were computed from mean squares and expected mean squares as follow:

$\sigma^2_g = (MS_g - MS_e)/r$ σ^2_e

$= MS_e/r$

$\sigma_{2ph} = \sigma_{2g} + \sigma_{2e}$ Where:

MS_g = mean squares due to genotypes σ^2_g = genotypic variance MS_e = error mean square σ^2_e = error variance r = number of replications σ^2_{ph} = phenotypic variance (ii) Heritability in narrow sense was calculated by the formulae given by Grafius *et al*.

(1952).

Narrow sense heritability (h^2_n) = $(\sigma^2_f + \sigma^2_m)/(\sigma^2_f + \sigma^2_m + \sigma^2_{fm} + \sigma^2_e/r)$

Where:

σ^2_f = genetic variance of female σ^2_e = error variance σ^2_m = genetic variance of male r = number of replication σ^2_{fm} = genetic variance of females x males

The heritability values were classified as low (<30%), moderate (30-60%) and high (>60%) according to Johnson *et al*. (1955).

According to Singh and Chaudhary (1985), the estimates of variances due to GCA_f, GCA_m and SCA in one location were computed from mean squares as follow:

$COV(H.S)_f = \sigma^2_f = (MS_f - MS_{fm})/rm$

$COV(H.S)_m = \sigma^2_m = (MS_m – MS_{fm})/rf$

$COV(F.S) = (MS_{fm} – MS_e)/r$ Where:

MS_f = mean square of female f = number of females

MS_m = mean square of male m = number of males

MS_e = mean square of error r = number of replications

MS_{fm} = mean square of females x males

CHAPTER FOUR

4.0. RESULTS

4.1. Chemical and physical properties of soil used

The pH of the soil used during this experiment was 5.00 which indicates a very acidic soil condition (Table 4.1). The soil textural class was sandy loam.

Table 4.1. Chemical and physical properties of soil used in the screen house experiment

Soil property	**Values**
Soil depth (cm)	0-100
Particle size (%) Sand	68.32
Silt	17.40
Clay	14.28
pH (1:1 soil:H_2O)	5.00
Organic carbon (%)	1.16
Organic matter (%)	2.00
Total N (%)	0.08
Available P (mg/kg)	9.43
Exchangeable cations (cmol/kg) Ca	4.98
Mg	1.76
Na	0.50
K	0.05
Total exchangeable bases	7.29
Exchangeable acidity (Al + H) (cmol/kg)	11.52
Effective cation exchange capacity (cmol/kg)	18.81
Base saturation (%)	38.76

Low values were recorded for organic matter (2.00%) and available phosphorus. The fertility status of the soil was generally low.

4.2. Climatic conditions in the screen house

The average temperatures recorded weekly in the plant house ranged from 30.20 to 35.38 °C, from 26.25 to 31.84 °C and from 28.40 to 32.55 °C respectively for air, soil well watered and soil drought stress. The scores were recorded between 12:00 to 2:00 pm. Table 4.2 shows the temperature averages recorded during the whole experiment. The results showed that the highest temperatures were recorded in the 4th week of April for all measurements taken; air 35.38 °C, optimal soil 31.84 °C and drought soil 32.55°C while the lowest were recorded in the 4th week of March for air (30.20 °C), in the 3rd week of May for optimal soil (26.25 °C) and drought soil (28.40 °C).

Table 4.2: Temperature measured per week in the screen house for air, soil well watered condition and soil drought condition

Week	Temperature (°C)		
	Air	**Soil (WW)**	**Soil (drought)**
Third week of March	33.20	31.10	
Fourth week of March	30.20	28.26	
First week of April	34.35	30.67	
Second week of April	32.62	29.10	
Third week of April	31.68	27.68	
Fourth week of April	35.38	31.84	32.55
First week of May	32.22	28.54	30.80
Second week of May	34.98	27.83	30.50
Third week of May	31.40	26.25	28.40
Fourth week of May	32.27	27.00	29.00

WW = well watered

Sometimes, the water applied to well watered condition was about two or three times higher than the one applied to drought stress condition.

4.3. Analysis of variance of combining ability across growing environments

The results of combined ANOVA for twelve maize traits studied under drought stress and well watered conditions are presented in Table 4.3. Mean squares for environments were highly significant ($p<0.01$) for all the traits except DT 50% and EEP, while only DT 50%, DS 50%, PHT and EHT were highly significant ($p<0.01$) for entries. Furthermore entry mean square for PASP and GY were significant at 0.05 probability level.

The interaction effects of entry x environment, GCA x environment and SCA x environment were highly significant ($p<0.01$) for all the characters studied except DT 50%, leaf senescence, PHT, EHT, EPP and 100 seed weight but for both DT 50% and PHT, GCA x environment effect was highly significant ($p<0.01$). On the contrary, reciprocal x environment interaction effect was highly significant ($p<0.01$) for only ASI, PASP, ear weight and GY and significant ($p<0.05$) for DS 50%. For number of EPP, concerning all the source of variance, only SCA showed significant different at 0.01 probability level.

Table 4.3: Combined analysis of variance and variance component of twelve maize characters in full diallel cross under drought and well watered conditions

Source of Variance	DF	DT 50%	DS 50%	ASI	Leaf R	Leaf S	PASP	PHT	EHT	EPP	Ear W	100 GW	GY
Env	1	4.5ns	518.9**	248.3**	234.7**	181.9**	131.0**	42282.9**	2824.9**	0.0002ns	104188.4**	1054.4**	115599116**
Entry	24	63.2**	51.7**	20.3ns	0.4ns	8.1ns	3.0*	3867.9**	1089.9**	0.008ns	1728.7ns	7.7ns	2419936*
Variance component													
GCA	4	236.5**	217.7*	57.3ns	0.11ns	22.3ns	4.0ns	14571.1*	3587.2**	0.007ns	2494.6ns	13.3ns	2775114ns
SCA	10	40.8**	23.4ns	22.1ns	0.69ns	4.4ns	5.0*	2465.1**	949.7**	0.0099**	2863.4ns	8.6ns	4292141ns
Reciprocal	10	16.3**	13.6ns	3.7ns	0.21ns	6.1ns	1.0ns	989.5**	231.2**	0.0067ns	287.7ns	4.7ns	405660ns
GCA/SCA		5.80	9.30	2.60	0.16	5.00	0.80	5.90	3.80	0.700	0.87	1.55	0.65
Entry x Env	24	4.1ns	11.6**	10.2**	0.64**	7.7**	1.2**	272.1ns	64.5ns	0.0048ns	888.5**	3.9ns	1125568**
GCA x Env	4	14.6**	26.9**	12.3**	0.70*	20.9ns	2.5**	1117.9**	85.1ns	0.0025ns	1282.2**	2.4ns	1236991**
SCA x Env	10	1.8ns	10.3**	17.2**	10.7**	4.0ns	1.4**	143.9ns	88.2ns	0.002ns	1310.1**	6.8**	1601067**
Rec x Env	10	4.2ns	6.8*	2.5**	0.19ns	6.2ns	0.6**	61.8ns	32.6ns	0.0086ns	309.4**	1.7ns	605499**
Residual	100	2.8	3.3	0.7	0.23	0.3	0.2	206.0	62.7	0.0068	120.2	2.6	128504

DT 50% = Day 50% tasseling, DS 50% = Days 50% silking, ASI = Anthesis-silking interval, Leaf R = Leaf rolling, Leaf S = Leaf senescence, PASP = Plant aspect, PHT = Plant height, EHT = Ear height, EPP = Ears per plant, Ear W = Ear weight, 100 GW = 100 grain weight, GY = Grain yield per hectare, Env = environment, Rec = reciprocal, GCA = general combining ability, SCA = specific combining ability, ns = non-significant, * Significant at 0.05 probability level, ** Highly significant at 0.01% probability level.

Partitioning the entry mean squares into components showed that GCA mean squares was highly significant ($p<0.01$) for only DT 50% and EHT and significantly different ($p<0.05$) for DS 50% and PHT. The genotypes were significantly different in specific combining ability for DT 50%, PHT, ear height and number EPP and significant ($p<0.05$) for PASP. It was noticed that both GCA and SCA effects were not significant for ASI, leaf rolling, leaf senescence, ear weight, hundred grain weight and GY. Besides, for GCA and SCA, GY and its components showed no significant difference ($p>0.05$) except SCA for ears per plant. All the characters showed more than unity GCA/SCA ratio values except leaf rolling, plant aspect, number of EPP, ear weight and GY. The highest ratio value was observed in days to 50% silking (9.30) while the lowest (0.16) was obtained from leaf rolling.

4.4. Mean performance of studied genotypes

The mean performances of the genotypes (5 parents, 20 hybrids and 2 checks) used in the study are shown in Table 4.4. In general the F_1 hybrids outperformed the inbred in many cases except in few instances. A total of 6 and 5 crosses under drought and non-drought stress condition respectively out yielded the best check OMANKWA as well as the best parent.

Table 4.4: Mean performance of 12 maize characters for inbreds, hybrids and checks under drought and well watered conditions.

ENTRIES	DT 50%		DS 50%		ASI		Leaf R		Leaf S		PASP	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
TZEI-13	47.33	46.67	55.33	54.67	4.33	4.00	2.00	1.78	4.55	1.00	4.44	4.00
TZEI-17	45.00	46.33	51.33	51.33	0.33	-1.33	3.00	1.11	1.00	1.00	4.44	3.67
TZEI-23	39.00	41.67	47.67	46.67	2.00	-2.00	3.00	1.22	3.89	1.00	4.33	4.67
TZEI-25	49.67	45.33	55.33	46.33	-6.33	1.33	3.00	1.11	3.78	1.00	4.89	4.00
TZEI-124	49.00	47.00	55.67	55.00	4.00	3.33	3.22	1.33	8.78	1.22	4.78	2.11
TZEI-13 X TZEI-17	42.00	43.00	54.00	47.67	6.00	1.33	3.67	1.00	1.33	1.00	4.56	2.33
TZEI-13 X TZEI-23	40.00	39.33	50.33	47.00	4.00	3.00	3.67	1.11	3.22	1.00	4.06	1.33
TZEI-13 X TZEI-25	46.00	44.00	53.67	48.33	5.67	2.33	3.6	1.00	1.22	1.11	4.00	1.78
TZEI-13 X TZEI-124	42.67	43.33	56.67	47.67	8.67	2.33	3.67	1.33	4.17	1.00	4.5	1.67
TZEI-17 X TZEI-13	48.00	50.00	57.00	55.67	6.33	4.67	3.60	1.33	1.22	1.00	4.72	3.89
TZEI-17 X TZEI-23	38.00	39.00	46.67	49.00	4.33	2.33	4.00	1.44	1.22	1.00	3.45	2.67
TZEI-17 X TZEI-25	46.00	43.67	51.67	47.67	4.33	1.67	3.78	1.000	1.00	1.00	3.11	1.55
TZEI-17 X TZEI-124	44.00	43.67	52.33	48.67	4.00	1.00	3.89	1.22	3.22	1.00	3.44	1.89
TZEI-23 X TZEI-13	39.33	41.33	51.00	48.00	5.33	2.67	4.22	1.22	6.01	1.11	4.44	2.56
TZEI-23 X TZEI-17	38.33	38.67	47.67	43.67	4.00	-1.00	4.11	1.00	1.22	1.00	4.11	2.56
TZEI-23 X TZEI-25	40.33	40.67	47.33	44.67	3.33	1.00	4.33	1.00	1.44	1.00	3.89	1.89
TZEI-23 X TZEI-124	39.33	38.33	50.00	45.67	4.33	1.33	3.89	1.00	6.56	1.00	3.89	1.11
TZEI-25 X TZEI-13	47.00	44.33	54.33	48.33	6.00	1.67	4.00	1.44	8.34	1.00	4.45	2.00

Table 4.4: continued

ENTRIES	DT 50%		DS 50%		ASI		Leaf R		Leaf S		PASP	
	DS	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
TZEI-25 X TZEI-17	42.33	42.67	48.00	45.67	2.67	1.00	4.11	1.00	1.56	1.00	3.39	1.45
TZEI-25 X TZEI-23	39.33	38.33	47.00	43.67	4.00	1.67	4.00	1.11	3.00	1.00	4.45	1.56
TZEI-25 X TZEI-124	44.33	43.00	54.67	48.00	6.00	3.00	3.78	1.11	3.33	1.00	3.89	1.00
TZEI-124 X TZEI-13	44.00	42.33	55.00	48.33	6.67	2.00	4.33	1.44	5.01	1.11	4.22	1.11
TZEI-124 X TZEI-17	43.00	42.00	54.00	48.33	5.33	2.33	4.67	1.22	1.22	1.00	3.89	1.33
TZEI-124 X TZEI-23	37.67	38.67	48.00	46.67	5.00	2.00	3.44	1.33	3.22	1.00	3.17	1.89
TZEI-124 X TZEI-25	44.67	44.33	54.33	49.33	7.33	1.67	3.67	1.11	1.11	1.00	3.22	1.00
MAMABA	47.00	47.00	55.00	51.00	6.00	1.00	3.67	1.00	2.55	1.00	3.56	1.66
OMANKWA	45.67	41.00	54.67	46.67	6.33	2.00	3.44	2.56	2.78	1.33	3.56	1.56
Mean	**43.30**	**42.84**	**52.17**	**48.23**	**4.44**	**1.67**	**3.69**	**1.20**	**3.2**	**1.03**	**4.03**	**2.16**
CV (%)	**3.50**	**4.10**	**3.40**	**3.00**	**22.90**	**27.7**	**15.6**	**21.70**	**24.9**	**14.5**	**11.50**	**23.2**
LSD (0.01)	**3.32**	**3.82**	**3.91**	**3.20**	**2.19**	**1.00**	**1.33**	**0.57**	**1.74**	**0.33**	**1.01**	**1.09**

