EVALUATION OF GENOTYPE BY ENVIRONMENT INTERACTION AND YIELD STABILITY OF EARLY MATURING MAIZE SINGLE CROSS HYBRIDS AT THREE LOCATIONS IN SOUTHERN GHANA

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MASTER OF SCIENCE DEGREE IN

AGRONOMY (PLANT BREEDING)

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DECLARATION

I hereby declare that, this work is the result of my own original research and that this thesis has neither in whole nor part been presented anywhere for a degree except for the references cited in relation to other works.

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DEDICATION

This work is dedicated to my mother, Mahawa Korhene, for all her struggle and labour in bringing me up to this level. I also dedicate it to my wife Angeline K. Ndebeh and my children Alex Ndebeh and Josephus Ndebeh.

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ABSTRACT

Multi-environment yield trial is essential in estimating genotype by environment interaction and identification of superior hybrids. Genotype by environment interaction effect on maize grain yield is usually significant due to large variation in soil and weather conditions at growing sites. The objective of the study was to evaluate 90 early maturing single cross maize hybrids and to identify stable and high-yielding hybrids with superior agronomic performance, to use GGE biplot to determine grain yield stability and the pattern of response of genotypes across three environments and to identify high yielding inbred lines that could be used as parental lines in hybrid development programmes in Ghana. The study materials comprised of 90 early maturing single cross hybrids tested across three environments, Fumesua, Ejura and Kpeve; representing the Forest, Forest-Savannahh Transition and Coastal-Savannahh Transition zones of Ghana, respectively. The experiment was laid out in a Randomized Complete Block Design with two replications at each of the sites. The Analysis of variance for grain yield demonstrated that genotypic and environmental mean squares effects were highly significant ($P<0.01$) while their interaction was only significant ($P<0.05$). The genotypes contributed 2.5 % of total variance while environment contributed 96 % of the total variance and their interaction contributed 0.95%. The genotype main effect plus genotype × environment interaction biplot explained 94.9% of total variation of G+ GE. The GGE biplot procedure provided results in terms of stability and performance of the hybrids and the discriminating environments. TZEI-36 X TZEI-39, TZEI-2 X TZEI-22, TZEI-11 X TZEI-15, TZEI-41 X TZEI-30, and TZEI-48 X TZEI-20 were identified as high yielding and stable genotypes while TZEI-45 X TZEI-47, TZEI-46 X TZEI-47, and TZEI-32 X TZEI-5, were very stable but low yielding. On the other hand, TZEI-22 X TZEI-45, TZEI-34 X TZEI-7, TZEI-10 X TZEI-11, TZEI-33 X TZEI-19, TZEI-48 X TZEI-20 TZEI-12 X TZEI-15, TZEI-45 X TZEI-34, TZEI-35 X TZEI-19, TZEI-25 X TZEI-23, TZEI-2 X TZEI-22, TZEI-22 X TZEI-48 and TZEI-34 X TZEI-46 were high yielding but not stable. The GGE biplot analysis identified Fumesua and Kpeve, located in the Forest and Coastal-Savannahh Transition zones as the most ideal environment for selecting high yielding genotypes. The correlation analysis revealed that grain yield was significantly and positively correlated with plant height (r = 0.633), cob length (r =.610) ear height (r = 0.410), and cob diameter (r = 0.443) and negatively correlated with anthesis-silking interval. However, grain yield did not correlate with days to silking. It was therefore recommended that the trial be repeated in several environments and years in order to effectively assess their yield potentials, the high and non stable yielding genotypes be tested extensively on farm and recommended for specific locations and that the high and stable yielding hybrids identified be further tested extensively on-farm and officially released for commercial production in Ghana.

TABLE OF CONTENT

TITLE PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AEC	Average Environment Coordinate
ANOVA	Analysis of Variance
ASI	Anthesis-silking-interval
CD	Cob Diameter
CFIA	Canadian Food Inspection Agency
CIMMYT	International Maize and Wheat Improvement Center
CL	Cob Length
Cm	Centimeter
CRI	Crop Research Institute
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of Variation
DF	Degrees of Freedom
DS	Days to Silking
DT	Days to Tasseling
EHT	Ear Height
et al.	And Others
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agricultural Organization Statistics
G x EI	Genotype by Environment Interaction
GGE	Genotype main effect plus Genotype by Environment Interaction
Ha	Hectare
IITA	International Institute of Tropical Agriculture
Kg	Kilogram
KNUST	Kwame Nkrumah University of Science and Technology
Lsd	Least Significant Difference
M	meter

MET	Multi Environment Trial
MiDA	Millennium Development Authority
MS	Mean Square
OPV	Open Pollinated Variety
PC	Principal Component
PCA	Principal Component Analysis
PHT	Plant Height
RCBD	Randomized Complete Block Design
SD	Seed diameter
SL	Seed length
SREG	Site Regression
SS	Sum of Square
SV	Singular Value Partitioning
T	Tons
WCA	West and Central Africa

CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.) is the most widely grown cereal in the world (Obeng-Bio, 2010). It is the third most important and highest industrial valued cereal after wheat and rice and serves as a primary staple food in most developing countries (Khalil *et al.,* 2011, Badu-Apraku *et al.*, 2010, Malik *et al.*, 2005).

It can be grown from latitude 58^{o}N to 40^{o}S, below sea level and at altitude higher than 3000 meters and in areas with rain-fall of about 250mm to 5000mm per annum and with growing season ranging from three months to about 13 months (Golam *et al.,* 2011, Dowswell *et al.,* 1996). It has a multiplication ratio of about 1:400 - 500 per plant bases under normal conditions making it the most productive crop among the cereals. The kernel contains excellent quality edible oil, carbohydrate, starch, protein, minerals and vitamin A (Amaregouda, 2007).

In most developing countries, about 77 percent of maize is used as food for humans. But in industrialized countries, about 70 per cent of this crop is used as cattle feed either in the form of fodder, grazing and forage; only three percent is used as food for human while the remainder is used for biofuel, industrial products and seed (Smale *et al.,* 2011).

Its high yield potential, wide adaptability, relative ease of cultivation, processing, storage and transportation has increased the potential of the crop for combating food security challenges posed by population increase in West and Central Africa (Badu-Apraku *et al.,* 2010).

The production and use of this crop has drawn the attention of not only the researchers, but it is growing worldwide pressure with the view that solution to low grain yield can be addressed through the use of early maturing hybrids that can produce high yield and desirable characters and are adapted to wide range of environments (Kim 1994).

The availability of early maturing cultivars in Ghana has significantly contributed to the rapid spread of maize into the Savannahs replacing the traditional crops such as millet and Sorghum in places where low rainfall had long prevented maize production (Badu-Apraku *et al*., 2010). These earlier maturing cultivars can be harvested much earlier in the season than the traditional crops and even give farmers the opportunity to sell their crops when prices are higher. These early maturing maize can even be intercropped with different crops like cassava and cowpea because they compete less for moisture (Vivek *et al*., 2009). Because of the delay in the onset of rain, the demand for these early maturing varieties continues to increase. This has given the wide believed that the fight against hunger could be achieved through the use of early maturing hybrid maize varieties (IITA, 1992). Thus early maturing maize cultivars will improve maize productivity and enhance food security in Ghana since agricultural production is at risk due to the unpredictability of global warming and its effect on climate change.

In the sub-region, most breeding programmes have taken different approaches, and are focused towards developing early maturing maize hybrids (varieties that flower between 55 to 60 days, and reach physiological maturity at 90-95 days after emergence) (Vivek *et al.*, 2009). This can be done if breeders properly understand the environmental factors that can affect the yield of these hybrids by assessing their yield potential in a wide range of environments (Sallah *et al.*, 2004).

However, the search for genotypes with high grain yield stability and adaptation to diverse environments is not easy. Varying environmental conditions and the expansion of maize production to new agro-ecologies requires that hybrids be selected for specific environments. Hence, the overall objective of the study was to evaluate 90 early maturing single cross maize hybrids and to identify stable and high-yielding hybrids with superior agronomic performance in Southern Ghana.

Specific objectives:

i) To use GGE biplot to determine grain yield stability and the pattern of response of genotypes across three environments.

ii) To identify high yielding inbred lines that could be used as parental lines in hybrid development programmes.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The origin of maize

Maize **(***Zea mays L***)** belongs to the grass family Poaceae (Gramineae), tribe Maydeae. According to McCann (2005), maize derived from a single parent (teosinte) which was cultivated in central Mexico 7000 years ago. It is strongly believed that maize originated from the highland of Peru, Ecuador, and Bolivia and the region of Southern Mexico and Central America where many types of maize have been found in all of these areas even though the exact date of first cultivation still remains a mystery (McCann, 2005).

2.2 The maize Crop

Maize is a tall, annual grass with both male and female organs on the same plant with overlapping sheaths and broad in a prominent way with double blades (CFIA, 1994). The height of the stem may vary from less than 0.6 m in some genotypes to more than 5.0 m in other varieties (Acquaah, 2007). Usually, early maturing varieties are shorter, and late maturing ones are taller. In areas where the growing season may be as long as 11 months, some late maturing varieties reach a height of 7 meters depending on the variety and growing condition of the genotype (Zsubori *et al.*, 2002). The stem is divided into nodes and internodes (Acquaah, 2007). The ear is enclosed in numerous large foliage bracts and a mass of long styles (silks) protrude from the tip as a mass of silky threads (CFIA, 1994). Pollen is produced entirely in the staminate flower and eggs are produced in the pistillate flower. It is mostly wind pollinated but both self and cross pollination is usually possible. Shed pollen usually remains viable for 10 to 30 minutes, but can remain viable for longer durations under favorable conditions (Borras *et al.,* 2007 Acquaah, 2007).

Maize is a protandrous plant (the male spikelets usually mature before the female spikelets). Pollen shed precedes silk emergence by about 1–3 days. Silks are receptive soon after emergence and remain receptive for up to about 10 days. For a breeder to have better results, the emerged silk should be pollinated within 3–5 days after first silk emergence. Fertilization usually occurs within 12–24 hours of pollination (Acquaah, 2007).

2.3 Maize distribution, production and uses

According to (FAOSTAT, 2008), maize is grown on global scale on 144 million hectare and has an annual production of about 700 million metric tons. It has a remarkable productive potential among the cereals, is the third important grain crop after wheat and rice and accounts for 4.8% of the total cropped area and 3.5% of the value of the agricultural output (Ochse *et al.*, 1996). Maize currently covers 25 million hectare in Sub-Saharan Africa, largely in smallholder systems that produced 38 million tons in 2005-2008, primarily for food (Smale *et al.,* 2011). From 2005-2008, maize represented an average of 27 percent of cereal area, 34 percent of cereal production and 8 percent of the value of all primary crop production (Smale *et al.*, 2011). Among the developing countries, it ranks first in Latin America and Africa (Dowswell *et al*., 1996). In the tropics, it is grown in about 66 countries and is of major economic significance in 61 of those countries (Paliwal, 2000).

According to Gama and Hallauer (1980), the development of maize hybrids which are high yielding and relatively stable when grown in different environments is of fundamental importance to commercial maize production.

In Ghana, maize is the highest ranking cereal in terms of production and consumption followed by rice (Twumasi-Afriyie *et al*., 1992). The domestic demand for this crop is growing because it serves as a major source of daily calories and dietary protein for most people who are under privileged, since poverty makes it difficult for such people to afford meat (Tengan, 2010; MiDA, 2006). According to a MOFA (2006) report, maize accounted for 50-60% of total production area of cereals with average yield approximately at 1.6 metric tons per hectare, but yields as high as 4.5- 5.0 metric tons per hectare can be realized by farmers using improved seeds and good management practices.

2.4 Hybrid Maize Development

Since the 1930s, hybrid maize varieties have caused a significant impact on crop yields for farmers on every continent (Pioneer, 2010). Hybrids are the offspring of a cross between two different parents. Commercial maize hybrids are produced by crossing two genetically pure parent lines, called “inbreds.” The goal of maize breeding is to develop hybrids with high yield potential, stable and has specific traits to suit the local environment, such as disease and drought tolerance. Maize farmers prefer hybrids even though their cost is high, but they are stronger and perform better across different environments than their parents. This improved performance of hybrids over their parents is called heterosis or hybrid vigor (Pioneer, 2010).

Before the introduction of hybrids in the 1930s, there was almost no increase in the open pollinated varieties (OPVs) era (Crow, 1998). But with the introduction of single cross hybrids, not only did yield increase, but the rate of increase improved. Breeders used closely related strains to produce the single crosses (Crow, 1998).

In 1979 Ghana maize breeding programme was given a boost as the result of the collaboration between CIDA and Gnana Grain Development Project (GGDP) although it was concentrated around developing open pollinated maize varieties (Sallah, 1986). This initiative led to the development and release of an open pollinated variety called Obatanpa, which is widely adopted in Ghana and elsewhere in Africa (Twumasi-Afriyie *et al.*, 1992). Alongside the development of Obatanpa, a QPM hybrid maize development programme was initiated in 1991. Three-way QPM hybrids, namely, GHllO-5 (Mamaba), GH132-28 (Dadaba), -and GH2328-88 (CIDA-ba*)* developed in this programme has been very productive, yielding between 6.3 and 7.3 tons ha^{-1} on experimental station (Tengan, 2010). Some of these varieties, noted for earliness developed by CIMMYT, IITA and CRI in 2007 were released to boost maize production but has began showing deficiencies in some important traits such as lodging and disease susceptibility in response to numerous demands by consumers and industries (Boakyewaa, 1012). It is therefore appropriate to breed for hybrids that are high yielding and tolerant to biotic and abiotic stress to boost the food production.

For the past years more attention has been given to developing intermediate to late maturing maize varieties as comparable to early maturing maize varieties in Ghana due to their supposed high grain yields. Unfortunitely due to the changes in climate, maize productions continue to be exposed to drought and nitrogen stress. Early maturing hybrids that are tolerant to drought and low-N could be suitable for the stabilization of yields in Ghana to ensure food security (Badu-Apraku *et al*., 2011). In the future, the release and commercial production of early maturing hybrid maize will be more appropriate to maintain food security and improve the livelihood of small-holder farmers in Ghana in the face of the current global climatic change.

2.5 The Importance of Early Maturing Maize hybrids

The availability of early maturing maize hybrids has significantly contributed to the rapid increase and spread of maize in WCA, where the short duration of rainfall had long caused stress to maize production (Boakyewaa, 2012). The use of outdated open pollinated varieties is a major factor responsible for low grain yield of maize in the sub-region. Chavez *et al.* (2005) reported that single cross hybrids are more productive than double crosses and OPVs. Keeping in mind the low socio-economic status of the farming community in WCA, the use of single cross hybrids will be much better rather than use of low yielding open pollinated varieties which has been the cause of low seed yield.

According to Badu-Apraku *et al.* (1995), the annual maize yield loss from drought stress in developing countries is estimated at 15% of total production and losses may even go much higher in areas where the annual rainfall is below 500 mm and soils are sandy or shallow especially for unadapted varieties.

The release of improved early maturing maize varieties will create assurance for increased maize productivity in the sub-region. These could not only be achieved by promoting the rate of adoption of improved maize cultivars by farmers, but also provide farmers opportunities to overcome the challenges to maize production, thereby improving food security in the WCA (Bello *et al*., 2012).

Intermediate to late maturing maize varieties in the tropics are continually exposed to drought and nitrogen stress. This may be partly attributed to global climatic changes or due to displacement of maize to more complex production environments by high value crops, and partly due to declining soil organic matter thereby reducing soil fertility and water holding capacity (Banziger and Cooper, 2001). Early maize hybrids are usually planted at the beginning of the rainy season and get fully established and matured sooner before the traditional crops. Since the timing of mid-season drought is unpredictable, early maize cultivars that can tolerate the effects of reduced moisture supply during flowering could reduce farmers' risk in drought affected environments (Hussain *et al*., 2011).

In some countries in WCA, most farmers prefer to grow early maturing maize hybrids because they do well during off-season planting, they provide an early harvest, thereby helping to minimize the hunger gap before the main harvest of full season crops especially where there are two growing seasons(Pswarayi and Vivek, 2008). Early maturing maize also enable multiple planting dates over an extended period of time as a measure to cope with the uncertainty of the rainfall patterns, for example mid season droughts. They also provide flexibility with planting dates which enable farmers to plant their crops later in the planting season and they are ideal for intercropping because they provide less competition for moisture, light, and nutrients than late maturing varieties (CIMMYT, 2000)

2.6 Genotype by environment interaction in maize

The relative performance of genotype(s) across environments has raised important and challenging issue among plant breeders, geneticists and agronomists (Babic *et al.*, 2008). The presence of genotype by environment interaction should be of great concern to plant breeders because, large interaction can reduce yield and even make the selection of superior cultivars difficult (Rasul *et al.*, 2005). Obeng-Antwi *et al.*, (2011) observed significant Genotype by Environment interaction in a varietal trial in different agro-ecologies of Ghana. They noted that the presence of G x E interaction in the evaluations complicated not only the selection of superior cultivars but also the best site that could be used to identify superior and stable genotypes.

Arusleivi and Selvi (2010) reported that the yield performances of 72 maize genotypes were mainly influenced by G x E interaction. Islam *et al.* (2008) evaluated different genotypes of maize in different environments and observed that one variety called “Sarhad white” showed great phenotypic stability and was less sensitive to changes in environment. G x E interaction causes variation in yield across environments (Basford and Cooper, 1998).

Environmental factors can greatly affect quantitative traits than qualitative traits, as a result of which performance tests of potential cultivars are conducted in multiple locations (Bernardo, 2002). The main effect of Genotype and environment and the performance of cultivars are influenced by the interaction between the genotype and the environment, which is the differential response of cultivars to environmental changes (Crossa *et al.*, 1990; Vargas *et al*., 1999).

According to Yan (2002), environment explains about 80% or higher of the total yield variation, but it is only Genotype and the interaction that are relevant to cultivar evaluation. Various abiotic, such as temperature, seasonal rainfall, season length, within-season drought, sub-soil pH and socio-economic factors that result in low input application and biotic stresses such as diseases, insect pests and weeds have been the cause of G x E interaction (Banziger *et al*., 2004). Maize is grown in diverse environments and is consumed by people with different food preferences and socio-economic backgrounds (Badu-Apraku *et al.*, 2011, 2006). To meet these demands, maize breeders must work in partnership with national maize programs to develop varieties that are adapted to the different agro-ecological zones and farming systems (Beyene *et al.*, 2011).

