GENOTYPE BY ENVIRONMENT INTERACTION AND GRAIN YIELD STABILITY OF EXTRA-EARLY MAIZE (*Zea mays* L.) HYBRIDS EVALUATED AT THREE LOCATIONS IN GHANA

BY

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JULY, 2012

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A Thesis Submitted To The Department Of Crop And Soil Sciences Of The Faculty Of Agriculture, Kwame Nkrumah University Of Science And Technology, In Partial Fulfilment Of The Requirement For The Award Of

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GLORIA ADU BOAKYEWAA

(BSc Agriculture)

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DECLARATION

I hereby declare that except for the references cited in relation to other works, 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.

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DEDICATION

I dedicate this work to my family and best friend Godfred Owusu.

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ABSTRACT

In Ghana, genotype by environment interaction effect on maize grain yield is usually significant due to considerable variation in soil and weather conditions at growing sites. A proper understanding of the effects of G x E interactions on variety evaluation and cultivar recommendations is vital. It was with this aim that this study was conducted to evaluate forty-four extra-early maize hybrids obtained from the International Institute of Tropical Agriculture (IITA) and a local check hybrid to identify stable and high-yielding hybrids with superior agronomic performance for commercial production in Ghana during the 2011 growing season. These hybrids were evaluated at Ejura, Fumesua and Kpeve; representing the forest transition, forest and transition zones of Ghana. The effects of genotype (G), location (L) and G × L were found to be highly significant ($P < 0{\cdot}01$) for grain yield. The variations among the genotypes (G) were the largest components of variance (79.16 %) for grain yield, whereas the locations effects and G × L accounted for 7.04 % and 7.37 %, respectively. The genotype main effect plus genotype × environment interaction biplot explained 0.97 of total variations in the sum of squares for grain yield. The GGE biplot procedure provided results in terms of stability and performance of the hybrids. This method identified the hybrids TZEEI 5 x TZEEI 4, TZEEI 1 x TZEEI 22, TZEEI 20 x TZEEI 19, TZEEI 31 x TZEE I8 and TZEEI 13 x TZEEI 22 as the high yielding and stable. TZEEI 11 x TZEEI 22, TZEEI 5 x TZEEI 50, TZEEI 8 x TZEEI 51 and TZEEI 8 x TZEEI24 are low yielding but stable. TZEEI 2 x TZEEI 11 and TZEEI 15 x TZEEI 8 was high yielding and the least stable and TZEEI 13 x TZEEI 12 and TZEEI 26 x TZEEI 24 had both low yielding and low stability. It identified Ejura, located in the forest transition zone, as the ideal testing environment for these set of hybrids.

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LIST OF ABBREVIATIONS

AMMI	Additive Main effects and Multiplicative Interaction
ANOVA	Analysis of variance
ASI	Anthesis -silking interval
ASV	AMMI Stability Value
ASL	Above sea level
ATC	average tester axis
CIDA	Canadian International Development Agency
CIMMYT	International Maize and Wheat Improvement Center
Cm	Centimetre
CRI	Crops Research Institute
CSA	Central Statistical Agency
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of Variation
DF	Degrees of Freedom
DA	Days to anthesis
DYSK	Days to silking
EHARV	Ear harvested
EHT	Ear height
EPP	Ears per plant

et al	And others
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural organization Statistics
G x E	Genotype x Environment
GEI	Genotype × environment interaction
GGDP	Ghana Grains Development Project
GGE	Genotype main effect plus genotype × environment interaction
Ha	Hectare
HC	Husk cover
IITA	International Institute of Tropical Agriculture
JLR	Joint Linear Regression
Km	Kilometre
LR	Linear Regression
LSD	Least Significant Difference
M	Meter
MET	Multi-environment Trials
ML	Maximum Likelihood
Mm	Millimetre
MS	Mean Square
MiDA	Millennium Development Authority
NPSA	Non-parametric Stability Analysis
OPV	Open-Pollinated Maize Variety
PC	Principal component
PCA	Principal Component Analysis
PHARV	Plant harvested