Table 4.4: continued

ENTRIES	PHT (cm)		EHT (cm)		EEP		Ear W (g)		100 GW (g)		GY (kg/ha)	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
TZEI-13	112.11	116.33	60.55	53.33	1.00	1.00	10.98	11.05	12.87	15.12	310.02	314.98
TZEI-17	120.44	134.56	65.34	67.56	1.00	1.00	12.92	20.61	10.44	13.48	413.36	658.96
TZEI-23	123.78	132.44	76.55	73.89	1.00	1.00	15.68	54.28	10.59	14.85	565.71	1559.29
TZEI-25	127.22	171.56	76.22	88.44	1.00	1.11	5.82	60.66	11.02	16.86	302.68	2152.90
TZEI-124	170.44	214.22	91.33	111.67	1.00	1.00	10.29	35.19	13.18	18.39	155.10	727.97
TZEI-13 X TZEI-17	145.45	167.11	83.11	89.22	1.11	1.16	9.17	57.91	11.78	18.88	241.74	2122.43
TZEI-13 X TZEI-23	137.00	160.33	80.00	88.44	1.00	1.00	27.50	79.61	11.84	18.15	1158.22	2834.98
TZEI-13 X TZEI-25	159.11	196.55	95.00	98.44	1.00	1.00	28.08	81.14	11.47	18.74	1439.98	2578.01
TZEI-13 X TZEI-124	163.17	203.67	87.50	102.67	1.00	1.00	10.17	91.97	14.64	17.53	802.50	3075.62
TZEI-17 X TZEI-13	96.89	120.44	54.28	74.67	1.00	1.00	14.09	19.25	10.35	15.2	381.61	544.42
TZEI-17 X TZEI-23	133.89	160.78	78.89	94.00	1.00	1.11	26.29	74.76	11.28	16.68	1110.31	3103.89
TZEI-17 X TZEI-25	161.22	210.55	100.00	109.00	1.00	1.00	38.55	95.13	11.57	15.58	1089.21	3183.37
TZEI-17 X TZEI-124	163.44	194.66	95.89	101.78	1.00	1.00	25.58	85.70	11.42	16.35	681.72	2800.66
TZEI-23 X TZEI-13	132.00	160.67	80.89	92.45	1.00	1.00	20.79	68.27	9.68	17.74	846.73	2516.52
TZEI-23 X TZEI-17	141.67	167.55	81.45	94.78	1.22	1.00	28.46	74.81	13.36	16.69	1160.24	2554.70
TZEI-23 X TZEI-25	163.78	205.44	99.33	102.78	1.00	1.00	27.41	87.02	12.39	18.87	1084.80	3187.59
TZEI-23 X TZEI-124	155.44	196.00	90.78	105.44	1.00	1.00	26.86	96.93	9.91	17.64	1080.58	3566.44
TZEI-25 X TZEI-13	150.56	190.42	95.78	104.00	1.00	1.00	20.63	80.81	10.25	18.09	668.50	2798.64
TZEI-25 X TZEI-17	153.67	204.00	93.67	97.78	1.00	1.00	24.86	91.56	12.15	17.22	903.27	3398.49
TZEI-25 X TZEI-23	151.00	178.44	91.89	95.11	1.00	1.00	32.51	84.18	13.36	18.96	1146.11	2935.94

Table 4.4: continued

ENTRIES	PHT (cm)		EHT (cm)		EEP		Ear W (g)		100 GW (g)		GY Kg/ha	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
TZEI-25 X TZEI-124	167.89	225.22	102.34	113.11	1.00	1.00	32.46	105.68	11.63	16.12	1049.56	3471.73
TZEI-124 X TZEI-13	154.67	190.22	89.78	99.89	1.00	1.00	16.63	113.76	14.22	19.00	499.82	3854.44
TZEI-124 X TZEI-17	140.00	188.22	82.67	94.33	1.00	1.00	20.7	115.52	11.43	17.71	611.6	3821.95
TZEI-124 X TZEI-23	163.22	190.78	92.44	96.78	1.00	1.00	29.97	76.78	11.41	17.56	1271.11	2680.25
TZEI-124 X TZEI-25	184.22	231.56	106.45	119.56	1.00	1.00	24.71	96.30	13.61	17.37	618.94	3042.95
MAMABA	172.9	235.3	101.28	114.9	1.00	1.00	30.38	103.50	10.98	17.79	976.69	2854.07
OMANKWA	172.7	223.9	112.00	123.1	1.00	1.00	32.18	91.10	16.34	22.32	1104.81	3254.40
Mean	**148.8**	**184.1**	**87.61**	**96.8**	**1.01**	**1.01**	**22.36**	**76.10**	**11.98**	**17.37**	**787.17**	**2577.33**
CV (%)	**7.70**	**8.7.00**	**8.40**	**9.15**	**8.10**	**7.60**	**19.20**	**19.70**	**15.50**	**9.40**	**19.22**	**19.16**
LSD (0.01)	**25.10**	**35.00**	**16.16**	**20.15**	**0.18**	**0.17**	**9.39**	**32.69**	**4.04**	**3.58**	**436.71**	**1048.01**

DT 50% = Day 50% tasseling, DS 50% = Days 50% silking, ASI = Anthesis-silking interval, Leaf R = Leaf rolling, Leaf S = Leaf senescence, PASP = Plant aspect, PHT = Plant height, EHT = Ear height, EPP = Ears per plant, Ear W = Ear weight, 100 GW = hundred grain weight, GY = Grain yield per hectare, CV = coefficient of variation, LSD = least significant difference.

Among the parents, high yields per hectare were for TZEI-23 (565.71 kg/ha) under drought and TZEI-25 (302.68 kg/ha) under well watered condition. Plate 4.1 shows differences in yield at well watered and drought stressed conditions. On the other hand lower yield were observed for TZEI-124 (155.1 kg/ha) under water stress and TZEI-13 (314.98 kg/ha) under well watered condition. For ear weight TZEI-23 (15.68g) under water stress condition and TZEI-25 (60.66g) under well watered condition performed also the best while TZEI-124 (13.18g and 18.39g) under both conditions was the best for hundred grain weight. For both ear weight and GY, TZEI-23 was the best under drought condition and followed TZEI-25 under well watered condition. Therefore TZEI-23 was the best in combination of these two characters. In contrast in term of combination, TZEI13 was the lowest for ear weight and GY under both conditions. TZEI-25 showed the highest number (1.11) of EPP under well watered condition. TZEI-23 was also the best among parents under drought and non-drought stress, conditions, respectively for DT 50% and DS 50%. Under drought stress condition TZEI-25 was the worst for DT 50% (49.67 days) and TZEI-124 for DS 50% (55.57 days). TZEI-17 performed the best among the parents for ASI (0.33 and -1.33 day), leaf senescence (1.00 and 1.00) under both conditions and leaf rolling (1.11) under well watered condition. In contrast TZEI-124 displayed the highest height under both conditions for plant and ear height, respectively.

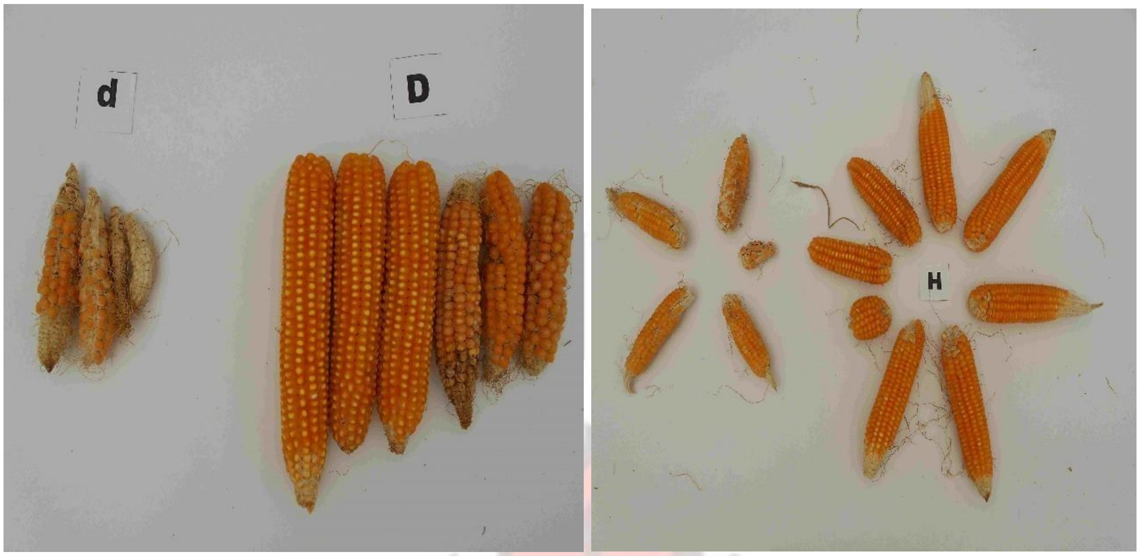

Plate 4.1. Cobs of inbred lines TZEI-25 (left) where d is under drought and D is under well watered condition, and cobs of hybrids TZEI-13 x TZEI-25 (right), H is under well watered and the second under water stress condition

Among all the hybrids and checks, GY per hectare ranged from 241.74 kg (TZEI-13 x TZEI-17) to 1439.98 kg (TZEI-13 x TZEI-25) under water stress condition and from 544.42 kg (TZEI-17 x TZEI-13) to 3854.44 kg (TZEI-124 x TZEI-13) under well watered condition. The five hybrids following the best under drought condition were obtained when TZEI-23 was used mostly as male parent TZEI-124 x TZEI-23 (1271.11 kg), TZEI23 x TZEI-17 (1160.24 kg), TZEI-13 x TZEI-23 (1158.22 kg), TZEI-25 x TZEI-23 (1146.11 kg) and TZEI-17 x TZEI-23 (1110.31 kg) while under well watered condition hybrids TZEI-124 x TZEI-17 (3821.95 kg), TZEI-23 x TZEI-124 (3566.44 kg), TZEI-25 x TZEI-124 (3471.73 kg) and TZEI-25 x TZEI-17 (3398.49 kg) were the best. In this case the first three hybrids were obtained when TZEI-124 was used either as female or male. For yet grain yield per hectare the five worst hybrids were TZEI-13 x TZEI-17 (241.74 kg) < TZEI-17 x TZEI-13 (381.61 kg) < TZEI-124 x TZEI-13 (499.82 kg) < TZEI-124 x

TZEI-17 (611.60 kg) < TZEI-124 x TZEI-25 (618.94 kg) under drought condition while under well watered condition, the five worst hybrids were TZEI-17 x TZEI-13 (544.42 kg) < TZEI-13 x TZEI-17 (2122.43 kg) < TZEI-23 x TZEI-13 (2516.52 kg) < TZEI-23 x TZEI-17 (2554.70 kg) < TZEI-13 x TZEI-25 (2578.01g) < TZEI-124 x TZEI-23 (2680.25 kg). The worst hybrids under both conditions were TZEI-13 x TZEI-17 and its reciprocal TZEI-17 x TZEI-13. Entries TZEI-25 x TZEI-23 and TZEI-23 x TZEI-124 exhibited the best performance for days to 50% tasseling (38.33 days each) under well watered condition and the cross TZEI-124 x TZEI-23 (37.67 days) under drought condition. Entry TZEI-17 x TZEI-23 performed the best for days to 50 silking (46.67 days) under drought while the reciprocal cross TZEI-23 x TZEI-17 and TZEI-25 x TZEI-23 were the best (43.66 days each) under well watered condition. Hybrid TZEI-25 x TZEI-17 showed the best performance in ASI under drought and well watered conditions respectively with 2.27 and 1 day, TZEI-13 x TZEI-124 was the lowest among all the genotypes in term of days to 50% silking and ASI under drought condition with 56.67 and 8.67 days.

Under drought stress condition, TZEI-13 for leaf rolling (2.00), TZEI-17 for leaf senescence (1.00) and TZEI-23 for plant aspect (4.33) were the best among the inbreds, while TZEI-23 x TZEI-25 (3.33 and 1.00) and TZEI-124 x TZEI-23 (3.44 and 1.33) for leaf rolling, TZEI-17 x TZEI-25 with 1.00 and 3.11 for leaf senescence and plant aspect, respectively were the best compared to the other hybrids and checks.

Furthermore, entry TZEI-124 x TZEI-25 measured the highest values for plant and ear height (184.22 and 106.46 cm) under drought while the checks MAMABA and OMANKWA ranged the highest for plant height(235.3 cm) and ear height (123.10 cm) under well watered condition. Hybrids with TZEI-23 and TZEI-124 parental background performed the best for grain yield per plant whereas those with TZEI-23 and/or TZEI-17 parental background were the best for exhibiting high values in almost all the other traits studied in water stress and well watered conditions.

4.5. General Combining Ability effects of parents

The results of GCA effects of inbreds in full diallel cross for twelve characters under two conditions are presented in Table 4.5. Entry TZEI-23 exhibited highly significant ($p<0.01$) negative GCA (highest negative for DT 50% and DS 50%) effects under drought stress and well watered conditions for DT 50% (drought -4.02 and well watered -2.94), DS 50% (drought -3.63 and well watered -2.07), ASI (drought -0.47 and well watered 0.83) PHT (well watered -11.98), and negative significance ($p<0.05$) for PHT (under drought -4.34) and EHT (well watered -3.01). In addition this entry recorded also the highest highly significant ($p<0.01$) positive general combining ability effects for ear weight (3.47) and GY per hectare (215.22) under drought condition. Therefore in terms of GCA, for a set of above traits TZEI-23 comes out successful in general under both environmental conditions for most of the important traits. On the contrary TZEI-124 showed highly significant ($p<0.01$) positive GCA effect under water stress and well watered conditions for DT 50%, DS 50%, ASI, PHT and EHT and leaf senescence under drought condition (1.31 highly significant) and well watered condition (0.03 significant). Thus TZEI-124 was the lowest GCA effect in combination of these traits. Even though negative GCA is required in PHT and EHT, this line had the highest positive GCA in these traits so in consequence it was the tallest among the lines in both conditions.

Table 4.5: General combining ability effects of twelve maize characters in full diallel cross under drought and well watered conditions

INBREDS	DT 50%		DS 50%		ASI		Leaf R		Leaf S		PASP	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
TZEI-13	1.31**	1.39**	2.31**	1.79**	1.43**	1.07**	-0.24*	0.14**	0.74**	0.01ns	0.31**	0.27**
TZEI-17	0.11ns	0.83**	-0.56ns	0.66*	-0.54**	-0.67**	0.07ns	-0.06ns	-1.82**	-0.02ns	-0.11ns	0.30**
TZEI-23	-4.02**	-2.94**	-3.63**	-2.07**	-0.47**	-0.83**	0.06ns	-0.03ns	0.14ns	-0.01ns	-0.06ns	0.29**
TZEI-25	1.88**	0.46ns	0.21*	-1.41**	-1.64**	-0.07ns	0.02ns	-0.10*	-0.37**	-0.01ns	-0.05ns	-0.18*
TZEI-124	0.71**	0.26ns	1.67**	1.03**	1.23**	0.50**	0.07ns	0.04ns	1.31**	0.03*	-0.09ns	-0.68**
SE	**3.89**	**2.06**	**3.83**	**1.97**	**1.29**	**0.45**	**0.03**	**na**	**1.02**	**na**	**0.03**	**0.15**

Table 4.5. Continued

INBREDS	PHT		EHT		EEP		Ear W		100 GW		GY	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
TZEI-13	-10.59**	-18.26**	-7.34**	-9.12**	-0.0023ns	0.0012ns	-4.74**	-12.87**	0.15ns	0.21ns	-117.82**	-443.98**
TZEI-17	-9.18**	-12.23**	-6.02**	-5.70**	0.0200ns	0.0120ns	-0.29ns	-8.77**	-0.43ns	-1.02*	-83.09**	-254.70**
TZEI-23	-4.34*	-11.98**	-1.21ns	-3.01*	0.0090ns	-0.0045ns	3.47**	0.74ns	-0.34ns	0.05ns	215.22**	110.40ns
TZEI-25	7.70**	18.06**	7.61**	6.90**	-0.0130ns	0.0065ns	2.44**	9.96**	0.00ns	0.31ns	76.84**	350.77**
TZEI-124	16.4**	24.41**	6.97**	10.92**	-0.0130ns	-0.0150ns	-0.88ns	10.95**	0.61*	0.45ns	-91.13**	237.51**
SE	**96.73**	**274.93**	**35.51**	**52.30**	**na**	**na**	**8.81**	**98.13**	**0.16**	**0.27**	**16398.84**	**110329.02**

DT 50% = Days 50% tasseling, DS 50% = Days 50% silking, ASI = Anthesis-silking interval, Leaf R = Leaf rolling, Leaf S = Leaf senescence, PASP = Plant aspect, PHT = Plant height, EHT = Ear height, EPP = Ears per plant, Ear W = Ear weight, 100 GW = hundred grain weight, GY = Grain yield per hectare, DS = drought stress, WW = well watered, na = not available, ns = non-significant, * Significant at 0.05 probability level, ** Highly significant at 0.01% probability level, SE = standard error.