According to Badu-Apraku *et al.* (2011), national maize research programs of WCA sometimes are not able to conduct cultivar evaluation in many locations owing to limited resources which sometimes lead to poor results. It is therefore, important to properly examine the environments for uniqueness and for information that would enable the selection and ranking of genotypes. This could enable the grouping of environments and identification of main locations where testing of cultivars can be carried out without losing much information about the genotypes. Furthermore, grouping of maize evaluation sites into mega environments can reduce the environmental influence on the trait, speed up the rate of gain from selection, strengthen the effort for seed production and maximize grain yields for farmers (Gauch and Zobel, 1997).

In the selection of broadly adapted hybrids, Genotype x Environment (G x E) interaction has become one of the main complications encountered by most breeding programs. Therefore, it is important that a breeder should have a proper understanding of the environmental and genetic factors causing the interaction and he should assess their importance in the applicable G x E system (Magari and Kang, 1993).

When G x E is present, one of the best things that a breeder can do is to use stability analyses to identify the most high and stable yielding cultivars (Beyene *et al.*, 2012). The sites regression (SREG) by Crossa and Cornelius (1997) has been suggested as the appropriate model for analyzing multi-environment trials when large yield variation is due to different environments (Yan, 2001). The SREG method uses a graphical display known as the 'genotype plus genotype by environment interaction (GGE) biplot' which identifies cultivars which are superior in different environments (Beyene *et al*., 2012). Thus, the estimation of stability of performance becomes important to identify consistent and high yielding genotypes

Kang and Gorman (1989) reported that hybrid maize cultivars evaluated in their study were more affected by differential fertility or cultural practices than by the weather factors. Sallah *et al.* (2004) reported that G x Y x L was highly significant in three maturity groups of maize tested in several locations. They noted that genotypes within early maturity group responded differently to different locations and that location by year combination was necessary to identify high and stable yielding varieties. Again, Carena *et al*. (2009) used MET and multi- stage trial in the identification of susceptible maize genotypes in their evaluation for drought tolerance in Northern Dakota.

2.7 Importance of Genotype by Environment Interaction

Understanding of environmental and genotypic causes and their interaction is important at all stages of plant breeding, including ideo-type design, parent selection, selection based on traits, and selection based on yield (Jackson *et al.*, 1998). It can be used to establish breeding objectives, identify ideal test conditions, and recommend environments for optimal cultivar adaptation (Yan and Hunt, 2001).

Newly developed maize cultivar(s) need to be tested in many locations so that their performance and adaptability can be determined before commercial release (Beyene *et al*., 2012). Meanwhile, genotypes that are unstable will respond to environmental factors such as temperature, soil moisture, and soil type or fertility level from location to location as a result of genotype by environment interaction (G x E) (Tyagi and Khan, 2009, Beyene *et al*., 2011). Unstable genotypes may produce outstanding yield in some environment and perform poorly when grown in other environments and this creates difficulties for a breeder to recommend a particular genotype. Nachit *et al*. (1992) observed that large G x E variation impairs the accuracy of yield estimation and reduces the relationship between genotypic and phenotypic values. Evaluation of genotypic performances of hybrid maize cultivars in a number of environments provides useful information to identify their adaptation and yield stability (Crossa, 1990; Tonk *et al.*, 2010). MET plays an important role in selecting the best cultivars to be used in future years at different locations and in assessing a cultivar's stability across environments before its commercial release. Grain yield is one of the most important traits to consider when the performance of cultivars is compared across environments (Vargas *et al*., 1999). According to Kang *et al*. (1991), selection based on yield only may not always be adequate when genotype by environment interaction is significant. Therefore, the use of a rank-sum method should be used as an alternative when testing is done in diverse environments.

Evaluation of hybrids across a wide range of environments can help breeders establish effective breeding objectives, identify ideal test conditions, and formulate recommendations for areas of optimal cultivar adaptation if they properly understand the causes of the interaction. It can also help to reduce the cost of broad genotype evaluation by eliminating unnecessary testing sites. The presence of a large G x E may require the establishment of additional testing sites, thus increasing the cost of developing commercially important varieties (Kang *et al* 1991).

2.8: Stability analysis

Most breeders focus on developing high yielding and stable cultivars in their breeding programs. An understanding of the environmental and agronomic responses of maize hybrids is fundamental to improving efficiency of maize production (Grada and Ciulca, 2012). Stability refers to the ability of a genotype to perform consistently, whether at high or low yield levels across a wide range of environments (Zivanovic *et al.*, 2004; Kandus *et al*., 2010). A hybrid is regarded as stable if its yield performance is high; regression coefficient is about 1 and a small deviation as much as possible (Zivanovic *et al.*, 2004). Stability measurements gives an indication of the ability of a genotype to maintain a relatively constant yield independent of changing environmental conditions (Odewale *et al*., 2012). The performance of a hybrid provides important information on the adaptation and yield stability within those environments in which they are grown and evaluated (Kang *et al*., 1991).

According to Becker and Leon (1988), stable genotype(s) will not change in performance in spite of differences in the prevailing environmental conditions. Its response to environments must be equal to the overall response of all genotypes in the experiment, it should have no deviations from the general response to environments and its residual mean square of regression to ecological index must be small. In this case, Finlay and Wilkinson (1963) reported that a stable genotype has no deviations from the general response to environments and it creates a possible way of predicting the response of a genotype to a certain environment.

2.8.1 Genotypic Stability

The term "genotypic stability" is fundamental to all types of analyses of G x E interactions especially with reference to plant breeding. Stability in common usage refers to the consistency in performance of a particular genotype which entails minimum variation among environments (Chahal and Gosal, 2002). The level of yield depends on genetic yield potential and that stability of yield or of any other trait depends on the ability of a given cultivar to react to changes in the environment which is also referred to as phenotypic plasticity (Zivanovic *et al*., 2004).

Tyagi and Khan (2009) reported that soybean genotypes identified were stable with respect to broad environments and specific environment despite the diversities of the environmental conditions. Obeng-Antwi *et al*. (2011) also reported that five single cross hybrids out of thirty three (33) varieties tested on-station were recommended for on-farm trial for further evaluation because of their consistency in performance across two seasons in different agro-ecologies in Ghana.

High yield stability refers to the ability of a genotype to perform consistently across a range of environments with high performance. A good maize hybrid should have a high mean yield combined with a low degree of variation under different environments (Grada and Ciulca, 2012). Many stability statistics have been used to determine whether or not cultivars evaluated in MET are stable, the reason being that most stable genotype(s) may not be the highest yielding thus the use of methods that integrate yield performance and stability to select superior genotypes becomes important (Kang and Magari, 1996; Hussain *et al*., 2011).

Issa (2009) described two basic concepts of phenotypic stability namely, the biological concept and dynamic concept. He related the biological concept of stability to the constant performance of a genotype over a wide range of environments and the dynamic stability, also known as agronomical concept of stability implies that a stable genotype should always give high yield at the level of productivity of the respective environments

In Biological stability, genotype(s) will not change in performance regardless of changes in environmental conditions, thus implying that differences among environments is zero and that stable genotype(s) should show minimal variance in different environments (Becker and Leon, 1988; Dabholkar, 1999).

2.9 Adaptation of Genotype

Adaptability of a given cultivar or hybrid is defined as inherent genetic ability of a cultivar to be stable and high yielding in various environments (Zivanovic *et al*., 2004). Living organisms are capable of adjusting to the normal functions of their environment, which enable them to cope with situations within their surroundings. Moreover, adaptability refers to the manner in which an organism adjusts to its environment. For example, certain genotypes may produce high yields under certain environmental conditions but poor yields in others conditions (Balzarini *et al*., 2005).

Maize yield is gradually increasing in the sub-region due to the ability of educated farmers or seed growers to adapt hybrid seed during planting seasons, but the hybrid seeds so far available is mostly imported and marketed by some multinational companies. Badu-Apraku *et al*. (2010) reported that there are limited commercial early maturing hybrids in the sub-region despite the abundance of high yielding inbred lines in the IITA breeding programs. So it is essential and urgent to take appropriate measures to improve the domestic grain yield potential of commercially grown varieties through the use of high yielding and early maturing maize hybrids.

Hussain (2011), reported that in order to improve the adaptation of new hybrids, it is important to test varieties across a wide range of environments as hybrids have limited adaptation. They concluded that both the hybrids YH-1978 and YH-1979 had wider adaptability in both spring and autumn. This was also buttressed by Badu-Apraku *et al.* (2010) that environments can differently affect the performances of hybrids especially in WCA where limited and erratic rainfall and deficient soil nutrient interact to create contrasting growing environments. Simmonds (1962) cited in Zivanovic *et al.* (2004) reported that a genotype has specific adaptation if it is able to adapt to a confined environment or it is generally adapted if it has the ability to produce high yield under a wide range of environments. This is true for a limited range of environments (Ramagosa *et al*., 1993).

It is more important to introduce stable and adaptable single cross hybrids of early maturity which are highly productive in high density than to improve maize yield.

This is possible by testing a large number of single-crosses in a number of locations, paying attention to genetic improvement of hybrids and combining abilities.

2.10 Correlations among Parameters

Correlation analysis is a technique which helps to explain the degree of relationship among quantitative traits of a given genotype (Malik *et al.,* 2005). The main goal of any maize breeding program is to obtain new cultivar that will outperform the existing cultivar with respect to a number of traits. Grain yield is a complex quantitative trait that depends on a number of environmental and genetic factors (Bocanski *et al*., 2009). Because of this during selection for grain yield, it is important to confirm relationship between traits that contribute to improved grain yield (Dudley and Moll, 1969, Hallauer and Miranda., 1988).

Grain yield is positively correlated with days to silking and tasseling, plant and ear heights, and cob length and diameter (Malik *et al*., 2005; Ahmad, 1997). Rather *et al.* (1999) reported that association of plant height with grain yield was not significant. According to Nemati *et al*. (2009), traits such as number of rows per cob, 1000 grain weight, and cob diameter and plant height are useful in improving grain yield in hybrids. Maize is a heterogeneous crop, therefore, grain yield cannot be directly improved through selecting desirable plants but selection for agronomic traits will certainly boost grain yield (Malik *et al.,* 2005). Significant traits influencing grain yield are number of grains per row and number of grains per cob, cob length and diameter, 1000-grain weight, plant height and ear height (Orlyan *et al*., 1999).

With increased industrial demands for maize, it is essential to increase maize production at a much faster rate than the present. Genotypes that have desirable traits are major contributing factors in grain yield per unit area. In order to develop promising genotypes, it is essential to know the associations among these different traits, especially with grain yield, which is the most important and ultimate objective in any breeding programme. Plant and ear height have been described to be important selection criteria for grain yield by many researchers (Esechie *et al*., 2004). Golam *et al.* (2011) reported that they did not find correlations between grain yield and days to 50% tasseling, days to 50% silking, ear plant^{-1} and thousand grain weights. Malik *et al*. (2005) reported that grain yield was highly correlated with plant height, ear height, cob diameter, kernel number per row and cob length but observed negative and significant correlation between ear height and days to 50% tasseling and days to 50% silking.

2.11 Genes and Environment

A breeder can determine the outcome of an organism based on the interaction between genes and environment (Suzuki *et al*., 1981). Genotype describes the complete set of genes that is inherited by an individual and is important for the expression of a trait under investigation, while phenotype describes all aspects of the individual's morphology, physiology and ecological relationships. The genotype is in actual fact a fixed character of the organism; it remains constant throughout life and is not affected by environmental effects. On the other hand, the phenotype changes continually and the direction of that change is the function of the effects of environments that the individual experiences (Suzuki *et al*., 1981).

The sum total of the effects of physical, chemical and biological factors of an individual other than its genotype is known as the environment (Issa, 2009). The populations of plants do not live in a vacuum but are surrounded and influenced by these factors. Comstock and Moll (1963) classified environments into two categories:

Macro environment is that which is associated with a given location or area at a particular period of time. While microenvironment represent the environment of a single organism as opposed to that of another organism growing at the same time and in almost the same place. It includes physical and chemical attributes of soil, climatic variables, solar radiation, insect pests and disease.

The macro environments bring about a collection of micro-environments which are more alike within each macro-environment with the result that macro-environments substantially differ from each other. The terms 'predictable and unpredictable environments' were coined by Allard and Bradshaw (1964) as follows:

i) Predictable factor of environment, includes the features of the environment that are controlled by human , soil type, planting date, spacing rainfall , plant density, the level of fertilizer applied, sowing date and sowing density, amount of irrigation and others that can be artificially created.

ii) Unpredictable or uncontrollable environments, on the other hand contribute greatly to G x E interaction. This includes weather fluctuations such as differences between seasons in terms of amount and distribution of rainfall and the prevailing temperature during the crop growth. The absence or low level of interaction will be useful for uncontrollable variables, whereas for the controllable variables a high level of interaction in the favorable direction is desirable to obtain maximal performance.

Hybrid cultivar is genetically unique concerning both adaptability and stability because all individuals are uniform (Zivanovic *et al*., 2004). Hybrid cultivar actually does not possess genetic variability, but opposite to inbred, it is completely heterozygous which accounts for its extremely developed physiological homeostasis. That is why hybrids have high yield potential and show high adaptability and stability of yield and other traits in different environments (Zivanovic *et al*., 2004**)**

2.12: GGE Biplot model

A biplot is a scatter plot that graphically exhibits a point for each genotype and each environment (Gabriel, 1971). GGE biplot have been use to identify “which-wins-where” patterns. In MET, lines are drawn to connect the markers of the furthest genotypes in the biplot such that they are the peak of an irregular polygon and, for each side of the polygon, drawing a line segment perpendicular to that side of the polygon so as to pass through the origin (Yan, 2002, Yang *et al*., 2009). These line segments subdivide the polygon into sectors involving different environments and genotypes. The genotype which is located at the corner of one polygon is the best performer in that environment included in that sector. Environment that is located far away from the origin discriminate the genotypes more than those near the origin (Dehghani *et al*., 2006

The biplot is referred to as environment-focused scaling if the scaling factor is (2) or if the SV is completely partitioned into the environment. The relative importance of PC1 and PC2 is fully reflected by the locations of the environment markers in the biplot. Therefore, a GGE biplot based on environment-focused scaling is most suitable for visualizing the interrelationship among the environments but not for that of the genotypes. (Yan and Tinker, 2006; Yan, 2002)

On the other hand, a biplot is referred to as genotype-focused scaling when the SV is partitioned entirely into the genotype eigenvectors. In this scaling, the unit of the genotype scores is the original unit of yield, and the environmental scores are unit less. Because all of the SV is partitioned into the genotype scores, the range of the genotype scores is likely to be many times greater than that of the environment scores. As a result, the environments, in the biplot are likely to be crowded relative to the genotypes (Yan, 2001, Dehghani *et al*., 2006).

CHAPTER THREE

3.0 MATERIALS AND METHODS

Table 3.1 Description of the evaluation sites

The experiment was conducted in three agro-ecological zones of Ghana (Table 3.1). The first site was at Fumesua which lies in the Forest ecology zone of Ghana. The second evaluation site, Ejura lies in the Forest –Savannah Transition ecology and the third location was at Kpeve, the Coastal-Savanna Transition. The three experimental sites experience a bimodal rainfall pattern. The major season stretches from April through July and the minor season from August to November.

Table 3.1 Description of the test environments used in the study

Location	Latitude	Longitude	Altitude	Mean rainfall (mm)	Agro-ecology
Femusua	6^0 43’N	$1^0$36W	228	142.4	Forest
Ejura	7^0 24’N	1^0 21’E	229	117.1	Forest Savannah Transition
Kpeve	3^0 20’N	$0^0$17’E	69	121.5	Coastal Transition

Rainfall data from April to August 2012

3.2 Planting materials

Forty one early maturing maize drought tolerant inbred lines (Table 3.2) used for this study were obtained from the International Institute of Tropical Agriculture (IITA), Nigeria, Ibadan through the Council for Scientific and Industrial Research (CSIR) – Crops Research Institute (CRI) breeding programme, Fumesua Ghana.

Table 3.2: List of 41 early maturing inbred lines used as parents for the single crosses used in the study.

No.	Inbred Line	Colour	No.	Inbred Line	Colour
1	TZEI-1	White	22	TZEI-25	Yellow
2	TZEI-2	White	23	TZEI-26	White
3	TZEI-3	White	24	TZEI-27	Yellow
4	TZEI-4	White	25	TZEI-28	Yellow
5	TZEI-5	White	26	TZEI-29	White
6	TZEI-7	White	27	TZEI-30	White
7	TZEI-9	Yellow	28	TZEI-31	White
8	TZEI-10	Yellow	29	TZEI-32	White
9	TZEI-11	Yellow	30	TZEI-33	White
10	TZEI-12	Yellow	31	TZEI-34	White
11	TZEI-13	Yellow	32	TZEI-35	White
12	TZEI-14	Yellow	33	TZEI-36	White
13	TZEI-15	White	34	TZEI-38	White
14	TZEI-16	Yellow	35	TZEI-39	White
15	TZEI-17	Yellow	36	TZEI-41	White
16	TZEI-18	White	37	TZEI-42	White
17	TZEI-19	White	38	TZEI-45	White
18	TZEI-20	White	39	TZEI-46	White
19	TZEI-21	White	40	TZEI-47	White
20	TZEI-23	Yellow	41	TZEI-48	White
21	TZEI-24	Yellow			

3.3 Inbred lines preparation

The inbred lines were crossed in a half diallel fashion without reciprocals at the breeding nursery of the CSIR-CRI at Fumesua, Kumasi. Before the appearance of the silk, developing ears were protected with shoot bags to ensure that emerging silks were not contaminated with any stray or unwanted pollen.

At anthesis, pollen was collected using brown paper bags (glaxin envelopes) from agronomically desirable plants from each of the plots. Tassel bagging was done fifteen hours prior to pollination. This involved the covering of the tassels with water proof glaxin envelopes. The bags were placed over the tassel and fastened with paper clip to avoid contamination by stray pollen. At the early hours after dawn, when pollen shed had begun, pollen was collected and bulked for each line and used to pollinate agronomically desirable plants in other plots in all possible combinations among the given set of inbred lines.