PHT Plant height

RL Root lodging

SARI Savanna Agriculture Research Institute

SL Stalk lodging

SREG Site regression

SS Sum of Squares

T Tons

UN United Nations

CHAPTER ONE

1.0 INTRODUCTION

Maize is virtually grown in all of the agro-ecological zones of Ghana. However, the main areas accounting for more than 60% of the 1,871,700 metric tonnes produced in 2010 (FAO, 2010) are in the middle parts of Ghana or the transitional zone. The area includes Brong Ahafo and parts of Ashanti and Eastern regions of Ghana. An estimated 15% is grown in the three northern regions of the country. The availability of the extra-early cultivars has significantly contributed to the rapid spread of maize into the savannas, replacing the traditional crops such as sorghum and millet, especially in the Sudan savanna and the northern fringes of the northern Guinea savanna, where the short duration of rainfall had long prevented maize production. These earlier maturing cultivars can be harvested much earlier in the season than the traditional sorghum and millet crops and thus play very important roles in filling the hunger gap in July in the savanna zone, when all food reserves are depleted after the long dry season. Furthermore, there is a high demand for the early (90–95 days to maturity) and extra-early (80–85 days to maturity) cultivars in the Forest zone for peri-urban maize consumers. They provide farmers the opportunity to market the early crop as green maize at a premium price, in addition to being compatible with cassava for intercropping. Another important advantage of the early and extra-early cultivars is that they provide farmers in various growing areas with flexibility in the dates of planting (IITA, 1992). Under traditional production methods and rain-fed conditions, maize yields are well below their attainable levels; maize yields in Ghana average approximately 1.5 metric tons per hectare. However, yields as high as 5.0-5.5 metric tons per hectare have been realized by farmers using improved seeds, fertilizer, mechanization and irrigation (MiDA, 2010). Lower yields have been attributed to traditional farming practices, the use of low-yielding varieties, poor soil fertility and limited use of fertilizers, low plant population, and inappropriate weed control. There is a believed that significant potential improvements in yields could be achieved through the use of hybrid maize varieties (Agribusiness Trade Project, 2008). Since maize production in developing countries is extensively dependent on rain-fed agriculture, vulnerability due to erratic rainfall and weather variability may be combated using extra-early hybrids (Oseni and Masarirambi, 2011). Thus extra-early maize cultivars will be indispensable in improving maize productivity and enhancing food security in Ghana. Obviously agricultural production in Ghana is fraught with risks and unpredictability (drought, parasitic weeds, and low - N etc.) and high inputs use do not always result in high returns. However, improvements may most often be realized by farmers who do invest in using improved seeds, fertilizer and improved production practices.

Crop breeders have been striving to develop genotypes with superior grain yield, quality and other desirable characteristics over a wide range of different environmental conditions. Genotype x environment interaction (GEI) effects is some of the main complications in the selection of broad adaptation in most breeding programmes. GEI refers to the differential ranking of genotype among locations or years. The phenotype of an organism is determined by the combined effects of the environment and the genotype which interact with one another. Numerous studies have shown that a proper understanding of the environmental and genetic factors causing the interactions as well as an assessment of their importance in the relevant GEI system could have a large impact on plant breeding (Magari and Kang, 1993; Basford and Cooper, 1998). GEI occurs universally when genotypes are evaluated in several different environments (Becker and Léon, 1988; Magari, 1989; Kang, 1990). Magari and Kang (1993) found that the contribution of different environmental factors, to the yield stability of maize in yield trials, had a significant impact on the heterogeneity of the results.

When environmental differences are large, like in Ghana, it may be expected that the interaction of GEI will also be higher. As a result, one cultivar may have the highest yield in some environments while a second cultivar may excel in others. Hence, it is important to know the magnitude of the interactions in the selection of genotypes across several environments besides calculating the average performance of the genotypes under evaluation (Fehr, 1991; Gauch and Zobel, 1997).

Various studies have been conducted to analyze the effect of GEI in Sub-saharan Africa and on Ghanaian maize varieties (Fakorede and Adeyemo, 1986; Badu-Apraku *et al*., 1995; 2003; Abdulai *et al*. 2007). However, the changing environmental conditions, the expansion of maize to new agro-ecologies coupled with inadequate maize varieties available for the different environments necessitate a rigorous and continuous study of GEI for a dynamic crop improvement programme. Hence, the study was conducted to evaluate 45 extra-early maize hybrids to identify stable and high-yielding hybrids with superior agronomic performance for commercial production in Ghana.

The specific objectives of the study were;

I. To evaluate the presence of genotype by environment interactions in the 45 extra-early maize hybrids, and to determine their grain yields and agronomic performance.