TZEI-25 had the highest highly ($p<0.01$) negative general combining ability effect for ASI (-1.64) under drought condition. TZEI-13 had either highly significant negative ($p<0.01$) and/or highly significant positive ($p<0.01$) GCA effects under drought and well watered conditions for all the characters except number of EPP, hundred grain weight and leaf senescence under well watered condition. It recorded the highest highly positive significant ($p<0.01$) GCA for ASI and highest highly negative significant ($p<0.01$) GCA for PHT and EHT (Table 4.5). Considering the lines individually for each trait under the two conditions it was the best donor for plant and ear height. Also this entry was the only one which showed highly significant general combining ability effects for leaf rolling (Table 4.5).

In terms of grain yield per hectare and its components, TZEI-23 had the highest and highly positive ($p<0.01$) GCA under drought condition for ear weight (3.47) and grain yield per hectare (215.22) while under well watered condition TZEI-124 showed the highly positive GCA for ear weight (10.95) and TZEI-25 for grain yield per hectare (350.77).
TZEI-25 exhibited highly significant positive GCA under both conditions for ear weight (2.44 and 9.96) and grain yield (76.84 and 350.77). For hundred grain weight only TZEI-124 had positive significant ($p<0.05$) general combining ability effect. Therefore TZEI23 was the best general donor for ear weight and GY under drought while TZEI-25 was the best general donor for ear weight and GY under non-drought condition (Table 4.5).

4.6. Specific Combining Ability effects of crosses

The estimates of SCA of twelve characters of twenty hybrids (set of F_1's and reciprocal F_1) under drought and non-drought stress conditions are presented in Table 4.6. Hybrids TZEI-25 x TZEI-13 showed the highest positive and highly significant ($p<0.01$) SCA effects for GY (385.74) followed by its reciprocal TZEI-13 x TZEI-25 (311.49) under water stress while under well watered condition, TZEI-13 x TZEI-124 (1132.01), TZEI17 x TZEI-13 (789.01) and TZEI-17 x TZEI-124 (789.01) were the highest and were highly significant (p<0.01) (Table 4.6). Under water stress, 10 hybrids showed positive significant SCA and ranged from 76.38 (TZEI-13 x TZEI-124) to 385.74 (TZEI-25 x TZEI-13). Under well watered condition, 7 hybrids showed positive significant SCA ranged from 434.11 (TZEI-17 x TZEI-23) to 1132.01 (TZEI-13 x TZEI-124). Cross TZEI-17 x TZEI-25 was the only one that exhibited best performance and showed highly positive and significant (p<0.01) SCA across both environments (218.76 under drought and 655.38 under well watered condition). For components of grain yield, 3 crosses showed positive significant (p<0.05) SCA for hundred grain weight under water stress whereas under well watered one hybrid showed positive highly significant (p<0.01) SCA (Table 4.6).

For the reproductive traits, only entry TZEI-17 x TZEI-13 exhibited the highest and highly significant (p<0.01) negative SCA for DT 50%, DS 50% and ASI. Also for DT 50% TZEI-13 x TZEI-124 showed highly negative significant (p<0.01) SCA under both conditions. However, TZEI-23 x TZEI-124 was the best in terms of SCA effect for DT 50% and DS 50% respectively under water stress and well watered conditions. For ASI only TZEI-13 x TZEI-25 (-0.73), TZEI-13 x TZEI-124 (-1.13) and TZEI-17 x ZEI-13 (1.67) showed highly negative significant SCA and TZEI-124 x TZEI-17 (-0.67) showed negative and significant (p<0.05) under well watered condition (Table 4.6).

Table 4.6: Specific combining ability effects of twelve maize characters in full diallel under drought and well watered conditions

	DT 50%		DS 50%		ASI		Leaf R		Leaf S		PASP	
CROSSES	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
TZEI-13 X TZEI-17	0.52ns	1.57*	1.79**	0.97ns	0.97**	0.87**	0.07ns	-0.12ns	-0.86**	-0.01ns	0.37*	0.34*
TZEI-13 X TZEI-23	-0.68ns	-0.83ns	0.03ns	-0.46ns	-0.59ns	0.87**	0.41ns	-0.14ns	0.51*	0.03ns	-0.08ns	-0.81**
TZEI-13 X TZEI-25	0.25ns	-0.39ns	-0.47ns	-0.29ns	1.74**	-0.73**	0.29ns	-0.02ns	1.19**	0.03ns	-0.10ns	-0.40*
TZEI-13 X TZEI-124	-1.75**	-1.53*	0.11ns	-3.06**	0.71**	-1.13**	0.46ns	-0.29ns	-0.69ns	0.03ns	0.07ns	-0.40*
TZEI-17 X TZEI-13	-3.00**	-3.50**	-1.50ns	-4.00**	-0.17ns	-1.67**	0.06ns	-0.17ns	0.06ns	0.00ns	-0.08ns	-0.78**
TZEI-17 X TZEI-23	-0.98ns	-1.76**	-0.61ns	-0.49ns	0.87*	0.43ns	0.21ns	0.11ns	-0.32ns	0.01ns	-0.12ns	-0.18*
TZEI-17 X TZEI-25	-0.88ns	-0.83ns	-1.77**	-0.83ns	1.37**	0.33ns	0.15ns	-0.04ns	0.25ns	0.01ns	-0.65**	-0.82**
TZEI-17 X TZEI-124	-0.38ns	-0.96ns	0.09ns	-1.43*	-0.33ns	0.10ns	0.42ns	0.01ns	-0.49ns	-0.06ns	-0.20ns	-0.21*
TZEI-23 X TZEI-13	0.33ns	-1.00ns	-0.33ns	-0.50ns	-0.67ns	0.17ns	-0.28ns	-0.06ns	-1.39**	-0.06ns	-0.19ns	-0.61**
TZEI-23 X TZEI-17	-0.17ns	0.17ns	-0.50ns	2.67**	0.17ns	1.67**	-0.06ns	0.22*	0.00ns	0.00ns	-0.33ns	0.06ns
TZEI-23 X TZEI-25	-1.08*	-0.73ns	-1.37*	-0.59ns	1.47**	0.50*	0.38ns	-0.01**	-0.78**	0.00ns	0.21ns	-0.59**
TZEI-23 X TZEI-124	-1.25*	-1.53*	-1.01*	-1.03*	-0.39ns	0.27ns	-0.17ns	-0.13ns	-0.21ns	-0.05ns	-0.39*	-0.31*
TZEI-25 X TZEI-13	-0.50ns	-0.17ns	-0.33ns	0.00ns	-0.17ns	0.33ns	-0.22ns	-0.22*	-3.56**	0.06ns	-0.22ns	-0.11ns
TZEI-25 X TZEI-17	1.83**	0.50ns	1.83*	1.00ns	0.83*	0.33ns	-0.17ns	0.00ns	-0.28ns	0.00ns	-0.14ns	0.05ns
TZEI-25 X TZEI-23	0.50ns	1.17ns	0.17ns	0.50ns	-0.33ns	-0.33ns	0.17ns	-0.05ns	-0.78*	0.00ns	-0.28ns	0.17ns
TZEI-25 X TZEI-124	-1.15*	0.24ns	0.66ns	0.81ns	2.77**	0.17ns	-0.08ns	-0.14ns	-1.95**	-0.05ns	-0.37*	-0.34*
TZEI-124 X TZEI-13	-0.67ns	0.50ns	0.83ns	-0.33ns	1.00*	0.17ns	-0.33ns	-0.05ns	-0.42ns	-0.06ns	0.14ns	0.28ns
TZEI-124 X TZEI-17	0.50ns	0.83ns	-0.83ns	0.17ns	-0.67ns	-0.67*	-0.39ns	0.00ns	1.00**	0.00ns	-0.22ns	0.28ns
TZEI-124 X TZEI-23	0.83ns	-0.17ns	1.00ns	-0.50ns	-0.33ns	-0.33ns	0.22ns	-0.17ns	1.67**	0.00ns	0.36ns	-0.39ns
TZEI-124 X TZEI-25	-0.17ns	-0.67ns	0.17ns	-0.67ns	-0.67ns	0.67*	0.06ns	0.00ns	1.11**	0.00ns	0.33ns	0.00ns
SE SCA	**1.85**	**1.93**	**1.07**	**1.92**	**3.07**	**0.42**	**0.15**	**na**	**0.74**	**na**	**0.11**	**0.45**
SE REC	**0.65**	**0.74**	**0.40**	**1.14**	**0.15**	**0.31**	**0.03**	**na**	**0.91**	**na**	**0.03**	**0.06**

Table 4.6. Continued

	PHT EHT EEP Ear W 100 GW DS WW DS WW DS WW DS WW DS WW										GY	
CROSSES											**DS**	**WW**
TZEI-13 X TZEI-17	-5.96ns	-6.21ns	-4.03ns	2.00ns	0.02ns	0.05*	-4.98**	-14.13**	-0.51ns	0.71ns	-271.14**	-507.37**
TZEI-13 X TZEI-23	2.53ns	10.27ns	2.91ns	7.81*	-0.02ns	-0.01ns	3.77**	11.72*	-0.9ns	0.54ns	121.35*	469.84**
TZEI-13 X TZEI-25	10.83*	13.22*	9.04**	8.68**	0.00ns	-0.02ns	5.01**	9.53*	-1.13*	0.74ns	311.49**	242.06ns
TZEI-13 X TZEI-124	6.21ns	10.33*	2.92ns	4.71*	0.01ns	0.02ns	-2.62ns	30.44**	1.82*	0.46ns	76.38*	1132.01**
TZEI-17 X TZEI-13	24.28**	23.33**	14.42**	7.28*	0.06ns	0.08*	-2.46ns	19.33**	0.71ns	1.84**	-69.94ns	789.01**
TZEI-17 X TZEI-23	4.40ns	7.90ns	1.31ns	8.33**	0.07*	0.03ns	2.55ns	8.46ns	1.24*	0.51ns	219.42**	434.11*
TZEI-17 X TZEI-25	12.04**	20.97**	9.17**	7.42*	-0.02ns	-0.03ns	7.91**	17.80**	0.44ns	-0.04ns	218.76**	655.38**
TZEI-17 X TZEI-124	-2.39ns	-1.21ns	2.25ns	-1.94*	0.03ns	0.03ns	2.67*	24.08**	-0.61ns	0.45ns	37.15ns	789.01**
TZEI-23 X TZEI-13	2.50ns	-0.17ns	-0.44ns	-2.00ns	0.00ns	0.00ns	3.36ns	5.67ns	1.08ns	0.20ns	155.75*	159.23ns
TZEI-23 X TZEI-17	-3.89ns	-3.39ns	-1.28ns	-0.39ns	-0.11**	0.06ns	-1.09ns	-0.03ns	-1.04ns	-0.005ns	-24.96ns	274.60ns
TZEI-23 X TZEI-25	7.14ns	5.39ns	3.13ns	0.29ns	-0.01ns	-0.02ns	2.41ns	0.55ns	1.36*	1.40*	39.67ns	61.11ns
TZEI-23 X TZEI-124	0.37ns	0.49ns	-0.23ns	-1.57*	0.02ns	0.01ns	4.18**	0.82ns	-1.47*	-0.06ns	268.03**	235.94ns
TZEI-25 X TZEI-13	4.28ns	3.07ns	-0.39ns	-2.78ns	0.00ns	0.00ns	3.72*	0.17ns	0.61ns	0.33ns	385.74**	-110.32ns
TZEI-25 X TZEI-17	3.79ns	3.28ns	3.17ns	5.61ns	0.00ns	0.00ns	6.84**	1.78ns	-0.29ns	-0.82ns	92.97ns	-107.56ns
TZEI-25 X TZEI-23	6.39ns	13.5*	3.72ns	3.83ns	0.00ns	0.00ns	-2.55ns	1.42ns	-0.49ns	-0.04ns	-30.65ns	125.83ns
TZEI-25 X TZEI-124	5.06ns	5.45ns	3.74ns	3.74ns	0.00ns	-0.09ns	5.38**	5.73ns	0.16ns	-1.18*	64.81ns	129.57ns
TZEI-124 X TZEI-13	4.25ns	6.72ns	-1.14ns	1.39ns	0.00ns	0.00ns	-3.23ns	-10.9ns	0.21ns	-0.74ns	151.34*	-389.41ns
TZEI-124 X TZEI-17	11.72*	3.22ns	6.61*	3.72ns	0.00ns	0.00ns	2.44ns	-14.91*	-0.005ns	-0.68ns	35.06ns	-510.65*
TZEI-124 X TZEI-23	-3.89ns	2.61ns	-0.83ns	4.33ns	0.00ns	0.00ns	-1.56ns	10.08ns	-0.75ns	0.04ns	-95.27ns	443.10*
TZEI-124 X TZEI-25	-8.17ns	-3.17ns	-2.06ns	-3.22ns	0.00ns	0.00ns	3.88*	4.69ns	-0.99ns	-0.63ns	215.31**	214.39ns
SE SCA	**71.13**	**160.96**	**37.51**	**54.72**	**na**	**na**	**30.72**	**339.72**	**0.68ns**	**0.70**	**49340.76**	**473679.86**
SE REC	**41.50**	**38.19**	**12.80**	**7.41**	**na**	**na**	**5.37**	**39.86**	**0.24**	**0.27**	**11999.42**	**63868.44**

DT 50% = Days 50% tasseling, DS 50% = Days 50% silking, ASI = Anthesis-silking interval, Leaf R = Leaf rolling, Leaf S = Leaf senescence, PASP = Plant aspect, PHT = Plant height, EHT = Ear height, EPP = Ears per plant, Ear W = Ear weight, 100 GW = hundred grain weight, GY = Grain yield per hectare, DS = drought stress, WW = well watered, SE = standard error, SCA = specific combining ability, REC = reciprocal, na = Not available, ns = non-significant, * Significant at 0.05 probability level, ** Highly significant at 0.01% probability level.