Some crosses had poor nicking or synchronization and hence some of the lines could not successfully cross to some others, subsequently resulting in poor seed set. Due to inadequate seeds from such crosses for field evaluation, these crosses were discarded. The crosses with good seed set were used in the next stage of the work. Therefore, ninety F1 crosses that had enough seeds were selected for evaluation.

3.4 Crop husbandry

Pre-emergence and post emergence chemical weed control was done with an application of Gramoxone and Atrazine respectively. Hand weeding was also done when necessary to control weeds during the growing period. NPK 15-15-15 fertilizer was applied at the rate of 30 kg N ha^{-1} and 60 kg P^2O^5 ha^{-1} as basal fertilizer at two weeks after planting and top-dressed with additional N at 60 kg N ha^{-1} at four weeks after planting. The trials were conducted under rain-fed condition and other management practices were done according to the recommendations of the specific areas.

Table 3.3 planting dates of the trials at the various locations

No	Location	Date of planting
1	Fumesua	04 May 2012
2	Ejura	15 May, 2012
3	Kpeve	28 May, 2012

3.5 Experimental design

The ninety F_1's were constituted into a hybrid trial and planted in a Random Complete Block Design at each of the sites. Each entry was planted on a one row plot `each plot measuring 5 m, spacing between hills of 0.45 m and spacing between plots of 0.75 m with two replications at each of the three evaluation sites. Three seeds were planted per hill and these were later thinned to two at establishment. Each plot contained eleven hills and each row contained twenty two plants to obtain a target plant density of approximately 60,000 plants ha^{-1}. The experiment was protected by two-guard rows of Dorke SR, an improved early maturing open-pollinated maize variety.

3.5.1 Data collection

Data were collected on the following traits during the pre-harvest stage:

Days to 50 per cent tasseling: This is the number of days from the date of sowing to the day on which 50 per cent of plants in a plot showed full tassel emergence.

Days to 50 per cent silking: The number of days from the date of sowing to the day on which 50 per cent of the plants in a plot showed complete silk emergence

Plant height: The height of five randomly selected plants in a plot were measured in centimeter with a graduated measuring stick from the ground level to the node bearing the flag leaf and averaged.

Ear height: The ear heights of the five previously selected plants in each plot were measured in centimeters from ground level to the node bearing the uppermost ear and averaged.

Cob length: The length of the cob was measured in centimeters using Vernier caliper (from the base of the ear to the tip). Five cobs were chosen at random from each plot and averaged.

Cob width: The widths of five randomly selected cobs were measured in centimeters as the thickness of the ear using Vernier caliper. Ten cobs were chosen at random from each plot and averaged.

Grain yield: Grain yield kg ha^{-1} was calculated for every entry from the data of harvested ear weight per plot using the following formula:

Grain yield (kg ha^{-1}) was calculated as = Harvested ear weight (kg $plot^{-1}$) × (100-MC) × 0.8 × 10,000/ (100-15) × $3.75m^2$ (at 15% moisture).

Seed length: The length of ten randomly selected seeds were measured in centimeters using Vernier caliper and averaged.

Seed diameter: The widths of ten randomly selected seeds were measured in centimeters as the thickness of the seed using Vernier caliper and averaged.

Anthesis- Silking interval: This was calculated as the difference between days to anthesis and days to silking

3.6 Data Analysis

The Analysis of Variance (Steel and Torrie, 1980) for grain yield for each location and across locations was conducted using Statistical Analysis System version 9.2 (SAS, 2003). The statistical analyses were performed to test the significance of grain yield of the genotypes, locations and their interactions, and to determine the correlations between grain yield and the other traits. Genstat version 9 was used to determine differences among agronomic traits and their significance levels (Genstat 2009). Subsequently, least significance difference test ($P \leq 0.05$) was used to determine the level of significance among the treatment means and environments.

Table 3.4: Form of variance analysis and expected means square for the combined data for the three environments (Kang, 1994)

Source	DF	Mean squares	Expected mean squares
Rep. in Envir. (r(β))	β(r – 1)	M2	$\sigma e^2 + g\sigma^2 r$
Environment (β)	β - 1	M1	$\sigma e^2 + r\sigma^2 g\beta + g\sigma^2 r + rg\sigma^2\beta$
Genotype (g)	g – 1	M3	$\sigma e^2 + r\sigma^2 g\beta + r\beta\sigma^2 g$
Genotype x Envir.	(g – 1)(β - 1)	M4	$\sigma^2 e + r\sigma^2 g\beta$
Error (e)	β(g – 1)(β – 1)	M5	$\sigma^2 e$

Where; β, g and r are the number of locations, genotypes and replications respectively. σe2 = plot error variance, σg2 = genotypic variance and σgβ2 = genotype x environment interaction variance.

3.6.1 Correlations among traits

Correlations among traits were determined using the Pearson coefficients of correlation. Calculation was done using the hybrids' least square means for all traits to determine associations among these parameters. Correlation coefficients ranged in values between -1 and +1; a perfect negative relationship and a perfect positive relationship, respectively.

3.7 Identification of superior hybrids

In an effort to identify superior hybrids to be used for production, a rank sum was calculated by ranking the hybrids' performance in grain yield. The twenty best hybrids were selected based on the rank sum values calculated by summing the ranks of each of the 90 hybrids.

3.8 The GGE Biplot analysis

The GGE biplot software (Yan, 2001) was used to explore the GGE biplot data set which allowed visualization of three important aspects: the genotype x environment relations as represented by the which-won-where pattern; (ii) the interrelationships among test environments, which enabled the identification of better environments for evaluation of maize and of redundant environments that can be dismissed and (iii) the interrelationships among genotypes, which facilitated comparison among genotypes and genotype ranking on both mean yield and stability (Yan and Hunt., 2001).

A GGE biplot is constructed by first subjecting the environment-centered data, to singular-value (SV) decomposition. The GGE matrix is decomposed into three component matrices, the Singular Value matrix (array), the genotype eigenvector matrix, and the environment eigenvector matrix so that each element in the GGE matrix is recovered through this formula (Yan, 2002)

$$\mathbf{Yij - \mu - \beta j = \lambda 1\ \xi\ i1\eta j1 + \lambda 2\ \xi i2\ \eta j2 + \varepsilon ij\ [1]}$$

where ***Yij*** is the measured mean of genotype i in environment j, μ is the grand mean, ***βj*** is the main effect of environment **j,** ***μ + βj*** being the mean yield across all genotypes in environment j, ***λ1*** and ***λ2*** are the singular values (SV) for the first and second principal component (PC1 and PC2), respectively, ***ξ1i*** and *ξ2i* are eigenvectors of genotype i for PC1 and PC2, respectively, ***ηj1*** and ***ηj2*** are eigenvectors of environment j for PC l and PC2, respectively, ***εij*** is the residual associated with genotype *i* in environment

CHAPTER FOUR

4.0 RESULTS

4.1 Mean squares for grain yield for the three test environments

The mean squares values for the single cross hybrids at the three separate locations for grain yield indicated that there were significant ($p<0.05$) differences among genotypes (Table 4.1). Differences observed were much larger at Fumesua and Kpeve than Ejura.

Table 4.1: Mean squares for grain yield (kg ha^{-1}) of 90 early maturing maize hybrids evaluated at three locations in Ghana during the 2012 growing season.

		Mean squares		
		Ejura	Fumesua	Kpeve
Source of variation	Degrees of freedom	Mean square	Mean squares	Mean squares
Replication	1	267158	1912966	2465962
Genotype	89	168726.5*	2026959**	3960373**
Residual	89	891492.6	783008	1034466
Total	179			

**** (P <0. 01) highly significant * (P <0. 05) Significant**

4.2 Combined mean squares for grain yield and other agronomic traits evaluated across three locations during 2012 growing season.

4.2.1 Grain yield

Results from the combined analysis of variance indicated that there were significant ($P<0.01$) differences among genotypes and environments and significant ($P<0.05$)

differences for their interaction for grain yield (Table 4.2). Percentage contribution of variance for environments (96%), was high as compare to genotype (2.5%) and their interaction (0.59%)

4.2.2 Plant height

The mean square in (Table 4.2) for plant height showed that differences among genotypes (G) and environment (E) were significant (P<0.01) but there was no significant interaction between them. Mean plant height across environments was 160.9 cm, and ranged from 115 cm (TZEI-12 X TZEI-13) to 186.4 cm (TZEI-39 X TZEI-22).

4.2.3 Ear height

The result showed that there were significant differences among genotypes and environments (P<0.01) but there was no significant significant G x E interaction (Table 4.2). Mean ear height was 76.9 cm and ranged from 52.1 cm (TZEI-12 X TZEI-13) to 97.2 cm (TZEI-35 X TZEI-19).

4.2.4 Days to silking

The mean square data (Table 4.2) for days to silking showed that differences among genotypes and environments and interaction were significant (P<0.01). Days to silking ranged from 38 to 54 days. The mean day to mid-silk was at 50. TZEI-45 X TZEI-47 was the latest to reach mid-silk, while TZEI-9 X TZEI-12 was the earliest to reach mid- silk.

4.2.5 Days to tasseling

Table 4.2 also showed that differences in days to tasseling among genotypes (G) and environment (E) were significant ($P<0.01$) and only significant for interaction ($P<0.05$). Mean days to tasseling was 47.6 days. Days to mid-tasseling ranged from 43 to 51.2 days. TZEI-12 X TZEI-13 recorded the highest number of days to tasseling while TZEI-9 X TZEI-12 recorded the lowest days to tasseling.

4.2.6 Seed diameter

The mean square for seed diameter showed significant differences among genotypes ($P<0.01$) and significant ($P<0.05$) for environment but their interaction was not significant (Table 4.2). Seed diameter ranged from 0.7cm (TZEI-14 X TZEI-17) to 0.9 cm (TZEI-3 X TZEI-1).

4.2.7 Seed length

The result from the analysis for seed length (Table 4.2) indicated that differences among genotypes were significant ($P<0.05$) and significant for environment ($P<0.01$) but there were no significant interaction between genotype and environment. Seed length ranged from 0.8 cm (TZEI-28 X TZEI-14) to 1.5 cm (TZEI-41 X TZEI-30).

4.2.8 Cob length

The data analysis for cob length (Table 4.2) revealed that differences among genotypes and environments were significant ($P<0.01$), but no significant interaction was noted. Mean cob length was 13. 4 cm and it ranged from 9.4 cm (TZEI-28 X TZEI-14) to 15.2 cm (TZEI-24 X TZEI-23).

4.2.9 Cob diameter

The mean square analysis for cob diameter (Table 4.2) revealed that differences among genotypes and environments were significant (P<0.01) and significant for their interaction (P<0.05). The mean cob diameter was 4.2 cm. TZEI-42 X TZEI- 22 recorded the highest value (5.6 cm) while TZEI-28 X TZEI-14 recorded the lowest value (2.9cm) for cob diameter.

4.2.10 Anthesis-silking interval

The combined mean square analysis across the three locations revealed highly significant differences (p < 0.01) among environments but there were no significant differences among genotypes and their interaction (Table 4.2.) . The mean square value for location was high as compared to genotype and the interaction. Mean days to ASI was 2.87 and ASI ranged from 2.2 to 3.7

Table 4.2: Mean squares analysis for grain yield and other agronomic traits of 90 early maturing maize single cross hybrids evaluated at three locations during 2012 growing season

		Mean squares									
Sourceof variation	Degrees of freedom	GY	PHT	EHT	DS	DT	SDD	SDL	CL	CD	ASI
Replication	1	1978949	38.6	32.6	195.6	170	0.0079	0.01	11.06	0.04	0.06
Environment	2	209832711**	5878**	2297**	3135**	4253**	0.025*	0.084**	148**	7.9*	139.2**
Genotype	89	5217241**	1156**	446**	19.07**	14.3**	0.0071**	0.010*	6.3**	0.63**	0.420
Genotype Environment	178	1228680*	283.8	132	6.2**	4.9*	0.0042	0.006	2.04	0.25	0.440
Error	269	906190	254	116	4.73	3.6	0.0042	0.006	1.61	0.24	0.47
Lsd (0.05)		20.7	18.1	12.2	2.5	2.2	0.07	0.09	1.4	0.56	0.78
CV (%)		1082	9.9	14	4.3	4	7.8	8.1	9.5	11.6	24.4

GY= Grein yield, PHT= Plant height, EHT= Ear height, DS= Days to silking, DT= Day to tasseling, SD= Seed diameter, SL = Seed length, CL= Cob length, CD= Cob diameter, ASI= Anthesis-interval

*, ** = significant 5 % and 1 % respectively.

4.3: Mean performance of single cross hybrids evaluated at three locations in Ghana during 2012 growing season.

4.3.1 Fumesua

From the analysis, the performances of genotypes for Grain yield were different at Fumesua ranging from 1366 kg ha^{-1} (TZEI-12 X TZEI-13) to 6278 kg ha^{-1} (TZEI-36 X TZEI-39) for all the hybrids (Table 4.3). The main grain yield was at 4594 kg ha^{-1}. TZEI-36 xTZEI-39 emerged as the highest yielding genotype and TZEI-12 x TZEI-13 emerged as the lowest yielding genotype.

Table 4.3: Grain yield (kg ha^{-1}) of the top 20 and bottom 10 yielding genotypes evaluated in Fumesua during 2012 major growing season

Genotype code	Entry Name	Yield (kg ha^{-1})
	Top 20 high yielding genotypes	
P40	TZEI-36 X TZEI-39	6278
P78	TZEI-34 X TZEI-7	6189
P12	TZEI-10 X TZEI-11	6159
P35	TZEI-30 X TZEI-47	6118
P9	TZEI-41 X TZEI-30	6115
P52	TZEI-22 X TZEI-48	6082
P8	TZEI-41 X TZEI-47	6072
P59	TZEI-22 X TZEI-45	6024
P34	TZEI-41 X TZEI-36	5847
P16	TZEI-35 X TZEI-19	5774
P77	TZEI-42 X TZEI-30	5770
P89	TZEI-24 X TZEI-12	5592
P62	TZEI-12 X TZEI-20	5590
P19	TZEI-39 X TZEI-36	5555
P32	TZEI-17 X TZEI-15	5536
P3	TZEI-48 X TZEI-20	5522
P27	TZEI-48 X TZEI-45	5519
P26	TZEI-25 X TZEI-23	5478
P56	TZEI-25 X TZEI-27	5448
P24	TZEI-13 X TZEI-17	5441

Table 4.3 cont'd

Bottom 10 low yielding genotypes		
P17	TZEI-39 X TZEI-34	3332
P47	TZEI-36 X TZEI-20	3327
P4	TZEI-4 X TZEI-2	3267
P64	TZEI-28 X TZEI-14	2985
P13	TZEI-32 X TZEI-5	2873
P22	TZEI-17 X TZEI-16	2862
P80	TZEI-46 X TZEI-47	2742
P85	TZEI-19 X TZEI-18	2723
P20	TZEI-45 X TZEI-47	1645
P15	TZEI-12 X TZEI-13	1366
Grand Mean		**4594**
CV (%)		**19.3**
Lsd (0.05)		**1758**

4.3.2 Ejura

There were significant differences among genotypes (P<0.05). Grain yield ranged from 579 kg ha^{-1} for TZEI-28 X TZEI-14 to 5269 kg ha^{-1} for TZEI-25 X TZEI-23 with mean grain yield of 3520 kg ha^{-1}. TZEI-25 X TZEI-23 was the highest yielding while TZEI-28 X TZEI-14 was the lowest yielding (Table 4.4.).

Table 4.4: Grain yield (kg ha^{-1}) of best 20 and least 10 yielding maize hybrids evaluated in Ejura during 2012 major growing season

Code	Entry Name	Yield (kg ha^{-1})
	Top 20 high yielding hybrids	
P26	TZEI-25 X TZEI-23	5269
P53	TZEI-33 X TZEI-19	5150
P12	TZEI-10 X TZEI-11	4969
P40	TZEI-36 X TZEI-39	4949
P44	TZEI-4 X TZEI-3	4767
P83	TZEI-25 X TZEI-14	4708
P89	TZEI-24 X TZEI-12	4696
P39	TZEI-13 X TZEI-10	4686
P11	TZEI-46 X TZEI-34	4653
P36	TZEI-11 X TZEI-9	4630
P19	TZEI-39 X TZEI-36	4570
P71	TZEI-36 X TZEI-35	4512
P90	TZEI-38 X TZEI-63	4453
P75	TZEI-31 X TZEI-7	4410
P1	TZEI-9 X TZEI-12	4356
P57	TZEI-22 X TZEI-20	4349
P42	TZEI-12 X TZEI-15	4345
P32	TZEI-17 X TZEI-15	4305
P68	TZEI-2 X TZEI-22	4275
P3	TZEI-48 X TZEI-20	4246
	Bottom 10 low yielding genotypes	
P58	TZEI-14 X TZEI-16	2617
P23	TZEI-11 X TZEI-12	2487
P22	TZEI-17 X TZEI-16	2329
P61	TZEI-33 X TZEI-2	2236
P13	TZEI-32 X TZEI-5	1932
P14	TZEI-38 X TZEI-35	1890
P80	TZEI-46 X TZEI-47	1163
P15	TZEI-12 X TZEI-13	1044
P20	TZEI-45 X TZEI-47	597
P64	TZEI-28 X TZEI-14	579
Grand Mean		**3520**
CV (%)		**26.8**
Lsd (0.05)		**1876**

4.3.3 Kpeve

The trial at Kpeve revealed that there were significant differences among genotypes ($P<0.05$) with grain yield ranging from 934 kg ha^{-1} to 8508 kg ha^{-1} and mean yield of 5680 kg ha^{-1} (Table 4.5). TZEI-45 X TZEI-34 (8508 kg ha^{-1}) emerged as the highest yielding hybrid and TZEI-45 X TZEI-47 (934 kg ha^{-1}) emerged as the lowest yielding hybrid.