II. To use the genotype main effect plus genotype by environment interaction (GGE) biplot methodology to determine grain yield stability and the pattern of response of the 45 extra-early maize hybrids across three environments, and to identify the best performing ones for future uses in Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin of Maize

There are lots of different views on the origin of maize. However, it is generally believed to have originated from Mexico and Central America from where it spread to the rest of Latin America, the Caribbean, the U.S, Canada and then to Asia and Africa (Dowswell *et al*., 1996).

Maize tolerates a wide range of environmental conditions; heavy rainfall and semi-arid, cool and very hot climates but grows well in warm sunny climates with adequate moisture (Purseglove, 1992). It is thus grown from latitude 58^{o}N without interruption through the temperate, sub-tropical and tropical regions of the world to latitude 40^{o}S (Hallauer and Miranda, 1988). It is reported to have the highest grain yield potential of all the cereals (Dowswell *et al*., 1996).

2.2 Maize Development and Release in Ghana

Maize variety development in Ghana in the past was concentrated on developing open-pollinated maize varieties because of socio-economic reasons, which included lack of efficient seed production and marketing systems. The importance of hybrid maize over the open-pollinated varieties were later realised and the development of hybrid maize varieties were rather started late in Ghana. Prior to the inception of the Ghana Grains Development Project (GGDP) in 1979, plant breeders working at CRI had developed and released several improved varieties of maize. Due to socio-economic reasons, these earlier improved open-pollinated varieties generated little interest among farmers, however, and they were not widely adopted. Under the GGDP, the Ghanaian national maize breeding programme was reorganized, and the links between CRI and CIMMYT were greatly strengthened. This collaborative process involving breeders from CIMMYT, IITA and CRI and Ghanaian farmers led eventually to the release, beginning in 1984, a series of maize varieties and hybrids. Aburotia, Dobidi, Kawanzie, Golden Crystal and Satia-2 were improved open-pollinated varieties released in 1984. Through 1988 to 1990 new open-pollinated varieties with improved yield potentials and resistance to maize streak virus were released. These included Okomasa, Abeleehi and Dorke SR (Morris *et al*., 1999).

Quality protein maize (QPM) development programme was started in 1989 at the crops research institute this initially led to the release of an open-pollinated variety, obatanpa, which has been widely adopted in Ghana and elsewhere in Africa and beyond (Twumasi-Afriyie *et al.*, 1992). Alongside the development of obatanpa, a QPM hybrid maize development programme was initiated in 1991. Three 3-ways QPM hybrids, namely, GH110-5 (Mamaba), GH132-28 (Dadaba), and GH2328-88 (CIDA-ba) developed in this programme were very productive, yielding among 6.3 and 7.3 t/ha on experimental station, representing an increase of 19 to 38 percent over obatanpa. The QPM hybrids were, therefore, released for production in 1997 (Morris *et al*., 1999).

Through further collaboration between the national maize programme, CIMMYT and IITA, CRI developed four new varieties of maize to replace the old varieties in 2007, which were released over a decade ago and had started showing deficiencies in important traits such as disease susceptibility and lodging in response to numerous demands by consumers and industry. The varieties included CSIR-CRI Golden Jubilee, CSIR-CRI “Aziga”, CSIR-CRI “Etuto-Pibi” and CSIR-CRI “Akposoe” (GNA, 2007).

In 2010, four quality protein maize (QPM) varieties tolerant to drought and *Striga hermontica* were also released to boost maize production in drought and *Striga* endemic areas. The varieties, which are early and extra-early maturing, were released jointly by the Crops Research Institute (CRI) and the Savanna Agricultural Research Institute (SARI) of the council for scientific and industrial research (CSIR) of Ghana. Of the four varieties, three were developed by IITA in the earliness programme and have the IITA designation, EV DT-W 99 STR QPM Co; TZE-W Pop STR QPM C0; and TZEE-W Pop STR QPM C0 (an extra-early maturing variety). The fourth, an intermediate maturing drought-tolerant QPM hybrid, was developed in the national maize programme of Ghana.

Over the years more attention has been given to the intermediate to late maturing maize varieties comparable to extra-early maize varieties in Ghana due to their supposed high grain yields. Maize in the tropics is continually exposed to different forms of drought and nitrogen stress. Extra-early maturing hybrids that are drought-avoiding and tolerant to low-N could stabilize yields in Ghana (Badu-Apraku *et al*, 2011a). In the future, the release and commercial production of extra-early hybrid maize will be more suitable to maintain food security and improve the livelihood of small-holder farmers in Ghana in the face of the current global climatic change trends.