Concerning leaf rolling under water stress and leaf senescence under well watered condition, specific combining ability was not significant (p>0.05). For leaf senescence under drought, 5 crosses showed highly negative significant (p<0.01) ranged from -0.78 (TZEI-23 x TZEI-25) to -3.56 (TZEI-25 x TZEI-13) whereas one cross TZEI-25 x TZEI23 (-0.78) exhibited negative significant (p<0.05) specific combining ability.

For PHT and EHT, either under drought or well watered conditions, only 2 hybrids TZEI17 x TZEI-124 (-1.94) and TZEI-23 x TZEI-124 (-1.57) showed negative significant (p<0.05) SCA. On the other hand, TZEI-17 x TZEI-13 and TZEI-17 x TZEI-23 under water and non-water stress conditions showed highly significance positive (p<0.01) SCA for PHT.

4.7. Heritability

Results from both narrow sense and broad sense heritability estimates in this study under drought stress and well watered conditions are presented in Table 4.7. Environment played its role in modifying narrow sense heritability while heritability in broad sense was not much influenced by environment. The heritability values were classified as low (<30%), moderate (30-60%) and high (>60%) according to Johnson *et al*. (1955).

Table 4.7: Estimates of narrow and broad sense heritability of ten maize characters in full diallel cross under drought and well watered conditions

Parameters	Days to 50% tasseling		Days to 50% silking		Anthesis-silking interval		Leaf senescence		Plant aspect	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
σ^2_g	12.43	8.13	10.25	8.61	7.55	2.14	5.08	0.0004	0.20	1.04
σ^2_{ph}	13.25	9.19	11.39	9.70	7.89	2.29	5.26	0.003	0.28	1.13
σ^2_e	0.81	1.05	1.38	1.09	0.33	0.15	0.19	0.003	0.07	0.08
h^2_n	0.69	0.50	0.80	0.54	0.05	0.43	0.61	0.01	0.03	0.03
h^2_b	0.94	0.89	0.90	0.89	0.96	0.94	0.96	0.12	0.73	0.93

Parameters	Plant height		Ear height		Ear weight		Hundred grain weight		Grain yield per hectare	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
σ^2_g	365.29	877.34	148.43	194.94	69.6	722.63	0.99	1.20	125445.2	1170124
σ^2_{ph}	414.19	965.81	164.76	220.05	75.27	797.13	1.76	2.13	133690.71	1286559.6
σ^2_e	48.90	88.47	16.67	25.11	5.66	74.50	0.77	0.93	8245.51	116435.6
h^2_n	0.52	0.65	0.36	0.43	0.13	0.12	0.05	0.20	0.001	0.25
h^2_b	0.88	0.91	0.90	0.89	0.92	0.91	0.56	0.56	0.94	0.93

DS = drought stress, WW = well watered, σ^2_g = genotypic variance, σ^2_{ph} = phenotypic variance, σ^2_e = error variance, h^2_n = narrow sense heritability, h^2_b = broad sense heritability.

The estimates of narrow sense heritability were high for only DT 50% (0.69), DS 50% (0.80) and leaf senescence (0.61) under drought while for plant height (0.65) under well watered condition (Table 4.7). The values ranged from 0.001 to 0.80 and from also 0.01 to 0.65 under water stress and well watered conditions, respectively. Under water stress 3 high, 2 moderate and 5 low narrow sense heritability were recorded while 1 high, 4 moderate and 5 low were recorded under well watered condition.

High magnitudes of broad sense heritability were found in all characters under both water stress and well watered conditions except for leaf senescence (0.12) under well watered condition and hundred grain weight under both conditions (0.56 each). The values of broad sense heritability were ranged from 0.56 to 0.96 under drought and from 0.12 to 0.94 under well watered condition. The following characters had high heritability above greater or equal to 0.90 under drought stress; DT 50% (0.94), DS 50% (0.90), ASI (0.96), Leaf senescence (0.96), EHT (0.90), ear weight (0.92) and GY (0.94) while under well watered ASI (0.94), PASP (0.93), PHT (0.91), ear weight (0.91) and GY (0.93) had broad sense heritability greater or equal to 0.90.

4.8. Heterosis

In this study both high parent heterosis (HPH) and mid-parent heterosis (MPH) were computed according to the formula given by Fehr (1987) as described in chapter II, 2.11.1. The study showed that the degree of heterosis varied water stress and well watered conditions, as well as from hybrid to hybrid and from character to character.

4.8.1. Heterosis over high parent

The estimates of HPH were computed for grain yield per hectare and yield related traits under water stress condition and well watered condition as presented in Table 4.8. The results revealed that hybrids TZEI-25 x TZEI-17 (-5.93% and -5.87% for DT 50% and 6.49% and -1.42% for DS 50%) and TZEI-124 x TZEI-13 (-7.04% and -9.30% for DT 50% and -0.60% and -11.60% for DS 50%) showed negative HPH for days to 50% tasseling and silking under both water stress and well watered conditions. However hybrids TZEI-13 x TZEI-124 (-9.85%) and TZEI-124 x TZEI-17 (-9.35%) showed the highest negative high parent heterosis for DT 50% under drought stress and well watered conditions, respectively and TZEI-25 x TZEI-17 (-6.49%) and TZEI-13 x TZEI-124 (12.80%) performed also the highest high parents heterosis for DS 50% under drought stress and well watered conditions, respectively. Regarding these results, hybrids TZEI25 x TZEI-17 and TZEI-124 x TZEI-13 came out as the best for days to DT 50% and DS 50% under both water stress and well watered conditions. For ASI, 4 hybrids exhibited negative high parents heterosis ranging from -135.86% (TZEI-25 x TZEI-17) to -194.79% (TZEI-25 x TZEI-13) under drought but 16 showed negative high parent heterosis under well watered which ranged from -30.03% (TZEI-13 x TZEI-124) to -451.13% (TZEI-17 x TZEI-13). Besides only hybrids TZEI-25 x TZEI-23 (-163.19% and -183.50%) and TZEI-25 x TZEI-17 (-135.86% and -175.19%) exhibited negative heterosis under drought stress and well watered conditions for ASI and performed the best. The inbred TZEI-25 gave maximum heterosis under well watered when used either female or male parent, it performed well under drought when used as female.

Eight and seven hybrids expressed negative high parent heterosis under both water stress and well watered conditions for plant height with TZEI-17 x TZEI-13 (-19.55% and 10.49%) and TZEI-124 x TZEI-17 (-17.86% and -12.14%) having the highest negative high parent heterosis. The lines TZEI-17 gave maximum heterosis in various cross combination when used as either female or male. For ear height only 5 and 6 hybrids exhibited negative high parent heterosis under water stress and well watered conditions, respectively. The degree for ear height ranged from -0.60% (TZEI-23 X TZEI-124) to 16.91% (TZEI-17 x TZEI-13) under water stress and from -8.06% (TZEI-13 x TZEI-124) to -15.53% (TZEI-124 x TZEI-17) under well watered. The maximum of heterosis was manifested in the derivatives of lines TZEI-17 used either as female or male under drought and TZEI-124 under well watered condition when used as female.

Only hybrids TZEI-23 x TZEI-17 (22.00%) and TZEI-13 x TZEI-17 (11.00%) recorded positive HPH under drought condition for EPP and TZEI-13 x TZEI-17 (17.00%) and TZEI-17 x TZEI-23 (11.00%) under well watered condition. For EPP hybrid TZEI-13 x TZEI-17 exhibited high positive higher parent heterosis under drought stress and well watered conditions and in all cases inbred line TZEI-17 gave the maximum heterosis when used either female or male parent followed by TZEI-23.

Table 4.8: Heterosis percentages (%) over better parents for twelve traits in full diallel under drought and well watered conditions

Gen	DT 50%				DS 50%				ASI				Leaf R			
	Mean		BPH		Mean		BPH		Mean		BPH		Mean		BPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P1	47.33	46.67			55.33	54.67			4.33	4.00			2.00	1.78		
P2	45.00	46.33			51.33	51.33			0.33	-1.33			3.00	1.11		
P3	39.00	41.67			47.67	46.67			2.00	-2.00			3.00	1.22		
P4	49.67	45.33			55.33	46.33			-6.33	1.33			3.00	1.11		
P5	49.00	47.00			55.67	55.00			4.00	3.33			3.22	1.33		
P1 X P2	42.00	43.00	-6.67	-7.19	54.00	47.67	5.20	-7.13	6.00	1.33	38.57	-200.00	3.67	1.00	83.00	-9.91
P1 X P3	40.00	39.33	2.56	-5.62	50.33	47.00	5.99	0.71	4.00	3.00	0.00	-250.00	3.67	1.11	83.00	-9.02
P1 X P4	46.00	44.00	-2.81	-2.93	53.67	48.33	-3.00	4.32	5.67	2.33	30.95	75.19	3.60	1.00	77.50	-9.91
P1 X P5	42.67	43.33	-9.85	-7.16	56.67	47.67	2.42	-12.80	8.67	2.33	100.23	-30.03	3.67	1.33	83.50	0.00
P2 X P1	48.00	50.00	6.67	7.92	57.00	55.67	10.05	8.46	6.33	4.67	1818.18	-451.13	3.60	1.33	77.50	19.82
P2 X P3	38.00	39.00	-2.56	-6.41	46.67	49.00	-2.10	4.99	4.33	2.33	1212.12	-216.50	4.00	1.44	33.33	29.73
P2 X P4	46.00	43.67	2.22	-3.66	51.67	47.67	0.66	2.89	4.33	1.67	1212.12	-225.56	3.78	1.00	25.67	-9.91
P2 X P5	44.00	43.67	-2.22	-5.74	52.33	48.67	1.95	-5.18	4.00	1.00	1212.12	-175.19	3.89	1.22	29.67	9.91
P3 X P1	39.33	41.33	0.85	-0.82	51.00	48.00	6.98	2.85	5.33	2.67	166.50	-233.50	4.22	1.22	111.00	0.00
P3 X P2	38.33	38.67	-1.72	-7.20	47.67	43.67	0.00	-6.43	4.00	-1.00	100.00	-50.00	4.11	1.00	37.00	-9.91
P3 X P4	40.33	40.67	3.41	-2.40	47.33	44.67	-0.71	-3.58	3.33	1.00	66.50	-150.00	4.33	1.00	44.33	-9.91
P3 X P5	39.33	38.33	0.85	-8.02	50.00	45.67	4.89	-2.14	4.33	1.33	116.50	-166.50	3.89	1.00	29.67	-18.03

: Continued

P4 X P1	47.00	44.33	-0.70	-2.21	54.33	48.33	-1.81	4.32	6.00	1.67	-194.79	25.56	4.00	1.44	100.00	29.73
P4 X P2	42.33	42.67	-5.93	-5.87	48.00	45.67	-6.49	-1.42	2.67	1.00	-135.86	-175.19	4.11	1.00	37.00	-9.91
P4 X P3	39.33	38.33	0.85	-8.02	47.00	43.67	-1.40	-5.74	4.00	1.67	-163.19	-183.50	4.00	1.11	33.33	0.00
P4 X P5	44.33	43.00	-9.53	-5.14	54.67	48.00	-1.19	3.60	6.00	3.00	-174.79	125.56	3.78	1.11	25.67	0.00

Gen	**DT 50%**				**DS 50%**				**ASI**				**Leaf R**			
	Mean		**BPH**		**Mean**		**BPH**		**Mean**		**BPH**		**Mean**		**BPH**	
	DS	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
P5 X P1	44.00	42.33	-7.04	-9.30	55.00	48.33	-0.60	-11.60	6.67	2.00	66.75	-39.94	4.33	1.44	116.50	8.27
P5 X P2	43.00	42.00	-4.44	-9.35	54.00	48.33	5.20	-5.84	5.33	2.33	33.25	-275.19	4.67	1.22	55.67	9.91
P5 X P3	37.67	38.67	-3.41	-7.20	48.00	46.67	0.69	0.00	5.00	2.00	25.00	-200.00	3.44	1.33	14.67	9.02
P5 X P4	44.67	44.33	-8.84	-2.21	54.33	49.33	-1.81	6.48	7.33	1.67	83.25	25.56	3.67	1.11	22.00	0.00
MAMABA	47.00	47.00			55.00	51.00			6.00	1.00			3.67	1.00		
OMANKWA	45.67	41.00			54.67	46.67			6.33	2.00			3.44	2.56		
Grand mean	**43.30**	**42.84**			**52.17**	**48.23**			**4.44**	**1.67**			**3.69**	**1.20**		
CV	**3.50**	**4.10**			**3.40**	**3.00**			**22.90**	**27.70**			**15.60**	**21.70**		
LSD	**3.32**	**3.82**			**3.91**	**3.20**			**2.19**	**1.00**			**1.33**	**0.57**		
Error	**1.24**	**1.42**			**1.45**	**1.18**			**0.83**	**0.38**			**0.47**	**0.21**		

Table 4.8: Continued

Table 4.8

Gen	Leaf S				PAST				PHT				EHT			
	Mean		BPH		Mean		BPH		Mean		BPH		Mean		BPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P1	4.55	1.00			4.44	4.00			112.11	116.33			60.55	53.33		
P2	1.00	1.00			4.44	3.67			120.44	134.56			65.34	67.56		
P3	3.89	1.00			4.33	4.67			123.78	132.44			76.55	73.89		
P4	3.78	1.00			4.89	4.00			127.22	171.56			76.22	88.44		
P5	8.78	1.22			4.78	2.11			170.44	214.22			91.33	111.67		
P1 X P2	1.33	1.00	33.00	0.00	4.56	2.33	2.70	-36.51	145.45	167.11	20.77	24.19	83.11	89.22	27.22	32.06
P1 X P3	3.22	1.00	-17.22	0.00	4.06	1.33	-6.24	-66.75	137.00	160.33	10.68	21.06	80.00	88.44	4.51	19.69
P1 X P4	1.22	1.11	-67.72	11.00	4.00	1.78	-9.91	-55.50	159.11	196.55	25.07	14.57	95.00	98.44	24.64	11.31
P1 X P5	4.17	1.00	-8.35	0.00	4.50	1.67	1.35	-20.85	163.17	203.67	-4.27	-4.92	87.50	102.67	-4.19	-8.06
P2 X P1	1.22	1.00	22.00	0.00	4.72	3.89	6.31	5.99	96.89	120.44	-19.55	-10.49	54.28	74.67	-16.91	10.52