Table 4.5: Grain yield (kg ha^{-1}) of the top 20 and bottom 10 yielding genotypes evaluated in Kpeve during 2012 major growing season

Code	Entry name	Yield (kgha^{-1})
	Top 20 high yielding hybrids	
P41	TZEI-45 X TZEI-34	8508
P68	TZEI-2 X TZEI-22	8295
P59	TZEI-22 X TZEI-45	8126
P16	TZEI-35X TZEI-19	7777
P53	TZEI-33 X TZEI-19	7710
P40	TZEI-36 X TZEI-39	7661
P50	TZEI-34 X TZEI-46	7551
P27	TZEI-48 X TZEI-45	7483
P76	TZEI-22 X TZEI-46	7420
P51	TZEI-1 X TZEI-19	7294
P71	TZEI-36 X TZEI-35	7224
P69	TZEI-27 X TZEI-19	7021
P63	TZEI-22 X TZEI-18	7018
P10	TZEI-11 X TZEI-15	6992
P46	TZEI-19 X TZEI-46	6982
P39	TZEI-13 X TZEI-10	6869
P78	TZEI-34 X TZEI-7	6864
P25	TZEI-25 X TZEI-16	6844
P52	TZEI-22 X TZEI-48	6838
P73	TZEI-27 X TZEI-14	6810

Table 4.5 continue

	Bottom 10 low yielding genotypes	
P13	TZEI-32 X TZEI-5	4144
P47	TZEI-36 X TZEI-20	4065
P14	TZEI-38 X TZEI-35	3848
P22	TZEI-17 X TZEI-16	3769
P57	TZEI-22 X TZEI-20	3715
P64	TZEI-28 X TZEI-14	3496
P23	TZEI-11 X TZEI-12	2677
P80	TZEI-46 X TZEI-47	1547
P15	TZEI-12 X TZEI-13	1172
P20	TZEI-45 X TZEI-47	934
Grand Mean		**5680**
CV (%)		**17.9**
Lsd (0.05)		**2021**

4.3.4 Combined means performances of grain yield (kg ha^{-1}) of early maturing single cross maize hybrids

The combined data analysis across the three environments (Table 4.6) showed significant ($P< 0.05$) genotype by environment interaction for grain yield. Differences among genotypes and environments were also significant ($p < 0.01$). Mean grain yield was 4598 kg ha^{-1} with yield ranging from 1058.4 kg ha^{-1} (TZEI-45 X TZEI-47) to 6296 kg ha^{-1} (TZEI-36 X TZEI-39)

Table 4.6: Mean grain yield (kg ha^{-1}) of best 20 and bottom 10 early maturing maize hybrids evaluated across three environments in southern Ghana

Code	Entry name	Yield (kg ha^{-1})
	Top 20 high yielding hybrids	
P40	TZEI-36 X TZEI-39	6296
P53	TZEI-33 X TZEI-19	6066
P16	TZEI-35 X TZEI-19	5850
P41	TZEI-45 X TZEI-34	5838
P59	TZEI-22 X TZEI-45	5784
P68	TZEI-2 X TZEI-22	5770
P78	TZEI-34 X TZEI-7	5682
P12	TZEI-10 X TZEI-11	5617
P27	TZEI-48 X TZEI-45	5514
P52	TZEI-22 X TZEI-48	5456
P50	TZEI-34 X TZEI-46	5453
P10	TZEI-11 X TZEI-15	5436
P9	TZEI-41 X TZEI-30	5406
P26	TZEI-25 X TZEI-23	5380
P3	TZEI-48 X TZEI-20	5352
P42	TZEI-12 X TZEI-15	5280
P5	TZEI-3 X TZEI-1	5266
P8	TZEI-41 X TZEI-47	5234
P75	TZEI-31 X TZEI-7	5221
P71	TZEI-36 X TZEI-35	5189
	Bottom 10 low yielding genotypes	
P70	TZEI-18 X TZEI-46	3712
P47	TZEI-36 X TZEI-20	3462
P14	TZEI-38 X TZEI-35	3263
P22	TZEI-17 X TZEI-16	2987
P13	TZEI-32 X TZEI-5	2983
P23	TZEI-11 X TZEI-12	2847
P64	TZEI-28 X TZEI-14	2354
P80	TZEI-46 X TZEI-47	1817
P15	TZEI-12 X TZEI-13	1194
P20	TZEI-45 X TZEI-47	1058
Grand Mean		**4598**
CV (%)		**20.7**
Lsd (0.05)		**1082**

4.4 Selection of superior hybrids by ranking method

Rank sum values based on the performance of hybrids using grain yield (kg ha^{-1}), are presented in (Table 4.7). TZEI-36 X TZEI-39, TZEI-33 X TZEI-19, TZEI-35 X TZEI-19, TZEI-45 X TZEI-34, TZEI-22 X TZEI-45, TZEI-2 X TZEI-22, TZEI-34 X TZEI-7, TZEI-10 X TZEI-11, TZEI-48 X TZEI-45, TZEI-22 X TZEI-48, TZEI-34 X TZEI-46, TZEI-11 X TZEI-15, TZEI-41 X TZEI-30, TZEI-25 X TZEI-23, TZEI-48 X TZEI-20, TZEI-12 X TZEI-15, TZEI-3 X TZEI-1, TZEI-41 X TZEI-47, TZEI-31 X TZEI-7, and TZEI-36 X TZEI-35 were the best 20 hybrids with superior yield and agronomic performance. The following ten hybrids were the poorest: TZEEI-18 X TZEI-46, TZEI-36 X TZEI-20, TZEI-38 X TZEI-35, TZEI-17 X TZEI-16, TZEI-32 X TZEI-5, TZEI-11 X TZEI-12, TZEI-28 X TZEI-14, TZEI-46 X TZEI-47, TZEI-12 X TZEI-13 and TZEI-45 X TZEI-47.

Table 4.7: Grain yield (kg ha^{-1}) and agronomic performances of the best 20 and bottom 10 yielding hybrids evaluated across three locations

Entry name	Yield	Rank	DS	DT	PHT	EHT	CL	CD	SDL	SDD	ASI
TZEI-36 X TZEI-39	6296	1	47.7	45.5	179	78	14.3	4.2	1.0	0.88	
TZEI-33 X TZEI-19	6066	2	51.2	48.2	174	87	14.0	4.6	1.1	0.87	2.7
TZEI-35 X TZEI-19	5850	3	51.5	48.3	183	97	13.7	4.4	1.1	0.83	2.8
TZEI-45 X TZEI-34	5838	4	51.0	48.2	175	78	13.6	4.4	1.0	0.79	3.0
TZEI-22 X TZEI-45	5784	5	51.0	48.3	178	90	14.3	4.3	1.0	0.83	2.8
TZEI-2 X TZEI-22	5770	6	50.7	47.5	183	91	13.4	4.5	1.1	0.88	3.0
TZEI-34 X TZEI-7	5682	7	46.3	44.2	164	80	12.6	4.4	1.0	0.86	3.3
TZEI-10 X TZEI-11	5617	8	48.0	45.7	162	80	14.1	4.1	1.0	0.85	2.7
TZEI-48 X TZEI-45	5514	9	51.2	48.2	164	85	14.9	3.9	1.0	0.85	2.7
TZEI-22 X TZEI-48	5456	10	51.0	48.3	173	94	13.6	4.3	1.0	0.83	2.8
TZEI-34 X TZEI-46	5453	11	51.5	48.3	155	69	14.5	4.3	1.0	0.8	3.0
TZEI-11 X TZEI-15	5436	12	48.5	45.8	159	76	14.7	4.2	1.0	0.8	2.8

TZEI-41 X TZEI-30	5406	13	49.8	47.2	168	85	13.5	6.0	1.0	0.82	2.8
TZEI-25 X TZEI-23	5380	14	48.0	45.3	156	81	14.0	4.1	1.0	0.85	2.7
TZEI-48 X TZEI-20	5352	15	49.8	47.2	175	92	14.5	4.3	1.0	0.8	3.2
TZEI-12 X TZEI-15	5280	16	47.5	45.2	165	70	14.5	4.3	1.0	0.85	3.0
TZEI-3 X TZEI-1	5266	17	49.7	47.2	181	81	13.9	4.6	1.0	0.9	3.0
TZEI-41 X TZEI-47	5234	18	51.0	48.2	152	74	13.3	4.0	1.5	0.83	2.8
TZEI-31 X TZEI-7	5221	19	49.5	47.0	174	80	14.5	4.4	1.1	0.88	2.6
TZEI-36 X TZEI-35	5189	20	48.0	45.5	166	78	14.7	4.1	1.1	0.82	2.8
TZEI-18 X TZEI-46	3712	81	52.2	49.0	161	79	14.7	4.1	1.1	0.83	3.0
TZEI-36 X TZEI-20	3462	82	50.7	47.8	137	71	13.1	4.1	1.0	0.85	2.7
TZEI-38 X TZEI-35	3263	83	50.7	47.7	159	77	12.3	4.5	1.0	0.8	3.2
TZEI-17 X TZEI-16	2987	84	53.8	50.3	134	61	12.7	3.5	0.9	0.82	2.7
TZEI-32 X TZEI-5	2983	85	51.3	48.5	168	86	12.5	4.5	1.0	0.83	2.7
TZEI-11 X TZEI-12	2847	86	52.3	49.7	140	64	13.6	3.7	0.9	0.8	2.8
TZEI-28 X TZEI-14	2354	87	53.8	50.8	133	59	9.4	2.9	0.8	0.65	3.0
TZEI-46 X TZEI-47	1817	88	54.2	50.3	140	67	11.0	3.6	1.0	0.81	3.7

TZEI-12 X TZEI-13	1194	89	54.3	51.2	116	52	10.9	3.6	0.9	0.83	3.0
TZEI-45X TZEI-47	1058	90	54.3	51	127	55	11.7	3.3	0.9	0.8	2.7
Grand mean	**4598**		**50.3**	**48**	**161**	**77**	**13.6**	**4.2**	**1.0**	**0.8**	**2.8**
CV (%)	**20.7**		**4.3**	**4.0**	**9.9**	**14**	**10**	**11.6**	**8.1**	**7.8**	**24.4**
Lsd (0.05)	**1082**		**2.5**	**2.2**	**18.8**	**12**	**1.0**	**0.7**	**0.09**	**0.07**	**0.78**

4.5 Correlations among measured traits

Results on correlation among agronomic traits are presented in (Table 4.8). Grain yield was positively correlated to days to tasseling, plant and ear height, cob length, cob diameter, seed length and seed diameter but there was no correlation between grain yield and days to silking.

Plant height contributed the highest correlation (r =0.633) to grain yield followed by cob length (r = 0.609) and ear height (r = 0.410). Days to tasseling, and seed length contributed weakly to the correlation.

Anthesis-silking-interval (Table 4.8) was negatively and significantly correlated with grain yield (r = -0.421), and cob length (r = -0.47) but was positively and significantly correlated with days to tasseling and days to silking and cob diameter.

Table 4.8: correlations among various traits of maize single cross hybrids evaluated across three Locations in Ghana during 2012 growing season

	GY	DS	DT	EHT	PHT	SD	SDL	CL	CD	ASI
DS	0.003									
DT	0.116**	0.969**								
EHT	0.410**	-0.370**	-0.332**							
PHT	0.633**	0.018	0.107*	0.669**						
SD	0.190**	0.055	0.071*	0.117**	0.220**					
SDL	0.362**	0.031	0.057	0.255**	0.340**	0.470**				
CL	0.609**	-0.048	0.033	0.339**	0.457**	0.244**	0.397**			
CD	0.402**	-0.007	0.050	0.304**	0.399**	0.315**	0.388**	0.335**		
ASI	-0.421**	0.24*	0.543**	0.143	0.042	0.0183	0.213	-0.470**	0.083*	

DT=days to 50% tasseling, DS = days to 50% silking, PHT = plant height, EHT = ear height, SD = seed diameter, SDL = seed length, CL = cob length, CD = cob diameter GY = grain yield, ASI = anthesis-silking-interval

*, ** = significant 5 % and 1 % respectively.

4.6 GGE biplot analysis for grain yield and stability of 90 early maturing maize hybrids evaluated across three locations in Ghana.

The biplot analysis was based on environment-focused singular value partitioning (SVP = 2) and genotype-focused singular value partitioning (SVP = 1) and it allowed visualization of the relationships among genotypes and among environments where desired. The principal component axis (PC1 and PC2) explained 87.3 % and 7.6 %. of the total G + GE. Thus, these two axes accounted for 94.9 % of the total variation for grain yield (Fig: 1, 2, and 3). The results of the GGE biplot analysis are presented in three sections. Section one presents the results of "which won-where" which rank the best genotypes for each environment. The second Section shows the discriminating power and representativeness of the test environments and the third section results of hybrids' performance and their stability.

4.6.1 The "which-won-where" patterns

From the polygon view of the GGE biplot (Fig. 1), the vertex genotype can be seen as the one that give the highest yield for each of the environment in which they lie. TZEI-36 X TZEI-39 was the highest yielding hybrid at Fumesua (best hybrid across environments) followed by TZEI-34 X TZEI-7 (7th best hybrid). Mean while, TZEI-12 X TZEI-13, TZEI-45 X TZEI-47, TZEI-19 X TZEI-18 and TZEI-46 X TZEI-47 performed very poor at Fumesua. TZEI-25 X TZEI-23 (14th best hybrid) was the highest yielding hybrid at Ejura followed by TZEI-33 X TZEI-19, (2nd best hybrid across environments and TZEI-10 X TZEI-11. TZEI-28 X TZEI-14, TZEI-45 X TZEI-47 , TZEI-12 X TZEI-13 , and TZEI-46 X TZEI-47 were the poorest performing hybrid at Ejura Meanwhile, TZEI-22 X TZEI-45 was the winning hybrid at Kpeve (5th best across environments) followed by TZEI-45 X TZEI-34, TZEI-35 X

TZEI-19 , and TZEI- 2 X TZEI- 22. Moreover, TZEI-45 X TZEI-47, TZEI-12 X TZEI-13 and TZEI-46 X TZEI-47 poorly performed at Kpeve. No environment fell into the sector where TZEI-45X TZEI-47, TZEI-12 X TZEI-13, TZEI-46 X TZEI-47 , TZEI-32 X TZEI-5 , TZEI-28 X TZEI-14 and TZEI-17 X TZEI-17 were the vertex hybrid.

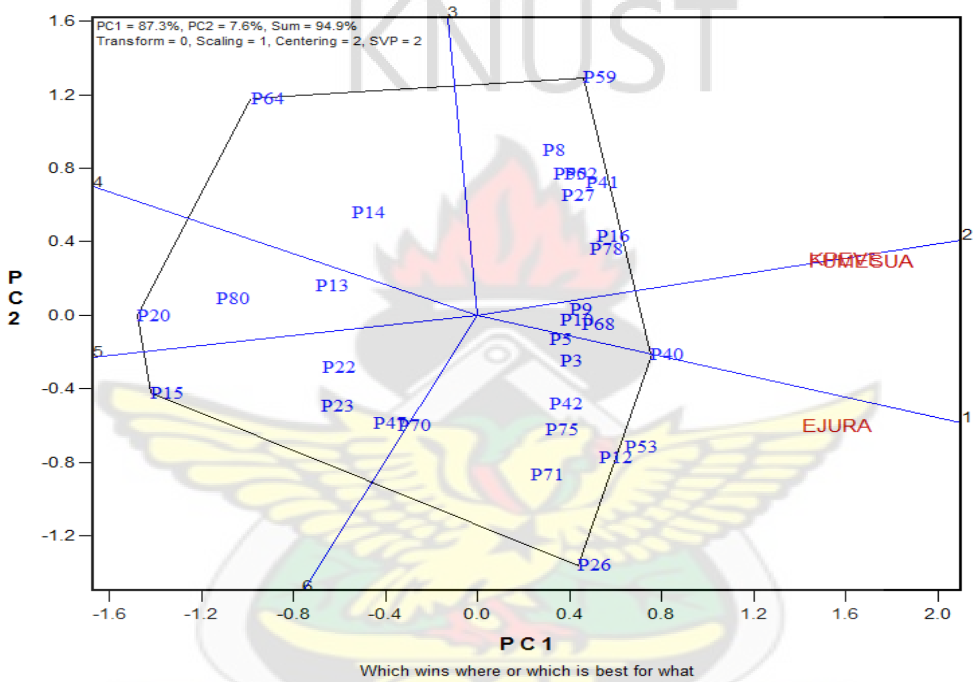

Figure 4.1: "Which won where" or which is best for what view based on genotype by environment interaction yield data of 90 early maturing maize hybrids evaluated in three environments in Ghana.

4.6.2 Discriminating ability and representativeness of the environment

The ideal environment represented by the small circle with an arrow pointing to it (Fig.4. 2) is the most discriminating of genotypes and representative of the other test environments. The lines connecting the biplot origin with the markers for the environments are called environment vectors (Brar *et al*., 2010). Based on the cosine of angles of environment vectors, the three locations for grain yield were grouped into two. The presence of wide obtuse angles among the locations indicates strong cross-over genotype by environment interactions (Yan and Tinker, 2006). The distance between two environments measures their dissimilarity and similarities in discriminating the genotypes. Thus, the three locations fell into two apparent groups, Fumesua Ejura and Kpeve (fig 4.2). The concentric circles on the biplot helped to visualize the length of the environment vectors, which is proportional to the standard deviation within the respective environments and its discriminating ability of the environments (Kroonenberg, 1995). A test environment with a smaller cosine of angle with Average Environment Coordinate (AEC) is more representative than other test environments. Fumesua and Kpeve were highly and positively correlated in terms of performance of the genotypes. Therefore, these two environments were considerd as the ideal environments.