2.3 Maize Production and Uses

Maize (*Zea mays* L.), with a remarkable yield potential among the cereals, is the third most 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). Among the developing economies, it ranks first in Latin America and Africa (Dowswell *et al*., 1996). In the tropics, maize is grown in 66 countries and is of major economic significance in 61 of those countries (Paliwal, 2000).

In developing countries maize is generally used as food, while in the developed world, it is used widely as a major source of carbohydrate in animal feed and as industrial raw materials for wet and dry milling (Paliwal, 2000). Apart from a strong demand for starches and sweeteners, there has been exponential growth in maize-based ethanol production, fuelled by rapid increases in world energy and petrol prices (FAO Food Outlook, 2006). Most people regard maize as a breakfast cereal. However, in a processed form it is also found as fuel (ethanol) and starch. Starch in turn undergoes enzymatic conversion into products such as sorbitol, dextrine, sorbic and lactic acid, and appears in household items such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint (Paliwal, 2000).

2.4 The Importance of Early and Extra-Early Maturing Maize Varieties

In Sub-Saharan Africa, in efforts to cope with rainfall risk, many small-scale farmers purposefully pursue multiple planting dates over extended periods of time in order to ensure that at least part of the crop is successful (Rorhrbach, 1998). According to Pswarayi and Vivek (2007), farmers grow early maturing maize varieties because such varieties provide an early harvest to bridge the hunger period before harvest of a full season crop, and this is especially important in areas where two growing seasons occur in a year. Farmers can produce an early maturing crop during the secondary, short season, enabling the planting of a full season maize crop or other crops in the following main season.

Early maturing varieties offer flexibility in planting dates which enables (1) multiple planting in a season to spread the risk of loosing a single crop to mid season droughts (2) late planting during delayed onset of rainfall and (3) avoidance of known terminal drought during the cropping season (Pswarayi and Vivek, 2007). Early maturing varieties are ideal for offseason plantings in drying riverbeds and are also suitable for intercropping as they provide less competition for moisture, light and nutrients than the late maturing varieties (CIMMYT, 2000). Using maize maturity to maintain grain yield in response to late season drought, in trials conducted in two locations over two seasons, Larson and Clegg (1999) found that use of well adapted early maturing hybrids could improve yield stability. They also found that an early maturing hybrid, Pioneer 3737, produced yield comparable to those of late maturing hybrids in all instances. Their results indicated that well adapted early maturing hybrids could produce yields comparable to late maturing hybrids in areas where late season water stress was prevalent. Kamara *et al*. (2006) evaluated three maize varieties that had been identified either as drought tolerant or as able to escape drought. The drought tolerant maize was evaluated on farmers' fields for two years. Farmers selected extra-early maturing varieties, placing great emphasis on earliness of crop maturity rather than on yield.

According to the prediction of Zhang *et al*. (2009), the gap between requirement and productivity of maize would be 5.1×10^{10} kg by 2020. The total production of maize may be enhanced by a variety of ways such as planting area expansion, soil improvement, fertilization and tillage optimization. However, the most effective and direct way is to breed varieties with high yielding potential and wide adaptability (Golbashy *et al*., 2010). Studies have proved that 52.9% of maize yield increment was attributed to varieties, and the rate of improvement was 89.1 kg/ ha per year (Ci *et al*., 2010; Li and Wang, 2009).

2.5 Genotype x Environment Interaction

The differential response of a genotype across environments is defined as the genotype (G) × environment (E) interaction GEI; Beyene *et al*. (2011) and Bernardo (2002) indicated that it is the rule in most quantitative characteristics. GEI makes it difficult to select the best performing and most stable genotypes. It is an important consideration in plant breeding programmes because it impedes progress from selection in any given environment (Yau, 1995). In breeding programmes, genotype stability for yield and agronomic performance is an important breeding objective. Previous research suggests that selection of superior genotypes for grain yield and agronomic traits in maize hybrid performance trials is impacted by GEI (Butron *et al*., 2004). The phenotype of an individual is determined by the effects of its genotype and the environment surrounding it. The effects of genotype and environment on phenotype may not be always independent. The phenotypic response to change in environment is not the same for all genotypes, the consequences of variation in phenotype depend upon the environment. Very often breeders encounter situations where the relative rankings of varieties change from location to location and/or from year to year.