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P2 X P3	1.22	1.00	22.00	0.00	3.45	2.67	-20.32	-27.25	133.89	160.78	8.17	19.49	78.89	94.00	3.06	27.22
P2 X P4	1.00	1.00	0.00	0.00	3.11	1.55	-29.95	-57.77	161.22	210.55	26.73	56.47	100.00	109.00	31.20	23.25
P2 X P5	3.22	1.00	222.00	0.00	3.44	1.89	-22.52	-10.43	163.44	194.66	-4.11	-9.13	95.89	101.78	4.99	-8.86
P3 X P1	6.01	1.11	54.50	11.00	4.44	2.56	2.54	-36.00	132.00	160.67	6.64	21.32	80.89	92.45	5.67	25.12
P3 X P2	1.22	1.00	22.00	0.00	4.11	2.56	-5.08	-30.25	141.67	167.55	14.45	24.52	81.45	94.78	6.40	28.27
P3 X P4	1.44	1.00	-61.90	0.00	3.89	1.89	-10.16	-52.75	163.78	205.44	28.74	19.75	99.33	102.78	29.76	16.21
P3 X P5	6.56	1.00	68.64	0.00	3.89	1.11	-10.16	-47.39	155.44	196.00	-8.80	-8.51	90.78	105.44	-0.60	-5.58
P4 X P1	8.34	1.00	120.63	0.00	4.45	2.00	0.23	-50.00	150.56	190.42	18.35	10.99	95.78	104.00	25.66	17.59
P4 X P2	1.56	1.00	56.00	0.00	3.39	1.45	-23.65	-60.49	153.67	204.00	20.79	18.91	93.67	97.78	22.89	10.56
P4 X P3	3.00	1.00	-20.63	0.00	4.45	1.56	2.77	-61.00	151.00	178.44	18.69	4.01	91.89	95.11	20.04	7.54
P4 X P5	3.33	1.00	-11.90	0.00	3.89	1.00	-18.62	-52.61	167.89	225.22	-1.50	5.13	102.34	113.11	12.06	1.29

Gen	**Leaf S**				**PAST**				**PHT**				**EHT**			
	Mean		**BPH**		**Mean**		**BPH**		**Mean**		**BPH**		**Mean**		**BPH**	
	DS	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
P5 X P1	5.01	1.11	10.11	11.00	4.22	1.11	-4.95	-47.39	154.67	190.22	-9.25	-11.20	89.78	99.89	-1.70	-10.55
P5 X P2	1.22	1.00	22.00	0.00	3.89	1.33	-12.39	-36.97	140.00	188.22	-17.86	-12.14	82.67	94.33	-9.48	-15.53
P5 X P3	3.22	1.00	-17.22	0.00	3.17	1.89	-26.79	-10.43	163.22	190.78	-4.24	-10.94	92.44	96.78	1.22	-13.33
P5 X P4	1.11	1.00	-70.63	0.00	3.22	1.00	-32.64	-52.61	184.22	231.56	8.08	8.09	106.45	119.56	16.56	7.07
MAMABA	2.55	1.00			3.56	1.66			172.90	235.30			101.28	114.90		
OMANKWA	2.78	1.33			3.56	1.56			172.70	223.90			112.00	123.10		
Grand mean	**3.20**	**1.03**			**4.03**	**2.16**			**148.80**	**184.10**			**87.61**	**96.80**		
CV	**24.90**	**14.50**			**11.50**	**23.20**			**7.70**	**8.70**			**8.40**	**9.15**		
LSD	**1.74**	**0.33**			**1.01**	**1.09**			**25.10**	**35.00**			**16.16**	**20.15**		
Error	**0.66**	**0.12**			**0.38**	**0.40**			**9.39**	**13.09**			**6.04**	**7.54**		

Table 4.8: Continued

Table 4.8
: Continued

Gen	EPP				Ear W				100 GW				GY			
	Mean		BPH		Mean		BPH		Mean		BPH		Mean		BPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P1	1.00	1.00			10.98	11.05			12.87	15.12			310.02	314.98		
P2	1.00	1.00			12.92	20.61			10.44	13.48			413.36	658.96		
P3	1.00	1.00			15.68	54.28			10.59	14.85			565.71	1559.29		
P4	1.00	1.11			5.82	60.66			11.02	16.86			302.68	2152.90		
P5	1.00	1.00			10.29	35.19			13.18	18.39			155.10	727.97		
P1 X P2	1.11	1.16	11.00	17.00	9.17	57.91	-29.02	180.98	11.78	18.88	-8.47	24.87	241.74	2122.43	-41.54	221.97
P1 X P3	1.00	1.00	0.00	0.00	27.50	79.61	75.38	46.67	11.84	18.15	-8.00	20.04	1158.22	2834.98	104.77	81.78
P1 X P4	1.00	1.00	0.00	-9.91	28.08	81.14	155.74	33.76	11.47	18.74	-10.88	11.15	1439.98	2578.01	364.48	19.74
P1 X P5	1.00	1.00	0.00	0.00	10.17	91.97	-7.38	161.35	14.64	17.53	11.08	-4.68	802.50	3075.62	158.79	322.47
P2 X P1	1.00	1.00	0.00	0.00	14.09	19.25	9.06	-6.60	10.35	15.20	-19.58	0.53	381.61	544.42	-7.72	-17.38
P2 X P3	1.00	1.11	0.00	11.00	26.29	74.76	67.67	37.73	11.28	16.68	6.52	12.32	1110.31	3103.89	96.30	99.05
P2 X P4	1.00	1.00	0.00	-9.91	38.55	95.13	198.37	56.82	11.57	15.58	4.99	-7.59	1089.21	3183.37	163.38	47.85
P2 X P5	1.00	1.00	0.00	0.00	25.58	85.70	97.99	143.54	11.42	16.35	-13.35	-11.09	681.72	2800.66	64.85	284.72
P3 X P1	1.00	1.00	0.00	0.00	20.79	68.27	32.59	25.77	9.68	17.74	-24.79	17.33	846.73	2516.52	49.76	61.37
P3 X P2	1.22	1.00	22.00	0.00	28.46	74.81	81.51	37.82	13.36	16.69	26.16	12.39	1160.24	2554.70	105.16	63.81
P3 X P4	1.00	1.00	0.00	-9.91	27.41	87.02	74.81	43.46	12.39	18.87	12.43	11.92	1084.8	3187.59	91.82	48.06
P3 X P5	1.00	1.00	0.00	0.00	26.86	96.93	71.30	78.57	9.91	17.64	-24.81	-4.08	1080.58	3566.44	91.04	128.71
P4 X P1	1.00	1.00	0.00	-9.91	20.63	80.81	87.89	33.22	10.25	18.09	-20.36	7.30	668.50	2798.64	115.63	29.97
P4 X P2	1.00	1.00	0.00	-9.91	24.86	91.56	92.41	50.94	12.15	17.22	10.25	2.14	903.27	3398.49	118.38	57.85

Table 4.8

P4 X P3	1.00	1.00	0.00	-9.91	32.51	84.18	107.33	38.77	13.36	18.96	21.23	12.46	1146.11	2935.94	102.63	36.37
P4 X P5	1.00	1.00	0.00	-9.91	32.46	105.68	215.45	74.22	11.63	16.12	-11.76	-12.34	1049.56	3471.73	246.55	61.25

: Continued

	EPP				**Ear W**				**100 GW**				**GY**			
Gen	**Mean**		**BPH**		**Mean**		**BPH**		**Mean**		**BPH**		**Mean**		**BPH**	
	DS	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
P5 X P1	1.00	1.00	0.00	0.00	16.63	113.76	51.46	223.27	14.22	19.00	7.89	3.32	499.82	3854.44	61.28	429.50
P5 X P2	1.00	1.00	0.00	0.00	20.70	115.52	60.22	228.28	11.43	17.71	-13.28	-3.70	611.60	3821.95	47.94	425.04
P5 X P3	1.00	1.00	0.00	0.00	29.97	76.78	91.14	41.45	11.41	17.56	-13.43	-4.51	1271.11	2680.25	124.73	71.74
P5 X P4	1.00	1.00	0.00	-9.91	24.71	96.30	140.14	58.75	13.61	17.37	3.26	-5.55	618.94	3042.95	104.36	41.33
MAMABA	1.00	1.00			30.38	103.50			10.98	17.79			976.69	2854.07		
OMANKWA	1.00	1.00			32.18	91.10			16.34	22.32			1104.81	3254.40		
Grand mean	**1.01**	**1.01**			**22.36**	**76.10**			**11.98**	**17.37**			**14.29**	**46.81**		
CV	**8.10**	**7.60**			**19.20**	**19.70**			**15.50**	**9.40**			**24.90**	**18.80**		
LSD	**0.18**	**0.17**			**9.39**	**32.69**			**4.04**	**3.58**			**7.77**	**19.20**		
Error	**0.07**	**0.06**			**3.51**	**7.54**			**1.51**	**1.34**			**2.91**	**7.18**		

DT 50% = Days to 50% tasseling, DS 50% = Days 50% silking, ASI = Anthesis-silking interval, Leaf R = Leaf rolling, Leaf S = Leaf senescence, PASP = Plant aspect, PHT = Plant height, EHT = Ear height, EPP = Ears per plant, Ear W = Ear weight, 100 GW = hundred grain weight, GY = Grain yield per hectare, DS = Drought stress, WW = Well watered, Gen = Genotype, BPH = Better parent heterosis, CV = coefficient of variation, LSD = least significant difference, P1 = TZEI-13, P2 = TZEI-17, P3 = TZEI-23, P4 = TZEI-25 and P5 = TZEI-124.

Eighteen hybrids had positive HPH under water stress and ranged from 47.94% (TZEI124 x TZEI-17) to 364.48% (TZEI-13 x TZEI-25) while under well watered condition 19 hybrids had positive HPH and ranged from 19.74% (TZEI-13 x TZEI-25) to 429.50% (TZEI-124 x TZEI-13) for GY per hectare. For ear weight 18 and 19 hybrids respectively under water stress and well watered conditions exhibited positive HPH while 9 and 12 hybrids showed positive HPH under water stress and well watered conditions for 100 grain weight. For ear weight the values ranged from 9.06% (TZEI-17 x TZEI-13) to 215.45% (TZEI-25 x TZEI-124) under drought condition and from 25.77% (TZEI-23 x TZEI-13) to 228.28% (TZEI-124 x TZEI-17) under well watered condition. All the heterosis percentage above 100% under drought for ear weight were obtained when TZEI25 was used either as female or male parent, whereas under normal condition TZEI-13, TZEI-17 and TZEI-124 were used as parents, hence under water stress TZEI-25 gave the maximum heterosis. TZEI-13 x TZEI-25 (364.48%) and TZEI-25 x TZEI-124 (246.55%) expressed the highest higher positive heterosis for GY per hectare under drought stress and TZEI-124 x TZEI-13 (429.50%) and TZEI-124 x TZEI-17 (425.04%) under well watered condition. TZEI-25 gave the maximum heterosis under drought condition when used either female or male parents while TZEI-124 gave the maximum under well watered condition when used as female. For EPP only 2 hybrids showed positive heterosis under drought and 2 under well watered condition.

4.8.2. Heterosis over mid-parent

The estimates of mid-parent heterosis (MPH) of 20 hybrids under water stress and well watered conditions are presented in Table 4.9. The results showed that 19 hybrids had negative MPH for DT 50% ranged from -2.82% (TZEI-17 x TZEI-25) to -14.39% (TZEI124 x TZEI-23) and from -3.63% (TZEI-25 x TZEI-13) to -13.45% (TZEI-23 x TZEI124) under drought stress and well watered conditions, respectively. Therefore hybrids TZEI-124 x TZEI-23 under water stress and its reciprocal TZEI-23 x TZEI-124 under well watered condition recorded the highest negative MPH. For DS 50% 16 hybrids exhibited negative MPH under drought while 18 under well watered condition. The highest negative MPH for DS 50% under drought were TZEI-25 x TZEI-17 (-9.99%), TZEI-25 x TZEI-23 (-8.74%) and TZEI-23 x TZEI-25 (-8.10%) while under well watered condition TZEI-13 x TZEI-124 (-13.07%) and TZEI-124 x TZEI-13 (-11.86%) were the highest negative. Thus, TZEI-25 gave maximum heterosis under drought for DS 50% when used as female or male. Under water stress only 5 crosses had negative MPH for ASI and all the 4 crosses TZEI-25 x TZEI-13 (-3736.36%), TZEI-25 x TZEI-124 (3736.36%), TZEI-25 x TZEI-23 (-443.35%) and TZEI-25 x TZEI-17 (-224.04%) with TZEI-25 as a female parent exhibited the highest negative MPH. Under well watered 10 hybrids showed negative MPH with TZEI-25 x TZEI-23 (-598.51%), TZEI-23 x TZEI25 (-398.51%) and TZEI-17 x TZEI-23 (-239.94%) having the highest negative, hence line TZEI-25 gave maximum heterosis under water stress and well watered conditions.

Two hybrids TZEI-17 x TZEI-13 (-16.67%) and TZEI-124 x TZEI-17 (-3.74%) showed negative MPH and 18 showed positive MPH for PHT under water stress while only one hybrid TZEI-17 x TZEI-13 (-3.99%) showed negative MPH under well watered condition.

Nineteen hybrids scored positive MPH under drought condition as well as under well watered condition for GY and the increase under drought ranged from 5.48% (TZEI-17 x TZEI-13) to 369.90% (TZEI-13 x TZEI-25) and from 58.17% (TZEI-25 x TZEI-23) to 489.76% (TZEI-13 x TZEI-124) under well watered. The highest positive and desirable heterotic effects for GY exhibited by TZEI-13 x TZEI-25 (396.90%), TZEI-25 x TZEI124 (358.17%) and TZEI-124 x TZEI-23 (252.64%) under water stress and TZEI-13 x TZEI-124 (489.76%), TZEI-124 x TZEI-13 (455.78%) and TZEI-124 x TZEI-17 (451.09%) under well watered. Line TZEI-25 gave maximum heterosis when used as female or male parent under drought while TZEI-124 and TZEI-13 gave also maximum heterosis when used as male or female under well watered condition. For ear weight under drought, 18 crosses showed positive MPH ranged from 17.91% (TZEI-17 x TZEI-13) to 311.42% (TZEI-17 x TZEI-25) while under well watered condition all the crosses exhibited positive heterosis and ranged from 21.60% (TZEI-17 x TZEI-13) to 392.04% (TZEI-124 x TZEI-13).