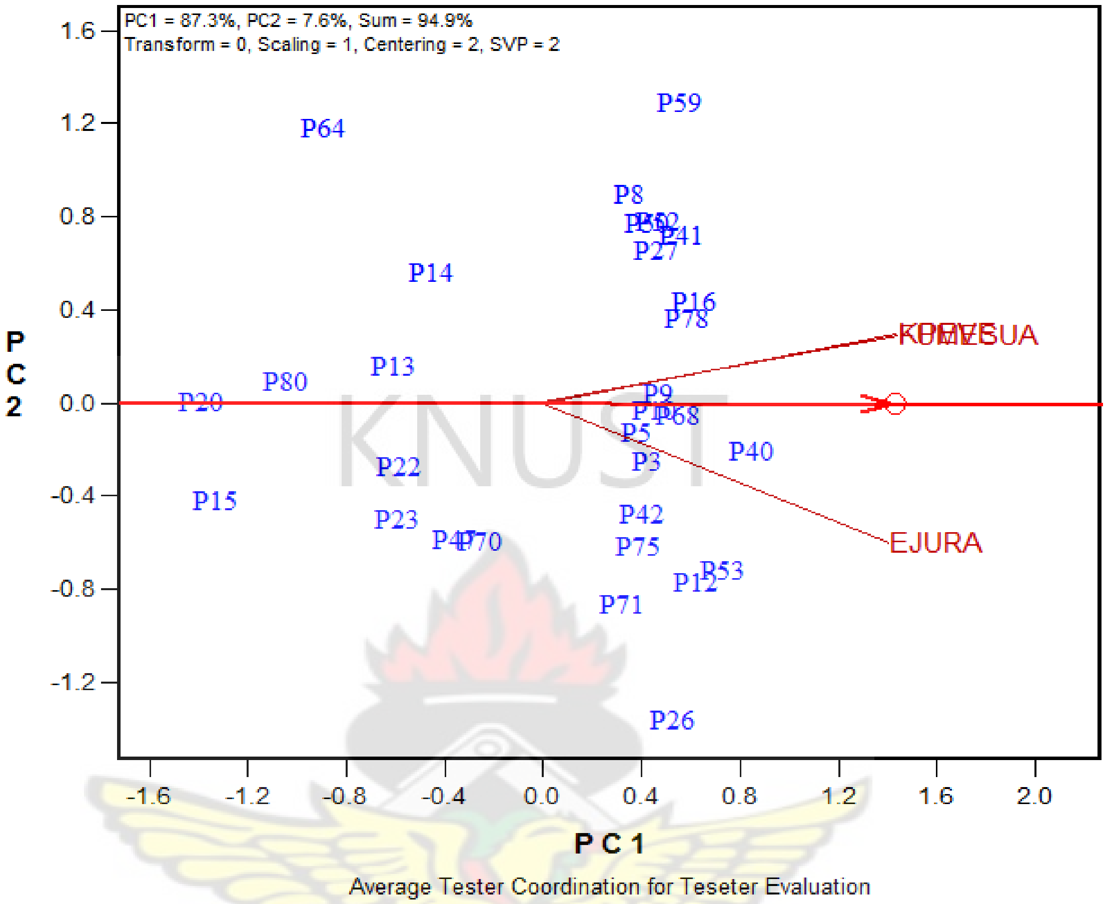

Figure 4.2: Discriminative ability and representativeness of the environments view based on genotypic-focused scaling for the mean performance and stability of 90 early maturing hybrids across three locations during 2012 cropping season

4.6.3 Performance of genotypes based on means and stability

The ranking of the genotypes were done on the biplot along the average-environment axis (AEC abscissa), with an arrow pointing to the greater value based on their mean performance across all environments (Figure 4.2). The double-arrowed line separates entries with below-average means from those with above-average means. The average yield of the cultivars is approximated by the projections of their markers on the average- environment axis. Based on this, 20 hybrids produced above-average grain yield and were ranked as follows: 40 > 53 > 16 > 12 >=16 =78 = 41 >59 > 26 =10 > 12> 52 >50=9 =26= 3 =42> 27 > 5 = 8.

The AEC abscissa estimates the genotypes' contributions to G × E, which is a measure of their instability. The stability of the cultivars is measured by their projections onto the average environment coordinate (AEC) y-axis double-arrowed line. The greater the absolute length of the projection of a cultivar, the less stable is the genotype (Yan *et al*., 2002). Based on this, TZEI-36 x TZEI-39, TZEI-2 x TZEI-22, TZEI-11 x TZEI-15, TZEI-41 x TZEI-30 and TZEI-3 x TZEI-1 were the most stable with an above average performance, as they were located away from the AEC ordinate and had a near zero projection onto the AEC abscissa. In contrast, entries TZEI-22 x TZEI-45, TZEI-45 x TZEI-34 TZEI-33 x TZEI-19, TZEI-25 x TZEI-23, TZEI-10 x TZEI-11, TZEI-34 x TZEI-7 and TZEI-35 x TZEI-19 were the least stable but high yielding hybrids. However, entries TZEI-45 x TZEI-47, TZEI-46 x TZEI-47 and TZEI-32 x TZEI-5 were the low yielding but very stable hybrids.

It can be demonstrated that some of the hybrids in the study exhibited different rank in performance across the three locations. However, these following hybrids performances were constant at the either two of the three environments. TZEI- 32 x TZEI-5 ranked as the 81st hybrid at Kpeve and 85th at Fumesua and Ejura. TZEI- 12 x TZEI-13 ranked as 89th, 88th, and 90th at Kpeve, Ejura and Fumesua respectively. TZEI-45 x TZEI- 47 ranked 90th, 89th and 89th at Kpeve, Ejura and Fumesua respectively. TZEI-46 x TZEI-47 ranked 88th, 87th and 87th at Kpeve, Ejura and Fumesua respectively. TZEI- 28 x TZEI-14th ranked 86th, 90th and 84th at Kpeve, Ejura and Fumesua respectively.

In addition there were some hybrids that performed very well at either two or three locations. For instance, TZEI-36 x TZEI-39 ranked 1st, 4th and 6th at Fumesua, Ejura and Kpeve and it emerged as the highest yielding genotype across environment. TZEI-10 x TZEI-11 ranked 3 at both Kpeve and Ejura.

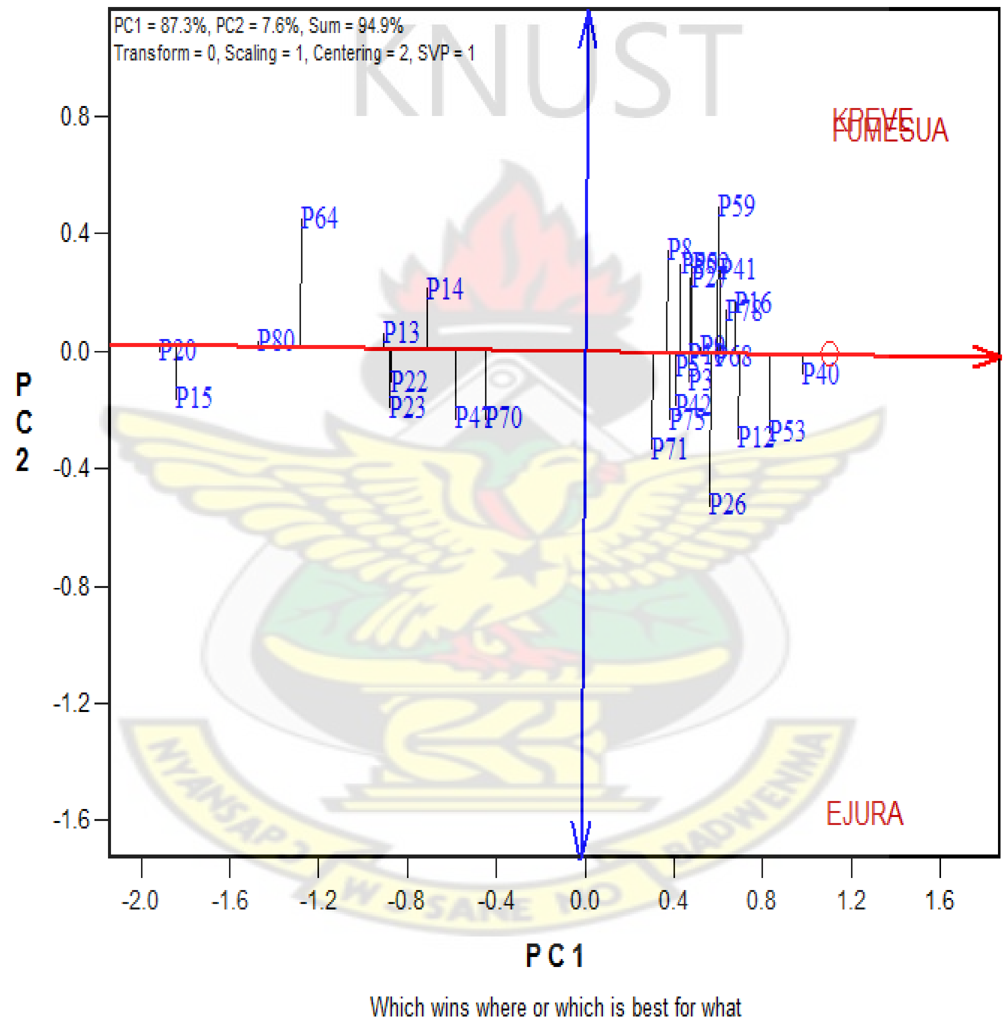

Figure 4.3: GGE-biplot view based on genotypic-focused scaling for the mean performance and stability of 90 early maturing hybrids across three locations during 2012 cropping season.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Performance of 90 early maturing hybrids evaluated at three locations in Ghana during the 2012 growing season

The significant mean square values for the three locations indicated that genetic potentials of the genotypes were influenced by the environments due to the effect of environmental diversity. Similar observation was reported by Butron *et al*. (2002) in which they mentioned that G x E effects for grain yield in maize were mainly due to environmental yield limiting factors such as the mean minimum temperature and relative humidity, moisture stress and pest and diseases.

The observed Significant G x E mean square for grain yield suggested that the locations for which the hybrids were tested comprised of a number of special environments and it also indicated that the performance across the three environments were not consistent. Hence, hybrids selected did well in one environment and performd poor in another environment. Therefore, hybrids with superior yield advantage could be selected for specific locations.

The result from the evaluation conducted for individual location showed that there were differences among genotypes. For Fumesua grain yield was generally moderate for all genotypes. Meanwhile, genotypes at Ejura did not produce good yield. This might have been probably due to adverse environmental conditions that prevailed at the site. In addition to this, there was an invasion of spittle bugs in Ejura and its surrounding areas which might have affected the yields in those areas. There was erratic rainfall at Ejura which resulted in less soil moisture during grain filling period. This resulted in poor flowering, subsequently affecting seed set which might have contributed to the rather low yields obtained. Furthermore, the unfavorable rainfall at some of these sites did not give individual genotypes ample opportunity to express their yield potentials. A similar observation has been reported by Denmead and Shaw (1960) who reported that drought stress may reduce yields by 21% when it occurs at the grain filling period and by 50% when it happens at flowering.

The combined ANOVA for grain yield was conducted to determine the variation among genotypes, location and their interaction. The variances component was used as an indication of the variation attributed to grain yield. Genotype performed differently at different locations. However, the magnitude of the contribution of these effects to the total variation was very high for environment as compare to genotype of total variance. This suggests that grain yield was greatly influenced by adverse environmental factors. This finding is in agreement with (Beyene *et al*., 2012; Yan and tinker, 2006; Badu-Apraku *et al*., 2005, Yan, 2002) who reported that environment contributed the largest proportion of total variance and that 80% and above of total sum of square variance is contributed by Environment and 10% contributed by genotype and interaction.

The significant mean squares for locations, genotypes, plant height, ear height, days to silking, days to tasseling, cob length and diameter, seed length and seed diameter suggest that the genetic expressions of these traits were affected by environmental conditions at the three environments during the growing period.

5.2 The GGE biplot analysis

The pattern displayed by the biplots may be more robust than the individual data points for genotypes because it places more weight on stability rather than rank (Yan

2002). The biplot analysis of the “which won where” indicated that genotype TZEI-22 X TZEI-45 was the highest yielder in Kpeve but from the SAS analysis, genotype TZEI-45 X TZEI-34 was the highest yielding in Kpeve even though there was no significant difference between these genotypes. Similar observation was reported by Yan (2002) who observed that genotype Mou was displayed on the biplot as the highest yielder in environment EA, HN, and WK whereas genotype Mac was actually the highest yielding. He further attributed it to the scaling methods which he noted, could influence the ranking of the genotypes based on mean performance and stability. Furthermore, Yan and Tinker (2006) reported that the best way to determine the best genotype in a test environment is to do scaling with environment standard deviation such that all environments are given the same weight. Based on the genotype-focused scaling, TZEI-22 X TZEI-45 was the most desirable followed by TZEI-45 X TZEI-34 even though TZEI-45 X TZEI-34 had the highest mean yield. Additionally, there were no significant differences among these two genotypes.

5.2.1 Discriminative ability and representativeness of the test environment.

An ideal environment should be highly differentiating of the genotypes and at the same time representative of the target environment (Tonk *et al*., 2010; Dehghani *et al.,* 2006).

When the biplot adequately approximates the environment-centered data, and when the environment-focused scaling is used, the cosine of the angle between the vectors of two environments approximates the correlation coefficient between them. This enable all environments to positively correlate because all angles among them are smaller than 90^0 (Dehghani *et al.,* 2006).

The angle between environments Fumesua and Kpeve is smaller than 90^0 therefore, thecorrelation between them was high. Similar observation was made by Yan (2002) who further reported that environment HN and WK were the most closely correlated environments even though the largest correlation coefficient was actually between RN and ID. Additionally, the angle between Fumesua (in the Forest ecology) and Kpeve in the (Coastal -Savannah Transition) indicated a positive correlation between them, implying that hybrids which performed well in one location also performed well in the other location. Therefore, Fumesua and Kpeve were considered areas with high potential for maize production in this study.

5.2.3 Hybrid performance and stability across environments

An ideal genotype must have both high mean performance and be stable for selection for broad adaptation (Tonk *et al.*, 2010). GGE biplot was used to determine the mean performance and stability of genotypes for grain yield because of the significant interaction for grain yield alone. The biplot displayed the pattern of variability of genotypes, environment and their interactions. It is important to know that different scaling methods put different weights on mean vs. stability (Brare *et al.*,2010). Consequently, the choice of scaling methods may influence the ranking of the genotypes based on mean performance and stability (Yan 2002). Against this, Entries TZEI-22 X TZEI-45, TZEI-45 X TZEI- 34, TZEI-33 X TZEI-19, TZEI-35 x TZEI-19, TZEI-34 x TZEI-7and TZEI- 25 X TZEI-23 were high yielding but unstable. This may pose a serious challenge to plant breeders in cultivar selection because the highest yielding genotype may not be preferred by farmers due to its instability. This finding agreed with what was reported by Obeng-Antwi *et al.* (2011) that high interaction caused difficulties in the selection of high yielding genotypes due to their inconsistency to perform across different environments. These inconsistencies in the performance of these hybrids across the three environments indicated that there was possibly crossover interaction and non crossover interaction. It also displays the instability of the genotypes which may require evaluating these genotypes in a wide range of environments.

5.3 Correlation among traits measured

Correlation is the measure of association between any two traits. Therefore, it is important for a breeder to understand that whenever two traits correlate positively, it indicates that selection based on one of these traits can also mean selecting for the other trait. Plant height significantly correlated with grain yield indicating that increase in plant height could lead to increase in grain yield (Zsubori *et al*., 2002). Plant height is strongly associated with the flowering date, both morphologically and ontogenetically, because internodes formation stops at floral initiation, which means that earlier flowering maize is usually shorter (Troyer and Larkins, 1985). Plant height has been observed to be controlled by the expression of many genes (Bello *et al.,* 2012). Therefore, Positive correlation with grain yield indicates that selection for this trait could help improve grain yield. Similar results were reported by Bocanski *et al*. (2009) and Malik *et al.* (2005). They observed high and significant correlation between grain yield and plant height ear height and cob length.

The nonsignificant correlation between grain yield and day to silking indicated that grain yield could not be improved through days to silking. Golam *et al.* (2011) reported that grain yield and plant height had no correlation with days to silking.

The negative correlated between Anthesis-silking-interval and grain yield indicated that grain yield could be reduced with high ASI. It is good to know that the long time interval between anthesis and silking could leads to pollen abortion during pollination especially in rainfed growing conditions where environmental conditions are harsh. This situation is also possible when there is less moisture in the soil to enhance the partitioning of dry matter which might result into low grain yield. Malik *et al*.(2005) reported that seed setting was reduced because of limited moisture towards the end of the season Denmead and Shaw, (1960) also reported that grain yield may be reduced by 21% if draught stress occur at grain filling period and 50% when it occur at flowering time.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

From the study conducted, G x E was found to be significant (P<0.01) for both genotypes and environment and significant (P<0.05) for their interaction. The combined analysis of variance revealed that environment contributed the greatest proportion 96% of the total variance component for grain yield while genotype contributed 2.5% and G x E and error contributed 0.95% and 0.5% respetively. The significant effects revealed that environmental conditions had major effects in selecting hybrids for high grain yield and wide adaptation. The high genotypic effect also revealed that hybrids could be selected for specific environments. The presence of significant genotypic mean square for grain yield, plant and ear heights, days to silking, days to tasseling cob length, cob diameter, seed length and seed diameter justify the use of multi-trait selection method to identify the best candidates for hybrid production.

Among the hybrids evaluated, TZEI-36 X TZEI-39, TZEI-33 X TZEI-19, TZEI-35 X TZEI-19, TZEI-45 X TZEI-34, TZEI-22 X TZEI-45, TZEI-34 X TZEI-7, TZEI-10 X TZEI-11, TZEI-48 X TZEI-45, TZEI-22 X TZEI-48, TZEI-34 X TZEI-46, TZEI-11 TZEI-15, TZEI-41 X TZEI-30, TZEI-25 X TZEI-23, TZEI-48 X TZEI-20, TZEI-12 X TZEI-15, TZEI-3 X TZEI-1, TZEI-41 X TZEI-47, TZEI-31 X TZEI-7, TZEI-36 X TZEI-35 were the best 20 hybrids with superior yield. Hence, these hybrids could be considered as candidate varieties for commercial production in Ghana. On the other hand, TZEEI-18 X TZEI-46 , TZEI36 X TZEI-20 , TZEI-38 X TZEI-35 , TZEI-17 X TZEI-16 , TZEI-32 X TZEI-5 , TZEI-11 X TZEI-12 , TZEI-28 X TZEI-14 , TZEI-46 X TZEI-47 , TZEI-12 X TZEI-13 and TZEI-45 X TZEI-47 were the poorest yielding hybrids .