GEI is of major consequence to breeders in the process of developing improved varieties. When varieties are grown at several locations for testing their performance, their relative rankings usually do not remain the same. This causes difficulty in demonstrating significant superiority of any variety. GEI is present whether varieties are pure lines, single crosses, double crosses, top-crosses, S1 lines or any other material with which the breeder is working (Dabholkar, 1999).

An understanding of environmental and genotypic causes of GEI is important at all stages of plant breeding, including ideotype design, parent selection based on traits, and selection based on yield (Jackson *et al.*, 1998). Understanding of the causes of GEI can be used to establish breeding objectives, to identify ideal test conditions, and to formulate recommendations for areas of optimal cultivar adaptation. It can also help to reduce the cost of extensive genotype evaluation by eliminating unnecessary testing sites and by fine tuning the breeding programmes. The presence of a large GEI may necessitate establishment of additional testing sites, thus increasing the cost of developing commercially important varieties (Kang, 1996).

2.5.1 Classification of Genotype x Environment Interaction

Different interest of breeders, as well as, seed producers and distributors, on the one hand, and farmers on the other hand, arise an important question: How broadly can a variety be adapted and be able at the same time to have a high yield in a given location? Farmers want a small genotype x year interaction. Breeders, seed producers and distributors want a broadly adapted genotype that will be a great success across a great area (small genotype x location interaction). Dividing broad areas into regions that are, first of all different units based on climatic and soil conditions, is one of methods to find out a compromising solution for these various interests (Babic *et al*., 2010). Successful breeding for targeted growing areas largely depends on identification of the main sources of phenotypic variation in that region. To obtain variety possessing diminished genotype by environment interaction for those predominant sources of variation means good ratio between the stable and high yield (Petrovic *et al*., 2009).

When two genotypes A and B are grown in two different environments E1 and E2, six types of interactions, some of which are crossovers and others non-crossovers, are possible (Allard and Bradshow, 1964). The two varieties may show similar behaviour i.e. parallel lines when grown in two environments (Figure 1.0a) which indicate independence in the performance of genotype and environment. The presence of GEI leads to non-parallel response curves of varieties without intersecting each other (Figure 1.0b) or with interaction (Figure 1.0c). The existence of non-intersecting but non-parallel lines suggests the relative ranking of varieties remains the same, though their absolute differences vary with the environment. The GEI is considered as crossover or qualitative if it leads to change in relative ranking of genotypes in different environments. The non-crossover or quantitative GEI, on the other hand results in differential change of mean but not of ranking of different genotypes.

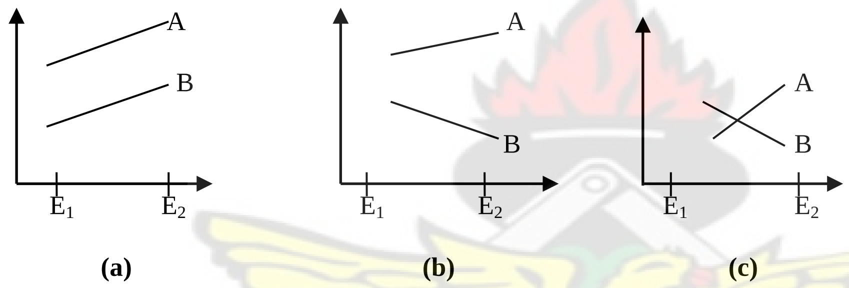

Figure 1.0 Different types of G x E interactions shown by two varieties grown in two environments

Crossover interactions are of interest in plant breeding because they affect the genotypes to be selected in a given environment. Such interactions also suggest that genotypes are specifically adapted to environments. The non-crossover interaction, on the other hand, influences the nature and magnitude of components of genetic variances and other related parameters like heritability and genetic advance. GEI can also be classified according to the behaviour of the genotypes, i.e. either stable or adapted to a particular environment in terms of their yield or in some other interesting agronomic feature. Generally, the term stability refers to the ability of the genotypes to be consistent, both with high or low yield levels in various environments. On the other hand, adaptability refers to the adjustment of an organism to its environment, e.g., a genotype that produces high yields in specific environmental conditions and poor yields in another environment (Balzarini *et al*., 2005). Several statistical methods have been developed to study the different types of GEI such as site regression analysis, SREG (Cornelius et al., 1996; Crossa and Cornelius, 1997; Crossa et al., 2002), also called GGE (Genotype Main Effect plus Genotype-Environment Interaction), and AMMI model. These techniques allow the detection of GEI in terms of the crossover effect resulting from great changes in the ranking of the genotypes across the environments.