Table 4.9

: Heterosis percentages (%) over mid-parents for twelve traits in full diallel under drought and well watered conditions

Gen	DT 50%				DS 50%				ASI				Leaf R			
	Mean		MPH		Mean		MPH		Mean		MPH		Mean		MPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P1	47.33	46.67			55.33	54.67			4.33	4.00			2.00	1.78		
P2	45.00	46.33			51.33	51.33			0.33	-1.33			3.00	1.11		
P3	39.00	41.67			47.67	46.67			2.00	-2.00			3.00	1.22		
P4	49.67	45.33			55.33	46.33			-6.33	1.33			3.00	1.11		
P5	49.00	47.00			55.67	55.00			4.00	3.33			3.22	1.33		
P1 X P2	42.00	43.00	-9.02	-7.53	54.00	47.67	1.26	-10.06	6.00	1.33	16.17	-0.37	3.67	1.00	46.40	-30.80
P1 X P3	40.00	39.33	-7.33	-10.96	50.33	47.00	-1.88	-7.24	4.00	3.00	-3.96	200.00	3.67	1.11	46.40	-26.00
P1 X P4	46.00	44.00	-5.15	-4.35	53.67	48.33	-3.00	-4.30	5.67	2.33	13.40	-12.57	3.60	1.00	42.00	-30.80
P1 X P5	42.67	43.33	-11.41	-7.48	56.67	47.67	2.11	-13.07	8.67	2.33	33.38	-36.43	3.67	1.33	40.61	-14.47
P2 X P1	48.00	50.00	3.97	7.53	57.00	55.67	6.88	5.04	6.33	4.67	90.09	249.81	3.60	1.33	42.00	-7.96
P2 X P3	38.00	39.00	-9.52	-11.36	46.67	49.00	-5.72	0.00	4.33	2.33	85.84	-239.94	4.00	1.44	33.33	23.61
P2 X P4	46.00	43.67	-2.82	-4.71	51.67	47.67	-3.11	-2.38	4.33	1.67	85.84	na	3.78	1.00	25.67	-9.91
P2 X P5	44.00	43.67	-6.38	-6.42	52.33	48.67	-2.19	-8.45	4.00	1.00	84.76	0.00	3.89	1.22	25.08	0.00
P3 X P1	39.33	41.33	-8.88	-6.43	51.00	48.00	-0.97	-5.27	5.33	2.67	45.43	167.00	4.22	1.22	68.80	-18.67
P3 X P2	38.33	38.67	-8.74	-12.11	47.67	43.67	-3.70	-10.88	4.00	-1.00	33.33	-39.94	4.11	1.00	37.00	-14.16
P3 X P4	40.33	40.67	-9.03	-6.51	47.33	44.67	-8.10	-3.94	3.33	1.00	24.95	-398.51	4.33	1.00	44.33	-14.16
P3 X P5	39.33	38.33	-10.61	-13.54	50.00	45.67	-3.23	-10.16	4.33	1.33	36.81	100.00	3.89	1.00	25.08	-21.57
P4 X P1	47.00	44.33	-3.09	-3.63	54.33	48.33	-1.81	-4.30	6.00	1.67	-3736.36	-37.34	4.00	1.44	60.00	-0.35

Table 4.9: Continued

P4 X P2	42.33	42.67	-10.57	-6.90	48.00	45.67	-9.99	-6.47	2.67	1.00	-224.04	na	4.11	1.00	37.00	-9.91
P4 X P3	39.33	38.33	-11.29	-11.89	47.00	43.67	-8.74	-6.09	4.00	1.67	-443.35	-598.51	4.00	1.11	33.33	-4.72
P4 X P5	44.33	43.00	-10.14	-6.86	54.67	48.00	-1.50	-5.26	6.00	3.00	-3736.36	28.76	3.78	1.11	21.22	-9.02

Table 4.9. Continued

Gen	**DT 50%**				**DS 50%**				**ASI**				**Leaf R**			
	Mean		**MPH**		**Mean**		**MPH**		**Mean**		**MPH**		**Mean**		**MPH**	
	DS	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
P5 X P1	44.00	42.33	-8.65	-9.62	55.00	48.33	-0.90	-11.86	6.67	2.00	25.02	-45.43	4.33	1.44	65.90	-7.40
P5 X P2	43.00	42.00	-8.51	-10.00	54.00	48.33	0.93	-9.09	5.33	2.33	14.26	133.00	4.67	1.22	50.16	0.00
P5 X P3	37.67	38.67	-14.39	-12.78	48.00	46.67	-7.10	-8.19	5.00	2.00	11.11	200.75	3.44	1.33	10.61	4.31
P5 X P4	44.67	44.33	-9.46	-3.97	54.33	49.33	-2.11	-2.63	7.33	1.67	29.39	-28.33	3.67	1.11	17.68	-9.02
MAMABA	47.00	47.00			55.00	51.00			6.00	1.00			3.67	1.00		
OMANKWA	45.67	41.00			54.67	46.67			6.33	2.00			3.44	2.56		
Grand mean	**43.30**	**42.84**			**52.17**	**48.23**			**4.44**	**1.67**			**3.69**	**1.20**		
CV	**3.50**	**4.10**			**3.40**	**3.00**			**22.90**	**27.70**			**15.60**	**21.70**		
LSD	**3.32**	**3.82**			**3.91**	**3.20**			**2.19**	**1.00**			**1.33**	**0.57**		
Error	**1.24**	**1.42**			**1.45**	**1.18**			**0.83**	**0.38**			**0.47**	**0.21**		

Gen	Leaf S				PAST				PHT				EHT			
	Mean		MPH		Mean		MPH		Mean		MPH		Mean		MPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P1	4.55	1.00			4.44	4.00			112.11	116.33			60.55	53.33		
P2	1.00	1.00			4.44	3.67			120.44	134.56			65.34	67.56		
P3	3.89	1.00			4.33	4.67			123.78	132.44			76.55	73.89		
P4	3.78	1.00			4.89	4.00			127.22	171.56			76.22	88.44		
P5	8.78	1.22			4.78	2.11			170.44	214.22			91.33	111.67		
P1 X P2	1.33	1.00	-52.07	0.00	4.56	2.33	2.70	-39.24	145.45	167.11	25.09	33.21	83.11	89.22	32.05	47.61
P1 X P3	3.22	1.00	-23.70	0.00	4.06	1.33	-7.41	-69.32	137.00	160.33	16.16	28.90	80.00	88.44	16.70	39.03
P1 X P4	1.22	1.11	-70.71	11.00	4.00	1.78	-14.26	-55.50	159.11	196.55	32.96	36.55	95.00	98.44	38.92	38.87
P1 X P5	4.17	1.00	-37.43	-9.91	4.50	1.67	-2.39	-45.34	163.17	203.67	15.50	23.23	87.50	102.67	15.22	24.45
P2 X P1	1.22	1.00	-56.04	0.00	4.72	3.89	6.31	1.43	96.89	120.44	-16.67	-3.99	54.28	74.67	-13.76	23.53
P2 X P3	1.22	1.00	-50.10	0.00	3.45	2.67	-21.32	-35.97	133.89	160.78	9.65	20.43	78.89	94.00	11.21	32.91
P2 X P4	1.00	1.00	-58.16	0.00	3.11	1.55	-33.33	-59.58	161.22	210.55	30.19	37.56	100.00	109.00	41.29	39.74
P2 X P5	3.22	1.00	-34.15	-9.91	3.44	1.89	-25.38	-34.60	163.44	194.66	12.38	11.62	95.89	101.78	22.42	13.57

Table 4.9: Continued

P3 X P1	6.01	1.11	42.42	11.00	4.44	2.56	1.25	-40.95	132.00	160.67	11.92	29.17	80.89	92.45	18.00	45.34
P3 X P2	1.22	1.00	-50.10	0.00	4.11	2.56	-6.27	-38.61	141.67	167.55	16.02	25.51	81.45	94.78	14.82	34.01
P3 X P4	1.44	1.00	-62.45	0.00	3.89	1.89	-15.62	-56.40	163.78	205.44	30.50	35.16	99.33	102.78	30.04	26.63
P3 X P5	6.56	1.00	3.55	-9.91	3.89	1.11	-14.60	-67.26	155.44	196.00	5.66	13.08	90.78	105.44	8.15	13.65
P4 X P1	8.34	1.00	100.24	0.00	4.45	2.00	-4.61	-50.00	150.56	190.42	25.82	32.29	95.78	104.00	40.06	46.72
P4 X P2	1.56	1.00	-34.73	0.00	3.39	1.45	-27.33	-62.19	153.67	204.00	24.10	33.28	93.67	97.78	32.35	25.36
P4 X P3	3.00	1.00	-21.77	0.00	4.45	1.56	-3.47	-64.01	151.00	178.44	20.32	17.39	91.89	95.11	20.30	17.18
P4 X P5	3.33	1.00	-46.97	-9.91	3.89	1.00	-19.54	-67.27	167.89	225.22	12.81	16.76	102.34	113.11	22.16	13.05

Table 4.9: Continued

Gen	Leaf S				PAST				PHT				EHT			
	Mean		MPH		Mean		MPH		Mean		MPH		Mean		MPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P5 X P1	5.01	1.11	-24.83	0.00	4.22	1.11	-8.46	-63.67	154.67	190.22	9.48	15.09	89.78	99.89	18.22	21.08
P5 X P2	1.22	1.00	-75.05	-9.91	3.89	1.33	-15.62	-53.98	140.00	188.22	-3.74	7.93	82.67	94.33	5.54	5.26
P5 X P3	3.22	1.00	-49.17	-9.91	3.17	1.89	-30.41	-44.25	163.22	190.78	10.95	10.07	92.44	96.78	10.13	4.31
P5 X P4	1.11	1.00	-82.32	-9.91	3.22	1.00	-33.40	-67.27	184.22	231.56	23.78	20.05	106.45	119.56	27.07	19.49
MAMABA	2.55	1.00			3.56	1.66			172.90	235.30			101.28	114.90		
OMANKWA	2.78	1.33			3.56	1.56			172.70	223.90			112.00	123.10		
Grand mean	**3.20**	**1.03**			**4.03**	**2.16**			**148.80**	**184.10**			**87.61**	**96.80**		
CV	**24.90**	**14.50**			**11.50**	**23.20**			**7.70**	**8.70**			**8.40**	**9.15**		
LSD	**1.74**	**0.33**			**1.01**	**1.09**			**25.10**	**35.00**			**16.16**	**20.15**		
Error	**0.66**	**0.12**			**0.38**	**0.40**			**9.39**	**13.09**			**6.04**	**7.54**		

Table 4.9: Continued

Gen	EPP				Ear W				100 GW				GY			
	Mean		MPH		Mean		MPH		Mean		MPH		Mean		MPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P1	1.00	1.00			10.98	11.05			12.87	15.12			310.02	314.98		
P2	1.00	1.00			12.92	20.61			10.44	13.48			413.36	658.96		
P3	1.00	1.00			15.68	54.28			10.59	14.85			565.71	1559.29		
P4	1.00	1.11			5.82	60.66			11.02	16.86			302.68	2152.9		
P5	1.00	1.00			10.29	35.19			13.18	18.39			155.10	727.97		
P1 X P2	1.11	1.16	11.00	17.00	9.17	57.91	-23.26	265.82	11.78	18.88	1.07	32.03	241.74	2122.43	-33.18	335.73
P1 X P3	1.00	1.00	0.00	0.00	27.50	79.61	106.30	143.72	11.84	18.15	0.94	21.12	1158.22	2834.98	164.53	202.47
P1 X P4	1.00	1.00	0.00	-5.21	28.08	81.14	234.29	126.30	11.47	18.74	-3.98	17.20	1439.98	2578.01	369.90	108.92
P1 X P5	1.00	1.00	0.00	0.00	10.17	91.97	-4.37	297.79	14.64	17.53	12.40	4.63	802.50	3075.62	244.85	489.76
P2 X P1	1.00	1.00	0.00	0.00	14.09	19.25	17.91	21.60	10.35	15.20	-11.20	6.29	381.61	544.42	5.48	-17.38
P2 X P3	1.00	1.11	0.00	11.00	26.29	74.76	83.85	99.65	11.28	16.68	7.28	17.76	1110.31	3103.89	126.77	179.82
P2 X P4	1.00	1.00	0.00	-5.21	38.55	95.13	311.42	134.11	11.57	15.58	7.83	2.70	1089.21	3183.37	204.07	126.40
P2 X P5	1.00	1.00	0.00	0.00	25.58	85.70	120.42	207.17	11.42	16.35	-3.30	2.60	681.72	2800.66	139.69	303.81
P3 X P1	1.00	1.00	0.00	0.00	20.79	68.27	55.96	109.00	9.68	17.74	-17.48	18.39	846.73	2516.52	93.46	126.86
P3 X P2	1.22	1.00	22.00	0.00	28.46	74.81	99.02	99.79	13.36	16.69	27.06	17.83	1160.24	2554.70	137.01	130.28
P3 X P4	1.00	1.00	0.00	-5.21	27.41	87.02	154.98	51.42	12.39	18.87	14.67	19.02	1084.8	3187.59	149.84	71.73
P3 X P5	1.00	1.00	0.00	0.00	26.86	96.93	106.85	116.68	9.91	17.64	-16.62	6.14	1080.58	3566.44	199.09	211.84
P4 X P1	1.00	1.00	0.00	-5.21	20.63	80.81	145.60	125.38	10.25	18.09	-14.19	13.13	668.50	2798.64	118.15	99.02
P4 X P2	1.00	1.00	0.00	-5.21	24.86	91.56	165.31	125.32	12.15	17.22	13.23	13.51	903.27	3398.49	152.11	141.71
P4 X P3	1.00	1.00	0.00	-5.21	32.51	84.18	202.42	46.48	13.36	18.96	23.65	19.58	1146.11	2935.94	163.92	58.17

Table 4.9: Continued

Gen	EPP				Ear W				100 GW				GY			
	Mean		MPH		Mean		MPH		Mean		MPH		Mean		MPH	
	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
P5 X P1	1.00	1.00	0.00	0.00	16.63	113.76	56.37	392.04	14.22	19.00	9.17	13.40	499.82	3854.44	114.91	455.78
P5 X P2	1.00	1.00	0.00	0.00	20.70	115.52	78.37	314.05	11.43	17.71	-3.22	11.14	611.60	3821.95	115.10	451.09
P5 X P3	1.00	1.00	0.00	0.00	29.97	76.78	130.80	71.63	11.41	17.56	-4.00	5.66	1271.11	2680.25	252.64	134.22
P5 X P4	1.00	1.00	0.00	-5.21	24.71	96.30	206.77	100.94	13.61	17.37	12.48	-1.45	618.94	3042.95	170.19	111.24
MAMABA	1.00	1.00			30.38	103.50			10.98	17.79			976.69	2854.07		
OMANKWA	1.00	1.00			32.18	91.10			16.34	22.32			1104.81	3254.40		
Grand mean	**1.01**	**1.01**			**22.36**	**76.10**			**11.98**	**17.37**			**14.29**	**46.81**		
CV	**8.10**	**7.60**			**19.20**	**19.70**			**15.50**	**9.40**			**24.90**	**18.80**		
LSD	**0.18**	**0.17**			**9.39**	**32.69**			**4.04**	**3.58**			**7.77**	**19.20**		
Error	**0.07**	**0.06**			**3.51**	**7.54**			**1.51**	**1.34**			**2.91**	**7.18**		
P4 X P5	1.00	1.00	0.00	-5.21	32.46	105.68	302.98	120.51	11.63	16.12	-3.88	-8.54	1049.56	3471.73	358.17	141.02

DT 50% = Days to 50% tasseling, DS 50% = Days 50% silking, ASI = Anthesis-silking interval, Leaf R = Leaf rolling, Leaf S = Leaf senescence, PAST = Plant aspect, PHT = Plant height, EHT = Ear height, EPP = Ears per plant, Ear W = Ear weight, 100 GW = hundred grain weight, GY = Grain yield per hectare, DS = Drought stress, WW = Well watered, Gen = Genotype, MPH = Mid-parent heterosis, na = not available, CV = coefficient of variation, LSD = least significant difference, P1 = TZEI-13, P2 = TZEI-17, P3 = TZEI-23, P4 = TZEI-25 and P5 = TZEI-124.