The GGE biplot analysis provided result in terms of stability and performance of the hybrids. The results showed that TZEI-36 X TZEI-39, TZEI-2 X TZEI-22, TZEI-11 X TZEI-15, TZEI-41 X TZEI-30, and TZEI-48 X TZEI-20 had high potential yield respectively and were near to ideal genotypes (Fig 3). Therefore, these were considered as stable and high yielding. On the other hand, TZEI-22 X TZEI-45, TZEI-34 X TZEI-7, TZEI-10 X TZEI-11, TZEI-33 X TZEI-19, TZEI-48 X TZEI-20 TZEI-12 X TZEI-15, TZEI-45 X TZEI-34, TZEI-35 X TZEI-19, TZEI-25 X TZEI-23, TZEI-2 X TZEI-22, TZEI-22 X TZEI-48 and TZEI-34 X TZEI-46 were high yielding but not stable. They could therefore be recommended for specific environments. TZEI-45 X TZEI-47, TZEI-46 X TZEI-47, and TZEI-32 X TZEI-5, were very stable but low yielding.

The GGE biplot approach used in this study could help breeders to make better decisions on what genotypes should be recommended for release in the region. From the GGE biplot analysis, Fumesua and Kpeve were identified as the most ideal environment even though Kpeve produced the highest yield.

The correlation studies among traits showed that grain yield was highly correlated with plant height, ear height, days to tasseling, cob length, cob diameter, seed length, and seed diameter with plant height contributing the highest effect (r = 0.633) followed by cob length (r = 0.610) and cob diameter (r = 0.402). There were no significant correlation between grain yield and days to silking. Negative correlation was found between grain yield and ASI, cob length and between ear height and days to tasseling and days to silking.

This result demonstrated that among the 41 inbred lines used to develop the 90 hybrids, TZEI-36, TZEI- 39, TZEI-19, TZEI-48, TZEI-35, TZEI-45, TZEI-34, TZEI-7, TZEI-10, TZEI-11, TZEI-22, TZEI-15, TZEI-41, TZEI-30, TZEI-25, TZEI-23, TZEI-20, TZEI-12, TZEI-3,TZEI-1 and TZEI-47 may be good combiners and can be use as parental lines for formation of more hybrids. From the results, 20 hybrids were identified to be high yielding. It is therefore recommended that this trial be repeated in many environments and years in order to effectively assess the yield potentials of these genotypes, the high and non unstable yielding hybrids be tested on farm and recommended for specific environment and that the high and stable yielding hybrids further be tested extensively on-farm and promoted for adoption and commercialization in Ghana

REFERENCES

Acquaah, G. (2007). Principles of plant genetics and breeding. Langston University, Langston, OK 73050, USA, *Blackwell publishing* PP485-498

Ahmad, S. (1997). Response to selection for grain yield and its components in a maize population, *M.Sc. Thesis*, Department of plant breeding and genetics, University of Agriculture, Faisalabad.

Allard, R.W. and Bradshaw, A.D. (1964). Implications of genotype-environment interactions in applied plant breeding. *Crop Science.* 4: 503-508

Amaregouda, H.M. (2007). Combining ability analysis of S_2 lines derived from yellow pool population in Rabi maize. *Msc. Thesis*, Department of Genetics and Plant Breeding College of Agriculture, Dharwad University of Agricultural Sciences, Pakistan – 580 005

Arusleivi, S. andSelvi, B. (2010). Grain yield stability of single crosses maize *(Zea mays* L.) hybrids over three different environments, *Journal of Plant Breeding*, 1(4):577-584

Babic, M, Anelkovic, V. and Babic, V. (2008). Genotype by environment interaction in maize breeding – *Genetika*, Vol. 40, No. 3, 303 -312.

Badu-Apraku, B, Oyekunle, M. Akinwale, R.O, and Lum,F. A. (2011). Combining ability of early maturing white maize inbred under stress and non stress environment. *Agronomy Journal*. 103:544-557.

Badu-Apraku, B., Menkir, A., Ajala, S.O., Akinwale, R.O., Oyekunle, M., and Obeng-AntwiK. (2010). Performance of Tropical early maturing maize cultivars in multiple stress environments. *Canadian Jouenal of Plant Science.* 90:831–852.

Badu-Apraku, B.,Menkir, A., Fakorede, M.A.B., Lum, A.F, and Obeng-Antwi, K. (2006). Multivariate analysis of the genetic diversity of forty-seven *Striga* resistant early maturing tropical maize inbred lines. *Maydica* 51:551–559

Badu-Apraku, B., Fajemisin, J. M. and Diallo, A.O. (1995). The performance of early and extra-early varieties across environments in West and Central Africa. In Contributing to Food Self-sufficiency: Maize Research and Development in West and Central Africa. Proceedings of a Regional Maize Workshop, 29 May–2 June 1995 (Eds B. Badu-Apraku, M. O. Fakoroda, M. Ouedraogo and F. M. Quin).pp. 149–159.Cotonou, Benin Republic: IITA.

Balzarini, M., Bruno, C. and Arroyo, A. (2005). Analisis de ensayos Agricola's multi-ambientales: Ejemplos con Info-Gen. Fac. de Cs. Agropec. U.N.C., Argentina, p 141

Banziger, M. and Cooper, M. E. (2001). Breeding for low-input conditions and consequences for participatory plant breeding - examples from tropical maize and wheat. *Euphytica* 122, 503-519.

Banziger, M, Setim ela, P.S,. Hodson, D. and Vivek, B. (2004). Breeding for improved drought tolerance in maize adapted to southern Africa. Proceedings of the 4th International *Crop Science* Congress pp 6-641

Basford, K.E. and Cooper, M. (1998). Genotype by environment interactions and some considerations of their implications for wheat breeding in Australia.*Australian Journal of Agricultural Research* 49: 154-174.

Becker, H.C. and Leon, J. (1988). Stability analysis in plant breeding. *Plant Breeding*, 101: 11-23.

Bello, O. B., Abdulmaliq, S. Y., Ige, S. A., Mahamood, J., Oluleye, F.,Azeez., M. A. and Afolabi, M. S. (2012). Evaluation of early and late/intermediate maize varieties for grain yield potential and adaptation to a southern Guinea Savannah agro-ecology of Nigeria. *Scholarly Journal of Agricultural Science* Vol. 2(3), pp. 42-51.

Bernardo, R. (2002). Genotype by environment interaction. In: Bernardo, R. (ed.) Breeding for quantitative traits in plants. *Stemma Press, Woodbury*, MN. pp 147-171.

Beyene, Y., Mugo, S. Mutinda, C., Tefera, T., Karaya, H., Ajanga, S., Shuma, J., Tenda, R, and Kanga, V. (2011). Genotype by environment interaction and yield stability of stem borer resistant maize hybrid in Kenya .*African journal of biotechnology* vol 10 (23); pp: 4752-4758

Beyene, Y., Mugo, S., Tefera, T., Gethi, J., Gakunga, J., Ajanga, S., Karaya, H, Musila, R.,Muasya. W., Tende, R. and Njoka, S. (2012). Yield stability of stem borer resistantmaize hybrids evaluated in regional trials in East Africa. *African Journal of Plant Science* Vol. 6(2), pp. 77-83

Boakyewaa, A. G. (2012). Genotype by Environment interaction and grain yield stability of extra-early maize (*Zea mays* l.) hybrids evaluated at three locations in Ghana. *MSc. Thesis Pdf*, Department of Crop and Soil Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Bocanski, J., Sreckov, Z. and Nastic, A. (2009). Genetic and phenotypic relationship between grain yield and components of grain yield of maize (*Zea mays* L.). – *Genetika*, Vol. 41, No. 2, 145 -154.

Borras, L., Westgate, M.E. and .Astini, J.P. (2007). Physiological processes to understand genotype × environment interactions in maize silking dynamics Agronomy department of Iowa state University,Ames, Iowa, USA.

Brar, K.S, Pritpal Singh, V.P. Mittal, Paramjit Singh, M.L. Jakhar, YashpalYadav M.M. Sharma, U .S. Shekhawat and Chakresh Kumar.(2010). GGEbiplot analysis for visualization of mean performance and stability for seed yield in taramira at diverse locations in India. *Journal of Oilseed Brassica* 1(2):66-74

Butron A, Widstrom N, Snook M, Wiseman B (2002). Recurrent selection for corn earworm (Lepidoptera: Noctuidae) resistance in three closely related corn southern synthetics. *Journal of. Economics and Entomoogy*. 95: 458-462.

Canadian Food Inspection Agency. (1994). The Biology of maize (*Zea may* L.) Ottawa, Ontario *K1A* 0Y9

Carena, M .J, Bergman, G., Riveland, N., Eriksmoen, E., Halvorson, M. (2009). Breeding maize for higher yield and quality under drought stress *Maydica* 54: 287-296

Chahal, G.S. and Gosal, S.S. (2002). Principles and procedures of plant breeding: Biotechnological and Conventional approaches, *Narosa Publishing House*, New Delhi, India.

Chavez, A., de Souza, C.L. and de Souza, A.P. (2005). Use of partial inbred S_3 lines for the development of maize single cross.*Maydica* 113-121

CIMMYT. (2000). CIMMYT-Zimbabwe: 2000 Research highlights. Harare, Zimbabwe

Comstock, R.E. and Moll, R.H., (1963). Genotype by environment interactions. In: Statistical Genetics and Plant Breeding. *NAS-NRC*. pp. 164-196.

Crossa, J., Fox, P.N., Peiffer, W.N., Rajaram, S. and Gouch, H.G. (1990). AMMI adjustment for statistical analysis of international wheat trial.

Crossa, J. (1990). Statistical analysis of multi-location trials. *Advances in Agronomy* 44:55-85.

Crossa, J. and Cornelius, P.L. (1997). Sites regression and shifted multiplicative modelclustering of cultivar trial sites under heterogeneity of error variances. *Crop Science* 37: 406-415.

Crow, J.F. (1998). 90 Years Ago: The beginning of hybrid maize. Genetics society of America.*Genetics*148: 923–928

Dabholkar, A.R. (1999).Elements of biometrical genetics.*Concept Publishing Company*. New Delhi, India

Dehghani, H, Ebadi, A. and Yousefi, A. (2006). Biplot analysis of genotype by environment interaction for barley yield in Iran.*Agronomy journal* 98:388-393

Denmead, O.T. and Shaw, R.H. (1960). The effect of soil moisture stress at different stages of growth on the development and yield of corn. *Agronomy Journal*. 52: 2728

Dowswell, C. R., Paliwal, R. L.and Ronald, P. C. (1996). Maize in the third world. *West view Press*, Inc. Pp.1 – 19. CIMMYT 2000. CIMMYT-Zimbabwe: 2000 Researchhighlights. Harare, Zimbabwe.

Dudley, J. W., and R. H. Moll.(1969). Interpretation and use of estimates of heritability and genetic variances in plant breeding. *Crop Sci*ence, *9*:257-262

Edmeades, G.O., Bolaños, J. and Chapman, S.C.(1997). Value of secondary traits in selecting for drought tolerance in tropical maize. *In* Edmeades,G.O., Banziger,M. Mickelson,H.R., and Pena-Valdivia,C.B. (eds.), Developing Drought and Low N Tolerant Maize. Proceedings of a Symposium, Elbatán, Mexico, 222-234. Mexico, D.F.

Esechie, H.A, Rodriguez, V. and Al-Asmi H. (2004).Comparison of local and exotic maize varieties for stalk lodging components in a desert climate. *European Journal of Agronomy*, 21(1): 21-30.

FAOSTAT.(2008). Statistical Database of Food and Agriculture Organization of the United Nations http://www.fao.org/waicent/portal/statistics_en.asp.

Finlay, K.W. and Wilkinson, G.N. (1963). The analysis of adaptation in a plant breeding program .*Australian Journal of Agricultural Research* 14: 742-754.

Gabriel, K. R. (1971). The biplot graphic display of matrices with application to principal component analysis. *Biometrika* 58:453-467.

Gama, E.E.G. and Hallauer, A.R. (1980). Stability of hybrids produced from selected and unselected lines of maize. *Crop Science.* 20(6): 623-626.

Gauch, H.G. and Zobel, R.W. (1997). Identifying mega-environments and targeting genotypes. *Crop Science* 37(2): 311-326.

Golam, F., Farhana, N. N., Zain, M. F., Majid, N.Z, Rahman, M. M, Rahman, M. M, and Kadir, M.A. (2011). Grain yield and associated traits of maize (*Zea mays* L.) genotypes in Malaysian tropical environment. *African Journal of Agricultural Research* Vol.6(28), pp: 6147-6154,

Grada, F. and Ciulca, S. (2012). Evaluation of grain yield stability for some maize hybrids using regression analysis. *Journal of Horticulture, Forestry and Biotechnology*. 123 Vol 16(1): 123-126

Hallauer, A.R. and Miranda, F.J.B. (1988). Quantitative genetics in maize breeding. 2nd ed. Iowa State University Press, Ames. pp: 683-689

Hussain, N., Khan, M. Y and Baloch, M. S. (2011). Screening of maize varieties for grain yield at Dera Ismail Khan. *journal of Animal and Plant Science*., 21(3): 626-628.

IITA, (1992). Sustainable Food Production in Sub-Saharan Africa. 1. IITA's Contribution. Ibadan, Nigeria: IITA.

Issa, A. B. (2009). Genotype by Environment Interaction and yield stability of maize hybrids evaluated in Ethiopia.*Thesis pdf*

Islam, M., Javed, H.I, Malik, H.N, and Ur-Rhaman.H. (2008). Genotype by EnvironmentInteraction among different maize varieties in Pakistan. *Pakistan Journal of Agriculture Research* vol l9 no 1

Jackson P., Robertson, M., Cooper, M. and Hammer, G.L. (1998). The rophysiological understanding in plant breeding: From a breeding perspective. *Field Crops Research* 49: 11-37.

Kandus, M. D.,Almorza, R. Boggio, R. and Salerno, J.C. (2010). Statistical models for evaluating the genotype-environment interaction in maize (*Zea mays* L.)

Kang, M. S. (1994). Applied Quantitative Genetics. M.S. Kang Publisher, Baton Rouge, LA, USA. Pp: 99 – 111

Kang, M.S, Gorman, .D.P, and Pham, H.N. (1991). Application of stability statistic to international maize yield trial. Baton Rouge LA, 70803-2110 USA Theory A*pply Genetics* 81:161-165

Kang, M.S. and Gorman, D.D. (1989). Genotype × Environment Interaction in Maize. *Agronomy Journal*., 81: 662-664.

Khalil, A.I, Ur- Rahman, H., Ur-Rehman, N., Arif, M, Khalil, I. H, Iqbal, M., Hidayatullah, A.K., Sajjad, M. and Ishaq, M. (2011). Evaluation of maize hybrids for grain yield stability in North-West of Pakistan, *Sarhad Journal of Agriculture*. Vol.27, No.2, 213

Kim, S.K. (1994). Genetics of maize tolerance of Striga hermonthica. *Crop Science*. 34: 900-907.

Kroonenberg, P. M. (1995). Introduction to biplots for G x E tables.Department of Mathematics, research Report 51, University of Queensland, Australia.

Magari and Kang, M.S. (1993). Genotype selection via a new yield-stability statistic in maize yield trials, Kluwer Academic publishers, Netherlands, *Euphytica*, 70:105-111.

Malik, H., Malik, S.I., .Hussain, M.Ur-Rehman, S., Habib, C. and Javid, I. (2005). Genetic correlation among various Quantitive characters in maize (*Zea mays l*) hybrids. *Journal of Agriculture& Social Sciences* 01–3–262–265 http://www.ijabjass.org

McCann, J.C. (2005). Maize and Grace: Africa's encounter with a new world crop, 1500-2000. Cambridge: Harvard University press, USA.

Millennium Development Authority. (2006). Maize, Soya and Rice production and Processing, Accra, Ghana p: 2-4 http://www.mida.gov.gh/mcaghana.php.

MoFA(2006). Statistics Research and Information Directorate of Ghana.Maize value chain study in Ghana, enhancing efficiency and competitiveness. Ministry of Food and Agriculture, Accra.

Nachit, M., Sorrells, M.E., Zobel, R.W., Gauch, H.G., Fischer, R.A., Coffman, W.R. (1992). Association of environmental variables with sites means grain yield and components of genotype by environment interaction in durum wheat. *Journal of Genetics and Breeding*. 46: 369372.

Nemati, A, Sedghi, M., Sharifi, R. S.and Seiedi M. N. (2009). Investigation of correlation between traits and path analysis of corn (Z*ea mays* L.) grain yield at the climate of Ardabil region (Northwest Iran) *Notulae Botanicae Horti Agrobotanici* 37 (1):194-198

Obeng-Antwi, K., Ewool, M.B and Tengan, M.L. (2011). Drafted report on maize varietal evaluation in Ghana. CSIR-Crop Research Institute/ACDI/VOCA-ADVANCE

Obeng-Bio.E. (2010). Selection and ranking of local and exotic maize (*Zea mays* l.) genotypes to drought stress in Ghana. *MSc Thesis*, Department of Crop and Soil Sciences, Faculty of Agriculture Kwame Nkrumah University Science and Technology. Ghana

Ochse, J. J, Soule, M. J, Dijkman M. J. and Welbery, C. (1996). The major cereals ranked in terms of production in tropical and Sub-tropical agriculture.Vol.11. Macmillan Company New York.

Odewale, J.O, Collins, A., Ataga, C.D., Odiowaya, G., Ahanor, M.J., Edokpayi, A.A.,Okoye, M.N. and Uwadiae, E.O. (2012). Comparison of yield and stability assessmentof five coconut (*Cocos nucifera* L.) varieties in a lethal yellow disease (LYD) endemic field over nine different environments. *World Journal of Agricultural Sciences* 8 (3): 229-233: 1817-3047

. Orlyan, N. A., Zubko D. G., Orlyan, N. A. and Goleva, G. G. (1999). Correlation analysis in breeding ultra early maturing maize hybrids. *Kukuruzai Sorgo*, 6:9-12.

Pswarayi, A. and Vivek, B. S. (2008). Combining ability among CIMMYT's early maturing maize (*Zea mays* L.) germplasm under stress and non-stress conditions and identification of testers. *Euphytica* 162**:** 353-362.

Paliwal, R. L.(2000). Breeding Special Purpose Maize.In: R. L. Paliwal, (ed.), Tropical maize improvement and production. FAO plant production and protection series No 28 Rome Italy, pp. 211-223

Pioneer. (2010). Increasing crop yields and farmer profitability through hybrid maize.