Kandus *et al.* (2010) evaluated GEI using AMMI and SREG for the yield of six balanced lethal systems lines (BLS61, BLS91, BLS1, BLS101, BLS16 and BLS14), two different "Normal" lines (without BLS) (LP109 and LP521) and a hybrid (ACA 2000) and classified genotypes performances and behaviour in terms of stability or adaptability into the following groups. The first group included hybrids with more stable yield; "BLS-BLS" and "BLS-Normal. Second group included hybrids that showed a specific adaptation to one or several environments that were correlated; ACA2000 and LP109 x LP521, BLS101 x LP109 and BLS101 x BLS1. The third and fourth groups consisted of hybrids specifically adapted to most of the environments evaluated and produced the highest levels of yield; ACA2000, LP109 x LP521 and BLS101 x BLS1 and the opposite trend occurred for BLS14 x BLS1 and BLS101 x LP109 hybrids, respectively. They attributed the observed differential behaviours to the existence of crossover interactions between them.

Crossa *et al*. 2002 and Yan *et al*. 2000 stated that in the two-dimensional biplot like the site regression analysis (GGE biplot); if the primary effects of the sites from the SREG model are all of the same nature (positive/negative), PC1 presents a non crossover GEI. A genotype with a larger PC1 score has a greater average yield and its performance varies across environments in direct proportion to the environment PC1 score. A similar finding was reported by Beyene *et al*. 2007 from their work on genotype by environment interactions and yield stability of stem borer resistant maize hybrids across 4 locations in Kenya. They concluded that out of the 35 hybrids used for the study only two Experimental hybrids, CKIR07004 and CKIR07013, were highly desirable in terms of grain yield (> 7.5 t/ha) and stability across environments, Indicating the suitability of the hybrids for cultivation in Kenya and other similar environments in sub-Saharan Africa, also implying the other genotypes were unstable across environments. Also, in a study with 17 maize genotypes consisting of 14 experimental hybrids and 3 hybrids check evaluated at 4 different locations, it was observed that 4 different experimental hybrids gave the highest grain yield in different environment. These differential and same rankings of hybrids maize genotypes across test environments demonstrated that there exists possibly in both crossover and non-crossover GEI (Emre *et al*., 2009).

2.5.2 Significance of Genotype x Environment Interaction

Factors that are of economic relevance may be related to complex or polygenic characteristics, and show a high influence of the environment. Because of this, in breeding programmes, various experiments are conducted in several locations to evaluate grain yield. In these experiments, changes in the relative performance of the genotype in different environments are usually observed (Kandus *et al*., 2010). The genotype by environment interaction is an important aspect in both, plant breeding programmes and the introduction of new maize hybrids. Deitos *et al*., (2006), indicated that genotype x environment interaction is important for plant breeding because it affects the genetic gain and recommendation and selection of cultivars with wide adaptability. On the other hand, different genotypes may have different performance in each region that can be capitalized to maximize productivity (Souza *et al*., 2008). Kang and Gorman (1989) indicated that, a significant GEI for a quantitative trait such as seed yield can seriously limit the efforts on selecting superior genotypes for improved cultivar development. For variety trials, which are tested in the same locations (L) and genotypes (G) and over years (Y), G x E analysis of variance may be partitioned into components due to G x L, G x Y and G x L x Y. Significance of mean square for G x L generally suggests that the region for which genotypes are being bred comprise of a number of special environments. In such circumstances the geographic region could be subdivided into sub regions which are relatively homogeneous. Varieties should be bred which are specifically adapted to these ecotypes. Implication of G x Y interaction is very different from G x L interaction. This is so because year to year fluctuations in the weather conditions cannot be predicted in advance and breeders can hardly aim their programmes to develop varieties suited to particular years (Dabholkar, 1999).

In some situations, environmental variation is predictable but can also be corrected. For example, saline soils can be corrected by certain agronomic practices or by addition of some amendments. This is easier and quicker than developing varieties suitable for such situations. However, breeding of varieties suitable for saline or acidic soils is low cost input and also a relatively permanent solution to the problem.

Genotype by environment interactions can be an outcome of genotype rank changes from one environment to another, a difference in scale among environments, or a combination of these phenomena. According to Becker and Léon (1988), cultivar rank changes are of greater importance than scale change interactions in cultivar trials conducted over a series of environments. Hence, GEI is critical only if it involves significant crossover interactions (significant reversal in genotypic rank across environments). Kang and Gorman (1989) noted that GEI reduce the correlation between the genotype and the phenotype hindering the evaluation of the genetic potential of the cultivars.