4.9. Correlation between grain yield and other agronomic traits

The Pearson correlation analysis between grain yield per hectare of the hybrids and other characters under water stress and well watered conditions are presented in Table 4.10. GY exhibited positive and highly significant ($p<0.01$) correlation with ASI (0.27 under water stress), PHT (0.40 and 0.61 under drought and well watered conditions, respectively), ear height (0.47 and 0.61 under water stress and well watered conditions, respectively), ear weight (0.78 and 0.92 under also drought stress and well watered conditions respectively) and 100 grain weight (0.49 under well watered condition). In contrast, the other traits were strongly ($p<0.01$) and negatively correlated to GY under water stress and well watered conditions. Furthermore, the traits such as leaf rolling and ears per plant were not correlated ($p>0.05$) with grain yield. The highest positive ($p<0.01$) correlation was found between ear weight and GY whereas the highest negative was between PASP and GY (Table 4.10).

Considering the overall data, the highest positive correlation ($p<0.01$) under drought stress was recorded between plant height and ear height (0.93) while under well watered condition ear weight and GY (0.92) was the highest.

Table 4.10: Correlations between grain yield and other traits under water stress and well watered conditions

Parameters	Env	DS 50%	ASI	Leaf R	Leaf S	PASP	PHT	EHT	EPP	Ear W	100 GW	GY
DT 50%	**DS**	0.74**	-0.11$_{ns}$	-0.20$_{ns}$	0.14$_{ns}$	0.22$_{ns}$	-0.07$_{ns}$	-0.08$_{ns}$	-0.13$_{ns}$	-0.30**	0.02$_{ns}$	-0.4**
	WW	0.8**	0.27*	0.12$_{ns}$	0.003$_{ns}$	0.32**	-0.07$_{ns}$	-0.15$_{ns}$	-0.01$_{ns}$	-0.40**	-0.26*	-0.55**
DS 50%	**DS**		0.28*	-0.12$_{ns}$	0.22$_{ns}$	0.30**	-0.02$_{ns}$	-0.08$_{ns}$	-0.09$_{ns}$	-0.40**	0.06$_{ns}$	-0.45**
	WW		0.49**	0.27*	0.05$_{ns}$	0.32**	-0.16$_{ns}$	-0.25*	0.15$_{ns}$	-0.49**	-0.29**	-0.63**
ASI	**DS**			0.21$_{ns}$	0.02$_{ns}$	-0.18$_{ns}$	0.33**	0.29**	-0.01$_{ns}$	0.24*	0.21$_{ns}$	0.27**
	WW			0.28*	0.09$_{ns}$	-0.19$_{ns}$	0.07$_{ns}$	0.05$_{ns}$	0.08$_{ns}$	-0.09$_{ns}$	0.12$_{ns}$	-0.31**
Leaf R	**DS**				-0.08$_{ns}$	-0.02$_{ns}$	0.07$_{ns}$	0.12$_{ns}$	0.09$_{ns}$	0.22$_{ns}$	-0.11$_{ns}$	0.19$_{ns}$
	WW				0.14$_{ns}$	0.13$_{ns}$	-0.19$_{ns}$	-0.12$_{ns}$	-0.01$_{ns}$	-0.16$_{ns}$	0.10$_{ns}$	-0.19$_{ns}$
Leaf S	**DS**					0.36**	0.06$_{ns}$	0.03$_{ns}$	-0.12$_{ns}$	-0.29**	-0.16$_{ns}$	-0.28*
	WW					-0.17$_{ns}$	-0.17$_{ns}$	0.24*	-0.04$_{ns}$	0.07$_{ns}$	0.24*	0.06$_{ns}$
PASP	**DS**						-0.49**	-0.53**	0.04$_{ns}$	-0.65**	-0.22*	-0.58**
	WW						-0.70**	-0.66**	0.07$_{ns}$	-0.76**	-0.43**	-0.74**
PHT	**DS**							0.93**	-0.04$_{ns}$	0.43**	0.36**	0.40**
	WW							0.91**	-0.05$_{ns}$	0.68**	0.43**	0.61**
EHT	**DS**								-0.06$_{ns}$	0.55**	0.34**	0.47**
	WW								-0.08$_{ns}$	0.67**	0.46**	0.61**
EPP	**DS**									0.06$_{ns}$	0.04$_{ns}$	0.08$_{ns}$
	WW									-0.13$_{ns}$	-0.04$_{ns}$	-0.11$_{ns}$
Ear W	**DS**										0.13$_{ns}$	0.78**
	WW										0.43**	0.92**
100 GW	**DS**											0.10$_{ns}$
	WW											0.49**

DT 50% = Days 50% tasseling, DS 50% = Days 50% silking, ASI = Anthesis-silking interval, Leaf R = Leaf rolling, Leaf S = Leaf senescence, PAST = Plant aspect, PHT = Plant height, EHT = Ear height, EPP = Ears per plant, Ear W = Ear weight, 100 GW = hundred grain weight, GY = Grain yield per hectare, DS = Drought stress, WW = Well watered, Env = environment, ns = non-significant, * Significant at 0.05 and ** Highly significant at 0.01% probability level.

CHAPTER FIVE

5.0. DISCUSSION

5.1. Chemical physical and properties of soil used for the study

The result of the analyzed soil used in the screen house experiment showed that the soil is sandy loam (Table 1). The pH was 5.00, indicating an acidic condition. According to Landon (1991 and 2014) and Page (1982), the chemical properties of the soil used were low. The soil analysis results gave very low values for nitrogen (0.08%) and organic carbon (1.16%) compared to optimum values given by Landon (2014. Phosphorus (9.43 mg/kg) value was moderate (Page, 1982).

5.2. Temperatures (°C) and amount of water applied (liter)

The weekly minimum and maximum air temperatures average recorded ranged from 30.20 (last week of March) to 35.38 °C (last week of April). Fourth week of April was the week that highest temperature was recorded and that week coincided with the week that drought was started. Since plants subjected to drought condition were watered once per week, many of them were stressed and showed high level of leaf rolling and wilting. That value of temperature (35.38 °C) could have caused yield reductions if plants were allowed to grow to maturity. IITA (2009), reported that critical temperature detrimentally affecting maize yield is approximately 32 °C.

5.3. Analysis of variance of combining ability across growing environments

Highly significant ($p<0.01$) environment mean squares for all the traits in the current study was observed except days to 50% tasseling and ears per plant. Similar results were published from other studies; such as grain yield (Doerksen *et al*., 2003 and Laouali 2014), days to 50% silking (Zare *et al*., 2011), leaf senescence (Badu-Apraku *et al*., 2011), plant aspect (Laouali, 2014) and ASI, PHT, EHT, leaf rolling (Premlatha and Kalamani, 2010; Aminu and Izge, 2013; Aminu *et al*., 2014a and Murtadha *et al*., 2016). This indicated that these traits were highly influenced by environmental factors and there is adequate genetic variability among the inbred lines to allow good progress from selection for improvement in the traits (Badu-Apraku *et al*., 2011). The significance of the entry and GCA in DT 50%, DS 50%, PHT, EHT and GY indicated that there was possibility for the improvement of these traits through selection (Badu-Apraku *et al*., 2011).

Significant ($p<0.05$) and highly significant ($p<0.01$) GCA x environment, SCA x environment, reciprocal x environment and entry x environment mean squares for the following characters; DS 50%, ASI, PASP, ear weight and GY indicated that there is a significant variation in the combining ability of the inbred lines under different environmental conditions (Badu- Apraku *et al*., 2005, 2007 and 2011). This exhibited that the potential performance of the inbreds and the F1 hybrids was affected by the frequency and the amount of water applied to each condition. Thus testing inbred lines (parents) under different environmental conditions will ensure selection of stable parents that can perform to the potential of that environment (Machado *et al*. 2009 and Murtadha *et al*. 2016) or interested in the influence of environment in phenotypic expression of traits

(Bello and Olaoye 2009 and Murtadha *et al*. 2016). The highly significant difference ($p<0.01$) between entries and environments indicates appreciable variability between environments and within entries (inbred lines and hybrids). The test of inbred lines across different environmental conditions, is therefore important to ensure getting stable parents for hybridization. The lack of both SCA x environment and reciprocal x environment interaction effect for DT 50%, leaf senescence, PHT, EHT and EPP indicates that the hybrids could perform better in specific environmental conditions. This was supported by Badu-Apraku *et al*. (2011) who observed that the hybrids expressed the traits consistently in different environments.

Significant ($p<0.05$) and highly significant ($p<0.01$) GCA and SCA variances for only these traits, DT 50%, PHT and EHT showed that inbred lines and hybrids were highly different from each other within the trait and that variability was controlled by both additive and dominance gene action. The result supported findings of Chaudhary *et al*. (2000) and Abdel-Moneam *et al*. (2009) that variability in the breeding materials was attributable to additive and non-additive gene effects. The predominance of GCA mean square over SCA mean square indicates that additive genetic action was more important than non-additive genetic action. The results of seven traits corroborate the findings of Sharma *et al*. (2004), Aminu and Izge (2013) who found the predominance of additive genetic effects in maize traits control. However, these results are in disagreement with the findings of other researchers such as Abdel-Moneam *et al*. (2009), Machado *et al*. (2009), Aminu *et al*. (2014a and 2014b) and Murtadha *et al*. (2016) who reported the predominance of non-additive gene effects for DT 50%, DS 50%, ASI, leaf rolling, PHT, EHT and GY. For grain yield, results found in this study showed the predominance of SCA mean square over GCA mean square which indicates that non-additive genetic action was more important than additive genetic action. However, it contradicts finding of Ojo *et al*. (2007) who found the preponderance of additive genetic action for grain yield.

5.4. Mean performances of genotypes

The results showed decreases under water stress and well watered conditions in the reproductive traits (DT 50%, DS 50% and ASI) as well as leaf rolling, leaf senescence and plant aspect while increase in PHT, EHT, number of EPP, ear weight, 100 seed weight and GY. This confirms the findings of several earlier workers that drought can affect adversely maize growth and yield (Norman *et al*., 1995, ChenZong-Long 1996). Water stress affects maize growth at all periods of development, directly and indirectly (Ribaut *et al*., 1996). For all the genotypes, high yield was obtained from the well watered condition compared to drought stress condition. This finding was previously reported by Campos *et al*. (2006), Badu-Apraku *et al*. (2011), Shushay (2011), Obed (2015), Umar (2015) and Murthada *et al*. (2016). Looking at all data collected for all the studied characters over the environments, ASI and GY were the most affected and there is high relationship between them. Tweneboa (2000) reported that wilting for one-two days during tasseling stage can reduce yield by up to 28% and 6-8 days wilting period can cause a reduction of yield of about 50%, which cannot be made up by later irrigation or precipitation. Added to this relationship between yield and the reproductive traits, the results show the top ranking hybrids for grain yield per hectare under drought and well watered conditions out yielded the best check under drought and well watered conditions, respectively. The delay of 4-5 days of ASI could have resulted in the high yield observed in this study with the five top entries TZEI-13 x TZEI-25 (5.67 days), TZEI-124 x TZEI-23 (5 days), TZEI-23 x TZEI-17 (4 days), TZEI-13 x TZEI-23 (4 days), TZEI-25 x TZEI23 (4 days). The results are in line with finding of Obeng-Bio (2010) and Murthada *et al*.

(2016) who reported that long ASI may allow genotype to receive pollen from nearby late flowering lines. Besides, Grant *et al*. (1989) reported that a flower delay beyond 5 days may result in significant reduction. Results of TZEI-13 x TZEI-25 which was highest in grain yield per hectare with a flower delay of 5.67 days contradicted their findings. Also findings of Obeng-Bio (2010) contradicted their findings.

In terms of leaf rolling, TZEI-23 x TZEI-25 (3.33 and 1.00) and TZEI-124 x TZEI-23 (3.44 and 1.33) with less than 40% were identified as genotypes tolerant to drought. It implies that large leaf area was exposed for adequate solar radiation interception and hence relatively good photosynthetic capacity. This supported results of Prabhu and Shivaji (2000) who reported that the main effect of drought stress in the vegetative period is to reduce leaf growth and induce leaf rolling, so the crop intercepts less sunlight. For leaf senescence 10 hybrids scored ≤ 2% and the variability (from 1.11 to 8.78) in this trait observed among genotypes indicates the significance in identifying maize drought tolerant as reported by Lin (1978) and Baker (1986). The capacity of these entries to delay senescence is due to their efficiency in maintaining relatively high water status despite the low moisture level within the environment of plant as reported by Fisher and Sanchez (1979).

The difference in plant height observed between water stress and non-water stress was in accordance with the finding of Abo-El-Kher and Mekki (2007) who reported that PHT of single cross maize hybrid was affected when deficit water was applied at different growth stage and also Obed (2015) found the same result.

The extend yield reduction under drought stress condition could be due to the increase in the values of DT 50%, DS 50%, ASI, leaf senescence and decrease in the values of PHT and EHT.

High performance showed by hybrids in almost all the traits over their parents across the environments can be attributed not only to the effects of inbreeding depression in the parents for several generations but also by the favorable recombinant alleles that hybrid received from their parents during crossing, thus the high performance exhibited by the crosses. The F_1 hybrids that showed the mean values better than the best parent and the best check indicated the possibility of obtaining good hybrids that accumulated several and potential desirable characters. This result suggests to maize drought program, possible selection of hybrids with many important traits.

5.5. General combining ability effect of parents

The estimates of GCA effects of five parents used in this study revealed that none of the parents had good GCA for all the traits either under one or both environmental conditions, thus the exhibition of variation both in direction and magnitude. However comparing the parents with each other, TZEI-23 was the best general combiner for DT 50%, DS 50% under both conditions and ear weight and GY per hectare under drought. TZEI-23 had high significant negative GCA for DT 50%, DS 50%, PHT and EHT whereas TZEI-13 had highest ($p<0.01$) negative significant GCA for PHT and EHT. TZEI-13 was the best combiner for PHT and EHT under both conditions. This can rank TZEI-23 as the best combiner in breeding program for early maturity and TZEI-13 for resistance to drought. Besides inbred lines with high negative GCA effects for DT 50%, DS 50%, PHT and EHT are desirable for selection under drought environment as these parents could escape drought. Similar results were reported by Izge *et al*. (2007), Aminu and Izge (2013) and Aminu *et al*. (2014a).

Furthermore TZEI-23 and TZEI-25 were good donors for ear weight and grain yield while TZEI-124 was a good donor for 100 grain weight. This suggest that inbreds possess high frequency of favorable genes for selection for grain. Similar result has been reported by Haydar and Paul (2014). In addition, parents which showed good GCA for at least one trait can be as good donor parents for the accumulation of favorable genes. This result corroborated the findings of Khalil *et al*. (2010), Singh *et al*. (2012), and Haydar and Paul (2014). The worst general combiner for both reproductive traits and grain yield and its components was TZEI-17 which did not exhibit even one best performance in any trait either under drought or normal condition. The general best combiner was ranked as followed TZEI-23 > TZEI-25 > TZEI-124 > TZEI-13 > TZEI-17.