Rasul, S., Khanm, I.M, Javed, M.M. and ul-Haq.I.(2005). Stability and adaptability of maize genotypes in Pakistan.*Journal of Applied Sciences Research* 1(3): 307-312

Ramagosa, I., Fox, P.N., Garcia, Del Moral, L.F., Ramos, J. M., Roca De Togores, F. and Molina Cano, J.L. (1993). Integration of statistical and physiological analyses of adaptation of near-isogenic barley lines. *Theoy of Apply Genetics*. *86*, 822-826.

Rather, A.G., Sheikh, F.A. and Wani, S.A. (1999). Variability and correlation studies in maize (*Zea mays* L.) under rainfed conditions. *Advance. Plant Science.,* 12: 539–42

SAS Institute, Inc. (2003). SAS proprietary software, SAS Institute, Inc, Cary, NC, Canada.

Sallah,P.Y.K, Abdulai, M.S. and Obeng-Antwi, K. (2004). Genotype x environmentinteraction in three maturity groups of maize cultivars, *African crop Science Journal,*Vol 12, N0 2; pp 95-104.

Sallah, P. Y. K. (1986). Maize Improvement Research in Ghana with special reference to Guinea Savannah zone of Ghana, organized by the CRI/GTZ joint project. Nyankpala Agriculture experimental station Nyankpala Agriculture College April 8-10 1986 pp 12

Smale, M., Byerlee, D. and Jayne, T. (2011). Maize Revolutions in Sub-Saharan Africa Policy Research Working Paper WPS5659.pp; 3-9

Steel, R.G.D and Torrie, J.H. (1980). Principles and procedures of Statistics, Abiometrical approach, 2nd Ed McGraw-hill book company pp 195-220.

Suzuki, D., Griffiths, A. and Lewontin, R. (1981). An introduction to genetic analysis.

W. H.Freeman and Company. San Francisco, USA.

Tengan, K. M. L. (2010). Conversion of okomassa normal maize open pollinated maize variety to quality protein maize using the backcross breeding approach MSc..*Thesis Pdf,* Department of Crop and Soil Sciences of The Faculty of Agriculture, Kwame Nkrumah University of Science and Technology,

Tonk, F. A., Ilker, E. and Tosun, M. (2010). Evaluation of genotype x environment interactions in maize hybrids using GGE biplot analysis. *Crop breeding and applied biotechnology* 11: 1-9, 2011

Troyer, A. F and Larkins, J. R. (1985): Selection for early flowering in corn: 10 late synthetics. *Crop Science*. 25. 695-697.

Twumasi–Afriyie, S, Badu–Apraku, B. Sallah, P.Y.K, and Dzah, B.D. (1992). The potentials of maize as a source of quality protein for Ghana. A paper presented at the twelfth national maize and legumes workshop organized by Ghana Grains Development Project, Crops Research Institute, march 1992, pp 9.

Tyagi, S. D and Khan, M. H. (2009). Genotypeby environment interaction and stability analysis for yield and its components in soybean (*Glycine max* L.) Merrill] Department of plant breeding and genetics K.P.G College Simbhoali, Giziabad kmudasirhafiz@yahoo.com

Vargas, M., Crossa, J., Van Eeuwijk, F.A., Ramirez, M. E. and Sayre, K.(1999). Using AMMI, factorial regression and partial least squares regression models for interpreting genotype by environment interaction. *Crop Science* 39: 955-967

Vivek, B.S, Crossa, J. and Alvarado G. (2009). Heterosis and combining ability among cimmyt's mid-altitude early to intermediate maturing maize (*Zea mays* L.*)* population. *Maydica* 54: 97-107

Yan, W. (2001). GGE biplot a Windows application for graphical analysis of multi-environment trial data and other types of two way data. *Agronomy. Journal*. 93: 1111–1118

Yan, W. (2002). Singular-value partitioning in biplot analysis of multi-environment trial data. *Agronnomy. Journal*. 94:990-996

Yan, W. and Hunt, L. A. (2001). Interpretation of genotype by environment interaction for winter wheat yield in Ontario. *Crop Science*., 41: 19-25.

Yan, W. and Tinker, N. A. (2006). Biplot analysis of multi-environment trial data: Principles and application. *Canadian Journal of Plant Science*. 86: 623-645

Yang, R.C, Crossa, J., Cornelius, P.L. and Burgucerio, J. (2009). Biplot analysis of genotype by environment interaction: Proceed with caution. *Crop Science Society of America*, 49: 1564-1576, USA

Zivanovic, T., Vracarevic, M., Krstanovic, S. and Surlan-Momirovic, G.(2004). Selection of uniformity and yield stability in maize. Institute of biological sciences, *Journal of Agricultural Sciences* Vol. 49, No 1: 117-130

Zsubori, Z., Gyenes-Hegyi, Z., Illés, O., Pók,I., Rácz,F. and Szőke,C.(2002). Inheritance of plant and ear height in maize (Z*ea mays L*). Agricultural Research Institute of the Hungarian Academy of Sciences, Martonvásár

LIST OF APPENDICES

Appendix 1: Analysis of variance for grain yield (kg ha^{-1}) for 90 early maturing hybrids evaluated at Fumesua during 2012 growing season.

Source of variation	Degrees of freedom	Sum of Squares	Mean Square	Variance	Pr> F
Replication	1	1912966	1912966	2.44	0.1216
Genotype	89	180399336	2026959**	2.59	< .0001
Error	89	69687734	783008		
Total	179	252000036			
CV (%)		19.3			
Lsd (0.05)		1758			

Appendix 2: Analysis of variance for grain yield (kg ha^{-1}) for 90 early maturing hybrids evaluated at Ejura during 2012 growing season.

Source of Variation	Degrees of freedom	Sum of Squares	Mean Squares	Variance	Pr> F
Replication	1	267158	267158	0.3	0.5855
Genotype	89	150166898	1687269*	1.89	0.015
Error	89	79342844	891493		
Total	179	229776900			
CV (%)		26.8			
Lsd (0.05)		1876			

Appendix 3: Analysis of variance for grain yield (kg ha^{-1}) for 90 early maturing hybrids evaluated at Kpeve during 2012 growing season.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance	Pr>F
Replication	1	2465962	2465962	2.38	0.126
Genotype	89	352473168	3960373**	3.83	<.0001
Error	89	92067469	1034466		
Total	179	447006599			
CV (%)		17.9			
Lsd (0.05)		2021			

Appendix 4: Combined analysis of variance with the proportion of total variance attributable to source of variation for grain yield (kg ha^{-1}) of 90 early maturing maize hybrids evaluated in three locations in Ghana during 2012 growing season

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance	p>F	Explain
Replication	1	1978949	1978949	2.18	0.1406	0.91
Environment	2	419665423	209832711**	231.5	<0.001**	96.0
Genotype	89	464334452	5217241**	5.76	<0.001**	2.5
Genotype x Environment	178	218704950	1228680*	1.36	0.0121*	0.59
Error	269	243765185	906190			
Total	539	1348448958		240.8		100
CV (%)		20.7				
Lsd (0.05)		1082				

****P<0.01 highly significant *P<0.5 significant**

Appendix 5: Combined ANOVA for days to 50% silking of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	Sum of Squares	Mean Squares	Variance	F pr.
Replication	1	195.6	195.6	41.4	
Environment	2	6269.8	3134.9**	663**	<.0.001
Genotype	89	1697.5	19.1**	4.0**	<.0.001
Genotype x Environment	178	1109.9	6.2	1.3*	0.020
Residual	269	1271.9	4.7		
Total	539	10544.7			
CV (%)	4.3				
Lsd (0.05)	2.5				

Appendix 6: Combined ANOVA for days to 50% tasseling of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	Sum of Squares	Mean Squares	Variance.	F pr.
Replication	1	170.0	170.0	47.0	
Environment	2	8505.7	4253**	1175.2**	<.0.001
Genotype	89	1269.3	14.3**	3.9**	<.0.001
Genotype x Environment	178	873.6	4.9*	1.4*	0.012
Residual	269	973.5	3.6		
Total	539	11792.1			
CV (%)		4			
Lsd (0.05)		2.2			

Appendix 7: Combined ANOVA for plant height of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	Sum of Squares	Mean Squares	variance	F pr.
Replication	1	39	39	0	
Environment	2	117552	58776**	231**	<.001
Genotype	89	102875	1156**	5**	<.001
Genotype x Environment	178	50517	284	1	0.205
Residual	269	68329	254		
Total	539	339312			
CV (%)		9.9			
Lsd (0.05)		18			

Appendix 8: Combined ANOVA for ear height of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	Sum of Squares.	Mean Squares	Variance	F pr.
Replication	1	33	33	0	
Environment	2	45915	22957**	198**	<.001
Genotype	89	39690	446**	4**	<.001
Genotype x Environment	178	23641	133	1	0.159
Residual	269	31230	116		
Total	539	140509			
CV (%)		14			
Lsd (0.05)		12.2			

Appendix 9: Combined ANOVA for cob length of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	Sum of Squares	Mean Squares	Variance	F pr.
Replication	1	11.1	11.1	6.9	
Environment	2	295.9	148.0	92.**	< 0.001
Genotype	89	562.3	6.3	3.9*	< 0.001
Genotype x Environment	178	363.0	2.0	1.3	0.039
Residual	269	432.6	1.6		
Total	539	1664.796			
CV (%)		9.5			
Lsd (0.05)		1.4			

Appendix 10: Combined ANOVA for cob diameter of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	Sum of Squares	Mean Squares	Variance	F pr.
Replication	1	0.0	0.0	0.2	
Environment	2	15.7	7.9**	33**	< 0.001
Genotype	89	56.2	0.6**	2.6*	< 0.001
Genotype x Environment	178	43.9	0.2	1.0	0.410
Residual	269	64.4	0.2		
Total	539	180.2			
CV (%)	11.6				
Lsd (0.05)	0.5				

Appendix 11: Combined ANOVA for seed length of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance.	F pr.
Replication	1	0.01	0.001	1.52	
Environment	2	0.17	0.08**	12.87**	<0.001
Genotype	89	0.97	0.01*	1.66*	0.001
Genotype x Environment	178	1.07	0.01	0.92	0.737
Residual	269	1.77	0.01		
Total	539	3.98			
CV (%)		8.1			
Lsd (0.05)		0.09			

Appendix 12: Combined ANOVA for seed diameter of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degree of freedom	Sum of Squares	Mean Squares	Variance	F Pr.
Replication	1	0.008	0.008	1.900	
Environment	2	0.050	0.025	5.9*	0.003
Genotype	89	0.635	0.007	1.7*	0.001
Genotype x Environment	178	0.755	0.004	1.0	0.453
Residual	269	1.124	0.004		
Total	539	2.572			
CV (%)		7.8			
Lsd (0.05)		0.07			

Appendix 13: Combined ANOVA for ASI of 90 early maturing maize hybrids evaluated across three locations

Source of variation	Degrees of freedom	sum of squares	Mean squares	Variance	F pr.
Replication	1	0.5	0.006		
Genotype	89	37.6	0.423	0.89	0.736
Environment	2	278.4	139.2	293**	<.001
Genotype X environment	178	79.5	0.446	0.94	0.669
Residual	269	127.6	0.475		
Total	539	523.6			
CV (%)		24.4			
Lsd (0.05)		0.75			

Appendix 14: Mean grain yield (kgha^{-1}) and agronomic performance of early maturing maize hybrids evaluated across three locations in the Forest, Forest Transition and Coastal Transitional zones of Ghana during 2012 growing season.

Entry name	Yield	Rank	DS	DT	PHT	EHT	CL	CD	SDL	SDD	ASI
TZEI-36 X TZEI-39	6296	1	47.7	45.5	179	78	14.3	4.2	1	0.88	2.7
TZEI-33 X TZEI-19	6066	2	51.2	48.2	174	87	14	4.6	1.1	0.87	2.8
TZEI-35 X TZEI-19	5850	3	51.5	48.3	183	97	13.7	4.4	1.1	0.83	3
TZEI-45 X TZEI-34	5838	4	51	48.2	175	78	13.6	4.4	1	0.79	2.8
TZEI-22 X TZEI-45	5784	5	51	48.3	178	90	14.3	4.3	1	0.83	3
TZEI-2 X TZEI-22	5770	6	50.7	47.5	183	91	13.4	4.5	1.1	0.88	3.3
TZEI-34 X TZEI-7	5682	7	46.3	44.2	164	80	12.6	4.4	1	0.86	2.7
TZEI-10 X TZEI-11	5617	8	48	45.7	162	80	14.1	4.1	1	0.85	2.7
TZEI-48 X TZEI-45	5514	9	51.2	48.2	164	85	14.9	3.9	1	0.85	2.8
TZEI-22 X TZEI-48	5456	10	51	48.3	173	94	13.6	4.3	1	0.83	3
TZEI-34 X TZEI-46	5453	11	51.5	48.3	155	69	14.5	4.3	1	0.8	2.8
TZEI-11 X TZEI-15	5436	12	48.5	45.8	159	76	14.7	4.2	1	0.8	2.8
TZEI-41 X TZEI-30	5406	13	49.8	47.2	168	85	13.5	6	1	0.82	2.7
TZEI-25 X TZEI-23	5380	14	48	45.3	156	81	14	4.1	1	0.85	3.2

TZEI-48 X TZEI-20	5352	15	49.8	47.2	175	92	14.5	4.3	1	0.8	3
TZEI-12 X TZEI-15	5280	16	47.5	45.2	165	70	14.5	4.3	1	0.85	3
TZEI-3 X TZEI-1	5266	17	49.7	47.2	181	81	13.9	4.6	1	0.9	2.8
TZEI-41 X TZEI-47	5234	18	51	48.2	152	74	13.3	4	1.5	0.83	2.6
TZEI-31 X TZEI-7	5221	19	49.5	47	174	80	14.5	4.4	1.1	0.88	2.8
TZEI-36 X TZEI-35	5189	20	48	45.5	166	78	14.7	4.1	1.1	0.82	2.5
TZEI-30 X TZEI-47	5185	21	48	51	184	82	14.5	4.3	1	0.82	2.8
TZEI-42 X TZEI-30	5179	22	50.5	47.8	176	82	13.4	4.4	1	0.85	2.7
TZEI-27 X TZEI-19	5143	23	52.7	49.3	179	79	13.1	4.4	1.1	0.88	2.3
TZEI-13 X TZEI-10	5124	24	49.2	46.8	150	71	13.8	4.2	1	0.82	2.3
TZEI-25 X TZEI-14	5115	25	51.8	48.7	157	77	15	4.3	1	0.78	2.7
TZEI-38 X TZEI-36	5076	26	50	47.5	166	78	12.8	4.2	1	0.83	2.8
TZEI-1 X TZEI-19	5022	27	51.5	48.5	181	91	12.7	4.2	1	0.83	2.7
TZEI-22 X TZEI-46	5008	28	51	47.7	175	80	14.4	4.3	1	0.8	3
TZEI-17 X TZEI-15	4995	29	49	46.5	148	76	13.7	4.3	1	0.84	2.8
TZEI-13 X TZEI-17	4987	30	49.8	47	148	71	14.2	4.4	1	0.82	3

TZEI-14 X TZEI-17	4984	31	51.5	48.7	147	70	13.8	3.9	0.9	0.77	2.7
TZEI-35 X TZEI-16	4949	32	51	48.3	164	77	13.6	4.2	1	0.85	
TZEI-48 X TZEI-16	4943	33	49.2	46.8	163	87	14.5	4	1	0.83	2.3
TZEI-12 X TZEI-20	4940	34	49.8	47.3	157	76	13.6	4.4	1	0.87	2.7
TZEI-19 X TZEI-48	4926	35	51.5	48.5	176	89	13.9	4.2	1	0.85	2.8
TZEI-46 X TZEI-34	4917	36	51.2	48.5	166	77	14	4.5	1.1	0.81	2.7
TZEI-39 X TZEI-36	4915	37	48	43.7	182	85	14.3	4	1	0.82	3.1
TZEI-14 X TZEI-15	4888	38	50.3	47.5	144	70	13.9	4.2	1	0.82	2.8
TZEI-36 X TZEI-34	4877	39	49	46.5	176	83	13.7	4.2	1.1	0.83	3.6
TZEI-36 X TZEI-33	4838	40	49.2	46.8	170	79	13.5	4.3	1	0.83	
TZEI-11 X TZEI-9	4738	41	49.8	47.7	152	69	13.7	4.2	1	0.85	3.2
TZEI-12 X TZEI-9	4821	42	47.5	45	149	74	13.6	4.2	1	0.8	3.1
TZEI-24 X TZEI-12	4820	43	51.5	48.8	155	68	15.1	4.2	1	0.83	2.6
TZEI-4 X TZEI-3	4802	44	49.2	46.8	168	82	13.4	4.6	1	0.87	2.2
TZEI-36 X TZEI-38	4800	45	51.2	48.3	162	75	12.6	4.2	1	0.83	3
TZEI-27 X TZEI-19	4784	46	51.2	48.3	165	92	13.1	4.6	1	0.8	3.1

TZEI-22 X TZEI-18	4779	47	49.8	47.2	163	76	12.7	4.3	1	0.92	3
TZEI-27 X TZEI-14	4766	48	51.3	48.8	158	79	13.7	4.2	1	0.85	2.6
TZEI-25 X TZEI-27	4740	49	51.5	48.8	167	73	14.9	4.1	1.1	0.87	3.1
TZEI-19 X TZEI-46	4705	50	52.5	49.7	169	88	13.2	4.2	1.1	0.8	2.8
TZEI-9 X TZEI-12	4698	51	46	43.5	151	72	14.5	4	1	0.8	2.3
TZEI- 9 X TZEI-15	4676	52	46.3	44	142	68	12.8	4	1	0.87	2.7
TZEI-2 X TZEI-34	4675	53	50.2	47.5	154	74	13.1	4.5	1	0.81	2.7
TZEI-41 X TZEI-36	4642	54	48.7	47.2	159	71	13.2	4.1	1.1	0.8	2.8
TZEI- 33X TZEI-46	4631	55	52.7	49.7	166	80	13	4.2	1	0.85	3.3
TZEI- 33X TZEI-3	4587	56	50.7	47.7	165	79	11.9	4.8	1	0.82	3.3
TZEI-9 X TZEI-11	4558	57	52.3	49.3	147	69	11.7	4.1	1	0.87	2.6
TZEI-31 X TZEI-18	4521	58	49.7	46.7	167	77	13.7	4.2	1	0.87	2.7
TZEI- 10X TZEI-12	4509	59	49.5	46.8	149	71	13.6	4.1	1	0.8	3
TZEI- 18X TZEI-26	4505	60	50.5	47.3	166	83	12.4	4.2	1	0.83	3
TZEI9- X TZEI-10	4499	61	48.3	47.8	151	72	14.4	4	1	0.8	2.7
TZEI-42 X TZEI-47	4482	62	50.8	48.2	154	78	14.2	4.4	1.1	0.83	3