2.5.3 The Concept of Stability and Adaptability

In maize breeding programmes, the search for genotypes with high grain yield adapted in the most varied environments is one of the most important objectives for breeders. For that, the choice of populations that show good genetic homeostasis is essential for yield increases. Souza *et al*. (2009) stated that, GEI is important for plant breeding because it affects the genetic gain and recommendation and selection of cultivars with wide adaptability. On the other hand, different genotypes have different performance in each region that can be capitalized to maximize productivity (Souza *et al*., 2008).

In attempts to provide a definition, Byth (1981) and Clements *et al.* (1983) argued that the term adaptation applied to both a 'condition' and a 'process'. The interpretation of their definition requires further consideration. The 'condition' or level of adaptation possessed by individuals or populations (hereafter referred to collectively as genotype) refers to the genetic constitution of a genotype and how this matches the plant to the environment it occupies. Ultimately this is a function of the genes possessed by the plant, the regulation of biochemical and physiological processes by these genes during growth and development and how well these are matched with the available environmental resources and possible hazards (Bidinger *et al.*, 1987). Therefore, a difference in the 'condition' of adaptation between individual's results from a genetic difference which influences the matching of their growth and development processes with the environment. Following this, the 'process' of adaptation is viewed as a change in the genetic constitution of individuals as they accumulate genes or a change in gene frequencies within populations which better match growth and development with the environment. From an evolutionary perspective, adaptation is evaluated in terms of reproductive capacity of the individual or Darwinian fitness. Under a particular set of environmental conditions, individuals with better adaptation will produce more offspring. Thus, over time the process of improving adaptation through natural selection will unfold and the level of adaptation of individuals within the population will improve.

The adaptability of a variety over diverse environments is usually tested by its degree of interaction with different growing environments. A variety or genotype is considered to be more adaptive or stable if it has a high mean yield but low degree of fluctuation in yielding ability when grown over diverse environments (Falconer, 1981). According to Simmonds (1962) adaptation has four separable aspects; these are:

1. Specific genotypic adaptation: it is close to adaptation of the corresponding genotypes to a limited environment.
2. General genotypic adaptation: is the capacity of a genotype to produce a range of phenotypes adapted to a variety of environments.
3. Specific population adaptation: is analogous to (1) and is the aspect of specific adaptation of heterogeneous population that is attributable to interaction between components rather than to the adaptations of components themselves.
4. General population adaptation: is analogous to general genotypic adaptation and is the capacity of a heterogeneous population to adapt to a variety of environments.

The concepts of broad and specific adaptation are often used to describe the relative performance of genotypes when adaptation is evaluated in more than one environment. Broad adaptation describes the response of a genotype where superior performance is expressed across the majority of, or all environments, and specific adaptation describes a response where a higher level of performance is expressed in specific environments. In general, the genetic and physiological basis of the distinction between broad and specific adaptation are poorly understood and the concepts are generally statistically defined. Specific adaptation is often associated with the occurrence of G x E interactions. The incidence of these interactions is of particular concern to the plant breeder as they complicate the process of selection for broad adaptation and bring into question the overall effectiveness of such a strategy (Ceccarelli, 1989).

A genotype is also considered to be stable if its environment variance is small. This is called stability statistic, or a biological concept of stability. A stable genotype possesses an unchanged or least changed performance regardless of any variation of the environmental conditions. This concept of stability is useful for quality traits, disease resistance and for stress characters (Baker and Leon, 1988).

Stability analysis provides a general solution for the response of the genotypes to environmental change. In this way, Yates and Cochran (1938) proposed linear regression analysis, which has been widely used and revised by a number of authors (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Lin and Thompson, 1975; Becker and Leon, 1988; Crossa, 1990). Abdulai *et al*. (2007) worked on the GEI of four open pollinated varieties and eight experimental hybrids which were late maturing lowland maize varieties. They concluded that, seven out of the nine genotypes were stable, when b-values alone were considered. When the b-values and the deviations from regression (s^2d) were considered, (GH24 x 1368) x 5012 and (GH22 x 1368) x 5012, were the most stable, but when the coefficient of determination was added to the b-value and s^2d, GH132 - 28 was the most stable genotype.