5.6. Estimates of specific combining ability effects of hybrids

The high estimates of specific combining ability grain yield per hectare for TZEI-17 x TZEI-25, TZEI-25 x TZEI-13 and TZEI-13 x TZEI-124 under water stress and well watered conditions suggest these hybrids as good combiners and their selection would lead to improvement in these characters. However hybrid TZEI-13 x TZEI-17 which showed higher negative SCA effects for GY indicates the unsuitability of both parents as good specific combiners for grain yield. This report supported the findings of Pswarayi and Vivek (2008) and Murtadha *et al*. (2016) who also observed differences in the expression of GCA and SCA with stress. Under both conditions, TZEI-17 x TZEI-25 was the most promising cross for improving grain yield per hectare followed by TZEI-13 x

TZEI-23 due to the highest positive SCA on one hand and high significant SCA on other hand for the following characters GY and ear weight. In addition, in this study, the highest SCA effects for GY were obtained from high x low and low x high combiners in the crosses TZEI-25 x TZEI-13 and TZIE-13 x TZEI-25 under drought condition. However low x high were observed in TZEI-13 X TZEI-124 and TZEI-17 x TZEI-124 under well watered condition. Results are in agreement with those obtained from Alam *et al*. (2008), Alam (2009), Singh *et al*. (2012) and Haydar and Paul (2014) who reported that the superiority of high x low or average x low could be explained on the basis of interaction between positive alleles from good/average combiners and negative alleles from the poor combiners as parents. The high yield of such hybrids would be non-fixable and thus could be exploited for heterosis breeding. Some of the hybrids were obtained from low x low general combiners as in the case of TZEI-17 x TZEI-13. This supported results of Premlatha and Kalamani (2010) and Aminu and Izge (2013). Hallauer and Miranda (1988) and Majid *et al*. (2010) reported that in low x low GCA combination, the superior cross could result from over dominance or epistasis. Such type of gene action may be exploited in cross-pollinated species like maize.

TZEI-23 x TZEI-124 was the best for both characters DT 50% and DS 50% under both environmental conditions. For ASI, highly negative and significant effect were recorded. Parents TZEI-124 comes out from the three crosses which indicated that this inbred was the best combiner for those traits, meanwhile it was one of the two worst parents. The performance of this hybrid can be explained by the fact that it was the cross from parents with high GCA. Therefore most of the superior hybrids were from either one of the parents with high general combining ability effect or parents that are low x low general combiners and suggests that the parents with either high GCA and or low SCA would have a higher chance of having excellent complementary genes with other parents that have high general combining ability. This supports results of Premlatha and Kalamani (2010) and Aminu and Izge (2013).

Even though, some few crosses showed negative and significant SCA effect under both environments in respect of plant and ear height, negative values of SCA in these traits mostly under drought are desirable as found in the studies of Aminu *et al*. (2014a) and Umar (2015) who reported that negative SCA effects in stress environments for plant and ear height are desirable especially in drought prone and windy areas against water stress and lodging.

5.7. Heritability in narrow and broad sense

Percentage of heritability in narrow sense greater than 50% were recorded for 4 traits under drought condition and 3 traits under well watered. This indicates that these traits were controlled by additive gene action. Only days to 50% tasseling under well watered condition exhibited 0.5 narrow sense heritability and this suggests that both additive and dominance gene action are important in influencing the expression of this trait. The relatively low narrow sense heritability recorded in almost all the traits in both environmental conditions were less than 0.5. This indicates that the expressions of the traits are mainly controlled by non-additive genes. Similar results were reported by Umar (2015) who said that the best exploitation of this type of gene action would be in F_1 hybrids implying that breeding gains can be made through selfing than cross breeding, with selection being made in later generation. Mhike *et al*. (2011) reported that heritability estimates for anthesis days, ASI, EHT and ear position were above 50% and for the other traits it was below 50%. In this study the heritability reported for grain yield per hectare was lower than that reported by Bolanos and Edmeades (1996) which was 40% under drought and 60% under well watered condition. However Falconer and Mackay (1996) reported that the magnitudes of heritability estimates are products of the traits being measured, the population being tested and the environments within which the testing is done. Therefore the variation observed in magnitudes here are the results of the differences in these three determinants (population, environment and trait) of the heritability estimates. It should therefore be understood that heritability values reported for a given character, are specific to a particular population under particular environmental condition (Hallauer and Miranda, 1981). Hence, it would be better to evaluate genotypes in different target environments.

All the results of heritability in broad sense showed high magnitude and this is in line with the results of studies of independent researchers such as Kashiani *et al*. (2008), Wannows *et al*. (2010), Olakojo and Olaoye (2011) and Umar (2015). This revealed that variations were transmitted to the progeny and implied the effective selection for genetic improvement of these characters. Hence provides better opportunities for selection of plant material regarding these traits. This is in line with the results of early workers; Kashiani *et al*. (2008), Wannows *et al*. (2010), Bello *et al*. (2012) and Aminu *et al*. (2014c). The broad sense heritability of DT 50%, DS 50%, ASI, leaf senescence, EHT, ear weight and GY per hectare increased as drought stress increased, whereas those for plant aspect and plant height decreased as drought increased. The broad sense heritability remains constant for ear height and hundred grain weight. Similar results have been found by Umar (2015) who reported that the broad sense heritability of ASI, leaf senescence, PHT, EHT, and EPP increased with increasing drought while those for DT 50%, DS 50% and GY decreased with increasing drought stress. Under water stress, the decreased heritability of traits indicates the need for selection of genotypes under particular environment for rapid genetic improvement. This agrees with the findings of Bolanos and Edmeades (1996) who reported decreased heritability under drought.

5.8. Heterosis

5.8.1. Better parent heterosis

The negative HPH observed in days to 50% tasseling and silking indicate that these hybrids are desirable candidates for earliness since it has been reported that maize crop is most susceptible at flowering under drought stress (Claassman and Shaw 1970 and Grant *et al*. 1989). Therefore hybrid that can tassel and produce silk early can take advantage in a drought environment due to the fact that it could escape drought. For ASI only, all the four crosses with line TZEI-25 as female exhibited the highest negative HPH under drought. High negative value for DT 50%, DS 50% and ASI are actually desirable and this can be explained as these hybrids could escape drought. This result is in line with the findings of Izge and Dugie (2011), Aminu *et al*. (2014c) and Umar (2015). The high level of HPH has also been recorded by Umar (2015) who reported that these crosses which featured prominently in the expression of higher level heterosis could form an initial gene pool for further breeding programme in developing high yielding varieties for cultivation in the Savannas.

Negative values for HPH for PHT and EHT are both desirable in breeding for drought tolerance. Therefore selection of hybrids showed that negative value is important as it implied that these hybrids could resist lodging confirming the results of Aminu *et al*. (2014c).

High positive HPH were obtained for grain yield per hectare, ear weight and hundred grain weight. Positive HPH is actually desirable in these traits. High heterotic values for grain yield have also been reported by Joshi *et al*. (2002), Ojo *et al*. (2007), Amanullah *et al*. (2011) and Aminu *et al*. (2014a). Therefore these hybrids could contain genes that could be introgressed to exploit heterosis for earliness and high grain yield. Similar results were reported by Kumar *et al*. (1998), Joshi *et al*. (1998), Bello and Olaoye (2009) and Aminu *et al*., (2014a).

5.8.2. Mid-parent heterosis

High level of heterosis was observed in this study, thus great potential to increase maize yield. High superior MPH for GY per hectare under both conditions were given by crosses made with TZEI-13 due to its low per se performance. TZEI-25 and TZEI-124 recorded high MPH in respect for grain yield per hectare due to its high per se performance. Under both conditions, for selection, the reliable criterion that should be taken is the performance per se in each combination across under specific growing condition. This could be applied to all traits. Thus, for most crosses the expression of MPH depended on genetic diversity between parents, parental per se performance and environmental conditions. Similar results were reported by many earlier independent workers (Jinks 1983, Miranda 1999 and Gezahegh 2005). Also lines with high yield under drought condition gave high hybrids under that condition. This confirmed that most of hybrids developed from drought tolerant lines performed well under water stress and well watered conditions. Betran *et al*. (1997) and Gezahegh (2005) have also reported similar results and there is the possibility to combine drought tolerance and yield potential in tropical maize hybrids (Betran *et al*., 2003).

From many crosses, negative MPH was observed for reproductive traits (DT 50% and DS 50%). This indicates early flowering stage of hybrids compared to their parents. The negative ASI observed in few hybrids either under drought or well watered condition showed shorter ASI than their parents. Negative MPH were also observed for EPP. Similar results were reported by Gezahegh (2005). In general, the MPH observed in reproductive traits, EPP and GY per hectare demonstrated the multiple advantages possessed by the hybrids across growing conditions. Thus the possibility to develop hybrids from drought tolerant parents especially for resource poor farmers in tropics who cannot afford to irrigate their farms.

5.9. Correlation coefficient between grain yield and other traits under water stress and well watered conditions

Drought tolerant genotypes are expected to suffer less yield reduction under water stress. They are expected to display better values mostly for secondary traits that are strongly correlated as reported by Bänziger *et al*. (2000) and Betràn *et al.* (2003).

Highly positive significant ($p<0.01$) correlation were detected between GY per hectare and PHT, EHT, and ear weight under both conditions. However ASI was correlated with GY under drought condition. In forecasting yield, breeders could focus on these characters which had significant positive correlation with grain yield under both conditions. Besides, whenever two characters are correlated with each other, selection for one would ensure increase in the other trait. Therefore, in this study, selection for the best of the traits that correlated with grain yield would result in increased grain yield. Manivannan (1998) and Vah (2013) also reported similar results in their studies on association between grain yield and other characters such as DT 50%, DS 50%, PHT and EHT.

Highly negative correlation was observed in this study for DS 50%, DT 50% and PAST under both conditions and for ASI under well watered condition. Breeders could therefore consider these traits in breeding for grain yield under water stress. Similar result was found by Laouali (2014) who reported highly negative correlation between grain yield and days to 50% anthesis, DS 50%, PHT and ASI under water stress and non-water stress conditions.

CHAPTER SIX

6.0. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The study revealed that both additive and non-additive gene actions were important in controlling GY and other characters in maize, and additive gene action was more important in controlling most of the traits. The best exploitation would be in F1 hybrids implying that breeding gains can be made through selfing than cross breeding.

The parents TZEI-23 and TZEI-25 were identified as the best general combiners, respectively under drought and well watered conditions. These parents could be more useful in hybridization programmes with those parents with low combining abilities. Best combiners did not always produce best hybrid combination, therefore, the complexity in predicting the productivity level of hybrids should require testing of specific parent combinations. TZEI-13 being one the lowest general combiners, performed best when crossed with parent with high GCA.

Almost all the traits studied exhibited high h^2_b while h^2_n was high, medium and low. High value of heritability indicates considerable potential for development of drought tolerance and high yielding varieties through selection of desirable traits in succeeding generations. The decrease broad sense heritability of GY per hectare and flowering traits under water stress suggests to breeders the need to select genotypes under specific environmental conditions for better results.

Finally, the following hybrids were the best among the twenty hybrids evaluated since they have high parent heterosis, TZEI-13 x TZEI-25 in GY, ear weight, PAST, leaf senescence, DT 50% and DS 50%, and TZEI-124 x TZEI-13 in GY, ear weight, PHT, EHT, PAST, DT 50% and DS 50%. Desirable heterotic levels in ASI, DT 50%, DS 50% and PHT are of tremendous advantage in areas with marginal rainfall.

6.2. Recommendations

Based on the above results, it is recommended that:

TZEI-13 x TZEI-25 and TZEI-124 x TZEI-23, the best hybrids under drought condition are recommended for further trial and release to farmers to increase productivity under drought condition;

TZEI-124 x TZEI-13 and TZEI-124 x TZEI-17, the best hybrids under well watered condition are also recommended for further trial and release to farmers to increase productivity under well watered condition;

It is recommended that the study be repeated by including large number of genotypes to increase genetic variation.

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APPENDICES

Appendix 1: List of genetic materials used in the study

Parents		Hybrids		Checks	
Entry	**Name**	**Entry**	**Name**	**Entry**	**Name**
Entry 1	TZEI-13	Entry 6	TZEI-13 X TZEI-17	Entry 26	MAMABA
Entry 2	TZEI-17	Entry 7	TZEI-13 X TZEI-23	Entry 27	OMANKWA
Entry 3	TZEI-23	Entry 8	TZEI-13 X TZEI-25		
Entry 4	TZEI-25	Entry 9	TZEI-13 X TZEI-124		
Entry 5	TZEI-124	Entry 10	TZEI-17 X TZEI-13		
		Entry 11	TZEI-17 X TZEI-23		
		Entry 12	TZEI-17 X TZEI-25		
		Entry 13	TZEI-17 X TZEI-124		
		Entry 14	TZEI-23 X TZEI-13		
		Entry 15	TZEI-23 X TZEI-17		
		Entry 16	TZEI-23 X TZEI-25		
		Entry 17	TZEI-23 X TZEI-124		
		Entry 18	TZEI-25 X TZEI-13		
		Entry 19	TZEI-25 X TZEI-17		
		Entry 20	TZEI-25 X TZEI-23		
		Entry 21	TZEI-25 X TZEI-124		
		Entry 22	TZEI-124 X TZEI-13		
		Entry 23	TZEI-124 X TZEI-17		
		Entry 24	TZEI-124 X TZEI-23		
		Entry 25	TZEI-124 X TZEI-25		

Appendix 2: Volume of water applied

In the rain forest agro-ecological zone in Ghana, the main annual rain is 2200 mm and the minimum rainy days are 150 during the major season. Therefore the moisture availability for maize [volume of water (cm^3) to apply] per day and per plant was calculated as follows:

Available moisture water = $\frac{2200\ mm}{150\ days}$ =14.666 mm/day = 1.466 cm/day

Depth of water (ϴz) 1.466 cm = volumetric water content (ϴv) x depth of soil

Depth of water (ϴz) 1.466 cm = $\frac{Volume\ of\ water\ X\ Depth\ of\ soil}{Volume\ of\ soil\ (volume\ of\ container)}$

Volume of water per day = $\frac{Depth\ of\ water\ (Oz)\ X\ volume\ of\ soil\ (volume\ of\ container)}{Depth\ of\ soil\ (depth\ of\ container)}$

But depth of water (ϴz) = 1.466 cm and depth of soil (depth of container) = 36 cm

Volume of soil = volume of container = 18 liters

Therefore, volume of water per day = $\frac{1.466\ cm\ x 18000\ cm3}{36\ cm}$ = 733 cm^3

To saturate the air dried soil to field capacity, a 7 days volume of water was considered. Thus, Volume of water applied initially = 733 cm^3 x 7 = 5131 cm^3

Before planting, a volume of 5 liters ≈ 5131 cm^3 was applied to the soil in each pot which filled with 18 kg of top soil.