TZEI-22 X TZEI-20	4364	63	49.2	46.2	167	78	13.7	4	1	0.83	2.7
TZEI-47 X TZEI-34	4333	64	50.5	47.7	164	77	13.6	4.3	1	0.87	2.6
TZEI-36 X TZEI-22	4308	65	50.5	47.8	168	76	13	4.1	1	0.85	2.8
TZEI-34 X TZEI-3	4285	66	50	47	159	69	12.6	4.6	1.1	0.82	3
TZEI- 4 X TZEI-2	4261	67	51.5	48.7	161	73	12.2	4.6	1	0.85	2.5
TZEI-34 X TZEI-22	4228	68	51.2	48.5	165	77	12.1	4.3	1	0.82	2.5
TZEI33- X TZEI-2	4174	69	51.2	48	176	68	12.2	4.6	1	0.83	3.2
TZEI-22 X TZEI-20	4161	70	51.2	47.7	158	76	13.4	4.2	1	0.85	2.7
TZEI-39 X TZEI-22	4106	71	50.5	47.7	186	88	12.3	4.3	1	0.84	2.5
TZEI-39 X TZEI-34	4082	72	52.5	49.3	153	72	12.7	4.3	1	0.83	3.3
TZEI-14 X TZEI-16	4081	73	53.3	50.5	154	71	12.7	3.8	1	0.79	2.7
TZEI-30 X TZEI-31	4078	74	50.5	47.5	164	67	12.1	4.5	1.1	0.87	2.8
TZEI-41 X TZEI-22	4037	75	51.2	48.2	173	85	12.6	5.6	1	0.9	2.6
TZEI-24 X TZEI-23	4012	76	46.8	44.8	136	56	12.9	4.3	1	0.82	2.5
TZEI-39 X TZEI-30	3950	77	49.7	47.2	181	81	12.9	4.2	1	0.8	2.8
TZEI-19 X TZEI-18	3923	78	51.2	48.7	172	87	13.5	4.2	1	0.83	2.5

TZEI-27 X TZEI-9	3919	79	47.8	45.5	146	82	12	4	1	0.83	2.3
TZEI-23 X TZEI-15	3898	80	49.3	46.5	149	70	12.1	4.1	1	0.82	2.8
TZEI-18 X TZEI-46	3712	81	52.2	49	161	79	14.7	4.1	1.1	0.83	3
TZEI-36 X TZEI-20	3462	82	50.7	47.8	137	71	13.1	4.1	1	0.85	2.7
TZEI-38 X TZEI-35	3263	83	50.7	47.7	159	77	12.3	4.5	1	0.8	3.2
TZEI-17 X TZEI-16	2987	84	53.8	50.3	134	61	12.7	3.5	0.9	0.82	2.7
TZEI-32 X TZEI-5	2983	85	51.3	48.5	168	86	12.5	4.5	1	0.83	2.7
TZEI-11 X TZEI-12	2847	86	52.3	49.7	140	64	13.6	3.7	0.9	0.8	2.8
TZEI-28 X TZEI-14	2354	87	53.8	50.8	133	59	9.4	2.9	0.8	0.65	3
TZEI-46 X TZEI-47	1817	88	54.2	50.3	140	67	11	3.6	1	0.81	3.7
TZEI-12 X TZEI-13	1194	89	54.3	51.2	116	52	10.9	3.6	0.9	0.83	3
TZEI-45 X TZEI-47	1058	90	54.3	51	127	55	11.7	3.3	0.9	0.8	2.7
Grand Mean	**4598**		**50.3**	**48**	**161**	**77**	**13.6**	**4.2**	**1**	**0.83**	**2.8**
CV (%)	**20.7**		**4.3**	**4**	**9.9**	**14**	**9.5**	**11.6**	**8.1**	**7.8**	**24.4**
Lsd (0.05)	**1082**		**2.5**	**2.2**	**18.1**	**12.2**	**1.4**	**0.6**	**0.09**	**0.07**	**0.78**

DS = 50 % days to silking, DT = 50 % days to tasseling, PHT = plant height, EHT = ear height, CL = cob length, CD = cob diameter, SDL = seed length, and SDD = seed diameter.

Appendix 15: List of 90 single crosses of early maturing maize hybrids evaluated at three locations in southern Ghana during 2012 major growing season.

Entry No.	Code	Entry Name	Entry No	Code	Entry Name
1	P1	TZEI-9 X TZEI-12	46	P46	TZEI-19 X TZEI-46
2	P2	TZEI-24 X TZEI-23	47	P47	TZEI-36 X TZEI-20
3	P3	TZEI-48 X TZEI-20	48	P48	TZEI-14 X TZEI-15
4	P4	TZEI-4 X TZEI-2	49	P49	TZEI-12 X TZEI-9
5	P5	TZEI-3 X TZEI-1	50	P50	TZEI-34 X TZEI-46
6	P6	TZEI-2 X TZEI-19	51	P51	TZEI-1 X TZEI-19
7	P7	TZEI-9 X TZEI-11	52	P52	TZEI-22 X TZEI-48
8	P8	TZEI-41 X TZEI-47	53	P53	TZEI-33 X TZEI-19
9	P9	TZEI-41 X TZEI-30	54	P54	TZEI-39 X TZEI-22
10	P10	TZEI-11 X TZEI-15	55	P55	TZEI- 9 X TZEI-10
11	P11	TZEI-46 X TZEI-34	56	P56	TZEI-25 X TZEI-27
12	P12	TZEI-10 X TZEI-11	57	P57	TZEI-22 X TZEI-20
13	P13	TZEI-32 X TZEI-5	58	P58	TZEI-14 X TZEI-16
14	P14	TZEI-38 X TZEI-35	59	P59	TZEI-22 X TZEI-45
15	P15	TZEI-12 X TZEI-13	60	P60	TZEI-19 X TZEI-48
16	P16	TZEI-35 X TZEI-19	61	P61	TZEI-33 X TZEI-2
17	P17	TZEI-39 X TZEI-34	62	P62	TZEI-12 X TZEI-20
18	P18	TZEI-22 X TZEI-20	63	P63	TZEI-22 X TZEI-18
19	P19	TZEI-39 X TZEI-36	64	P64	TZEI-28 X TZEI-14
20	P20	TZEI-45 X TZEI-47	65	P65	TZEI-2 X TZEI-34
21	P21	TZEI-36 X TZEI-34	66	P66	TZEI-34 X TZEI-22
22	P22	TZEI-17 X TZEI-16	67	P67	TZEI-36 X TZEI-38
23	P23	TZEI-11 X TZEI-12	68	P68	TZEI-2 X TZEI-22
24	P24	TZEI-13 X TZEI-17	69	P69	TZEI-27 X TZEI-19
25	P25	TZEI-35 X TZEI-16	70	P70	TZEI-18 X TZEI-46
26	P26	TZEI-25 X TZEI-23	71	P71	TZEI-36 X TZEI-35
27	P27	TZEI-48 X TZEI-45	72	P72	TZEI-14 X TZEI-17
28	P28	TZEI-42 X TZEI-47	73	P73	TZEI-27 X TZEI-14

29	P29	TZEI-31 X TZEI-18	74	P74	TZEI-36 X TZEI-33
30	P30	TZEI-9 X TZEI-15	75	P75	TZEI-31 X TZEI-7
31	P31	TZEI-47 X TZEI-34	76	P76	TZEI-22 X TZEI-46
32	P32	TZEI-17 X TZEI-15	77	P77	TZEI-42 X TZEI-30
33	P33	TZEI-39 X TZEI-30	78	P78	TZEI-34 X TZEI-7
34	P34	TZEI-41 X TZEI-46	79	P79	TZEI-33 X TZEI-3
35	P35	TZEI-30 X TZEI-47	80	P80	TZEI-46 X TZEI-47
36	P36	TZEI-11 X TZEI-9	81	P81	TZEI-41 X TZEI-22
37	P37	TZEI-27 X TZEI-9	82	P82	TZEI-33 X TZEI-46
38	P38	TZEI-36 X TZEI-22	83	P83	TZEI-25 X TZEI-14
39	P39	TZEI-13 X TZEI-10	84	P84	TZEI-34 X TZEI-3
40	P40	TZEI-36 X TZEI-39	85	P85	TZEI-19 X TZEI-18
41	P41	TZEI-45 X TZEI-34	86	P86	TZEI-48 X TZEI-16
42	P42	TZEI-12 X TZEI-15	87	P87	TZEI-10 X TZEI-12
43	P43	TZEI-30 X TZEI-31	88	P88	TZEI-18 X TZEI-26
44	P44	TZEI-4 X TZEI-3	89	P89	TZEI- 24 X TZEI-12
45	P45	TZEI-23 X TZEI-15	90	P90	TZEI-38 X TZEI-36

Appendix 16: Grain yield (kg ha^{-1}) and relative ranking of early maturing maize hybrids evaluated at three locations in the Forest, Forest Transition and Coastal Transition zones of Ghana in 2012.

Code	Name of entry	Kpeve	Rank	Ejura	Rank	Fumesua	Rank	Across	Rank
P1	TZEI-9 X TZEI-12	5686	54	4356	15	4051	65	4698	51
P2	TZEI-24 X TZEI-23	4874	70	3196	62	3965	67	4012	76
P3	TZEI-48 X TZEI-20	6287	29	4247	20	5522	16	5352	15
P4	TZEI-4 X TZEI-2	6025	24	3490	44	3267	83	4261	67
P5	TZEI-3 X TZEI-1	6333	28	4061	26	5404	22	5266	17
P6	TZEI-2 X TZEI-19	5520	59	4018	28	4814	41	4784	46
P7	TZEI-9 X TZEI-11	5444	60	3913	32	4317	57	4558	57
P8	TZEI-41 X TZEI-47	6450	24	3179	65	6072	7	5234	18
P9	TZEI-41 X TZEI-30	6017	35	4086	24	6115	5	5406	13
P10	TZEI-11 X TZEI-15	6992	14	4075	25	5242	27	5436	12
P11	TZEI-46 X TZEI-34	5792	45	4653	9	4307	58	4917	36
P12	TZEI-10 X TZEI-11	5722	50	4969	3	6159	3	5617	8
P13	TZEI-32 X TZEI-5	4144	81	1933	85	2873	85	2983	85
P14	TZEI-38 X TZEI-35	3848	83	1890	86	4050	66	3263	83
P15	TZEI-12 X TZEI-13	1172	89	1044	88	1366	90	1194	89
P16	TZEI-35 X TZEI-19	7777	4	3998	30	5774	10	5850	3
P17	TZEI-39 X TZEI-34	5624	56	3290	56	3332	81	4082	72
P18	TZEI-22 X TZEI-20	4863	71	3584	42	4644	47	4364	63
P19	TZEI-39 X TZEI-36	4619	72	4570	11	5555	14	4915	37
P20	TZEI-45 X TZEI-47	934	90	597	89	1645	89	1058	90

P21	TZEI-36 X TZEI-34	5711	51	3905	33	5016	35	4877	39
P22	TZEI-17 X TZEI-16	3769	84	2329	83	2862	86	2987	84
P23	TZEI-11 X TZEI-12	2677	87	2487	82	3379	80	2847	86
P24	TZEI-13 X TZEI-17	5788	46	3731	39	5441	20	4987	30
P25	TZEI-25 X TZEI-16	6844	18	3415	48	4587	50	4949	32
P26	TZEI-25 X TZEI-23	5393	61	5269	1	5478	18	5380	14
P27	TZEI-48 X TZEI-45	7483	8	3540	43	5519	17	5514	9
P28	TZEI-42 X TZEI-47	5852	43	3022	71	4572	51	4482	62
P29	TZEI-31 X TZEI-18	5654	55	3423	47	4487	54	4521	58
P30	TZEI-9 X TZEI-15	5864	42	3402	50	4763	43	4676	52
P31	TZEI-47 X TZEI-34	5024	68	3892	34	4083	63	4333	64
P32	TZEI-17 X TZEI-15	5145	67	4305	18	5536	15	4995	29
P33	TZEI- 39X TZEI-30	4485	74	3886	35	3478	79	3950	77
P34	TZEI-41 X TZEI-36	4986	69	3094	68	5847	9	4642	54
P35	TZEI-30 X TZEI-47	6185	30	3254	59	6118	4	5185	21
P36	TZEI-11 X TZEI-9	4602	73	4630	10	5281	26	4838	41
P37	TZEI-27 X TZEI-9	5173	66	2828	78	3755	74	3919	79
P38	TZEI-36 X TZEI-22	5190	65	2993	74	4741	44	4308	65
P39	TZEI-13 X TZEI-10	6869	16	4686	8	3819	71	5125	24
P40	TZEI-36 X TZEI-39	7661	6	4949	4	6278	1	6296	1
P41	TZEI-45 X TZEI-34	8508	1	3681	41	5324	24	5838	4
P42	TZEI-12 X TZEI-15	6544	21	4345	17	4952	37	5280	16
P43	TZEI-30 X TZEI-31	4341	78	3049	70	4844	40	4078	74
P44	TZEI-4 X TZEI-3	5573	58	4768	5	4064	64	4802	44
P45	TZEI-23X TZEI-15	4357	77	3193	63	4143	62	3898	80
P46	TZEI-19 X TZEI-46	6982	15	2930	75	4204	60	4705	50

P47	TZEI-36 X TZEI-20	4065	82	2994	73	3327	82	3462	82
P48	TZEI-14 X TZEI-15	6524	23	3078	69	5061	32	4888	38
P49	TZEI-12 X TZEI-9	5920	38	3367	54	5178	29	4821	42
P50	TZEI-34 X TZEI-46	7551	7	3377	52	5432	21	5453	11
P51	TZEI-1 X TZEI-19	7294	10	2700	79	5070	31	5022	27
P52	TZEI-22 X TZEI-48	6838	19	3447	46	6082	6	5456	10
P53	TZEI-33 X TZEI-19	7710	5	5150	2	5339	23	6066	2
P54	TZEI-39 X TZEI-22	4469	75	3190	64	4660	46	4106	71
P55	TZEI-9 X TZEI-10	4264	79	4216	22	5016	34	4499	61
P56	TZEI-25 X TZEI-27	5844	44	2928	76	5448	19	4740	49
P57	TZEI-22 X TZEI-20	3715	85	4349	16	4420	55	4161	70
P58	TZEI-14 X TZEI-16	5742	48	2617	81	3884	69	4081	73
P59	TZEI-22 X TZEI-45	8126	3	3203	60	6024	8	5784	5
P60	TZEI-19 X TZEI-48	5919	39	4049	27	4810	42	4926	35
P61	TZEI-33 X TZEI-2	5875	41	2236	84	4412	56	4174	69
P62	TZEI-12 X TZEI-20	6056	33	3175	66	5590	13	4940	34
P63	TZEI-22 X TZEI-18	7018	13	3391	51	3927	68	4779	47
P64	TZEI-28 X TZEI-14	3496	86	579	90	2985	84	2354	87
P65	TZEI-2 X TZEI-34	5692	53	3698	40	4636	48	4675	53
P66	TZEI-34 X TZEI-22	5249	64	3280	57	4155	61	4228	68
P67	TZEI-36 X TZEI-38	5710	52	4166	23	4525	52	4800	45
P68	TZEI-2 X TZEI-22	8295	2	4275	19	4740	45	5770	6
P69	TZEI-27 X TZEI-19	7021	12	3457	45	4951	38	5143	23
P70	TZEI-18 X TZEI-46	4417	56	3197	61	3520	77	3712	81
P71	TZEI-36 X TZEI-35	7224	11	4512	12	3830	70	5189	20
P72	TZEI-14 X TZEI-17	6070	32	3753	28	5128	30	4984	31

P73	TZEI-27 X TZEI-14	6810	20	2866	77	4621	49	4766	48
P74	TZEI-36 X TZEI-35	6009	36	4017	29	4488	53	4838	40
P75	TZEI-31 X TZEI-7	6397	26	4410	14	4855	39	5221	19
P76	TZEI-22 X TZEI-46	7420	9	3788	36	3815	72	5008	28
P77	TZEI-42 X TZEI-30	6354	27	3414	49	5770	11	5179	22
P78	TZEI-34 X TZEI-7	6864	17	3993	31	6189	2	5682	7
P79	TZEI-33 X TZEI-3	5737	49	4240	21	3783	73	4587	56
P80	TZEI-46 X TZEI-47	1547	88	1163	87	2742	87	1817	88
P81	TZEI-41 X TZEI-22	5332	62	3262	58	3516	78	4037	75
P82	TZEI-33 X TZEI-46	6445	25	3756	37	3692	76	4631	55
P83	TZEI-25 X TZEI-14	5611	57	4708	6	5026	33	5115	25
P84	TZEI-34 X TZEI-3	5745	47	3376	53	3733	75	4285	66
P85	TZEI-19 X TZEI-18	5888	40	3159	67	2723	88	3923	78
P86	TZEI-48 X TZEI-16	6172	31	3349	55	5308	25	4943	33
P87	TZEI-10 X TZEI-12	5921	37	2644	80	4963	36	4509	59
P88	TZEI-18 X TZEI-26	5331	63	3000	72	5183	28	4505	60
P89	TZEI-24 X TZEI-24	4172	80	4696	7	5592	12	4820	43
P90	TZEI-38 X TZEI-36	6532	22	4453	13	4242	59	5076	26
GM		**5680**		**3520**		**4594**		**4598**	
CV(%)		**18**		**27**		**19**		**21**	
Lsd (0.05)		**2021**		**1876**		**1758**		**1082**	