This analysis, which involves regressing the average of the genotypes on an environmental index (the average yield of all the genotypes evaluated in each environment), provides a stability index. However, the analysis has several limitations and criticisms from both the biological and statistical points of view. The main biological problem appears when only a few very low and very high yielding sites are included in the analysis, and the fit is determined by the genotype behaviour in a few extreme environments (Crossa, 1990). The main statistical problem is that the average of all genotypes evaluated in each environment is not independent of the average of each genotype in a particular environment (Freeman and Perkins, 1971). Another statistical limitation is that the errors associated with the slopes of the genotypes are not statistically independent. The last problem is the assumption of a linear relationship between interaction and environmental means, when the actual responses of the genotypes to the environments are intrinsically multi-variated (Crossa, 1990). Multivariate analysis has three main purposes: (i) to eliminate"noise" in the data set (for example, to distinguish systematic and non-systematic variation); (ii) to summarize the information and (iii) to reveal a structure in the data (Crossa *et al*., 1990; Gauch, 1992).

However, other methods for identifying cultivars with adaptability and stability have been developed and many multivariate techniques are available such as GGE (Genotype main effects and Genotype x Environment interaction) and AMMI (Additive Main effects and Multiplicative Interaction) with new information for cultivars, environmental stratification and genotype x environment interaction (Miranda *et al*., 2009; Yan *et al*., 2000).

2.5.4 Statistical Methods to Measure G x E Interaction

There are many statistical methods available to analyse GEI: for example, combined ANOVA, stability analysis and multivariate methods. Combined ANOVA is more often used to identify the existence of G x E interactions in multi-environmental experiments. However, the main limitation of this analysis is the assumption of homogeneity of variance among environments required to determine genotype differences. Although this analysis allows the determination of the components of variance arising from different factors (genotype, environment and the GEI), it does not allow exploring the response of the genotypes in the non-additive term: the GEI (Zobel *et al*., 1998).

There are other methods for evaluating the performance of hybrids and their genotypic interactions with the environment (Cornelius *et al*., 1996; Crossa, 1990 and Crossa and Cornelius, 1997). These methods differ in the parameters used in the assessment, the biometric procedures employed, and the analysis. The sites regression (SREG) (Crossa and Cornelius, 1997) has been suggested as the appropriate model for analyzing multi-environmental trials when large yield variation is due to environments (Yan *et al*., 2000). The SREG method supplies a graphical display called genotype plus genotype by environment interaction (GGE) biplot that identifies cultivars that are superior in different environments.

Finlay and Wilkinson (1963) also indicated that for dealing with GEI, regression on the environmental means can be used. Pattern analysis methods (Byth *et al.,* 1976.), principal coordinate analysis (Eisemann, 1981), canonical variate analysis and principal component analysis (Zobel *et al*., 1988) with each proving successful in the analysis of univariate GEI data in certain situations.

The usual analysis of variance (ANOVA), having a merely additive model, identifies the GEI as a source but does not analyse it; PCA analysis, on the other hand, is a multiplicative model and hence contains no sources for additive genotype or environment main effects; and linear regression (LR) analysis is able to effectively analyse interaction terms only where the pattern fits a specific regression model. The consequence of fitting inappropriate statistical models to yield trial data is that the interaction may be declared insignificant, although a more appropriate analysis would find agronomically important and statistically significant patterns in the interaction. Since ANOVA, PCA, and LR are sub-cases of the more complete AMMI model, AMMI offers a more appropriate first statistical analysis of yield trials that may have a GEI.

Among the statistical analyses proposed for the interpretation of the GEI based on the use of biplots, the AMMI (additive main effect and multiplicative interaction) model stands out due to the largest group of technical interpretations available (Duarte and Vencovsky, 1999). AMMI analysis interprets the effect of the genotype (G) and sites (E) as additive effects plus the GEI as a multiplicative component and submits it to principal component analysis. Its biplot was identified as GE biplot by Yan *et al*. (2000).

Yan *et al*. (2000) proposed a modification of the conventional AMMI analysis called GGE (genotype main effect and genotype-environment interaction) that has been used for GEI analysis. The GGE analysis pools genotype effect (G) with GE (multiplicative effect) and submits these effects to principal component analysis. According to Yan *et al*. (2000), this biplot is identified as a GGE biplot. The GGE biplot has been recognized as an innovative methodology in biplot graphic analysis to be applied in plant breeding.

In the last years, the AMMI and GGE analyses were debated in relation to graph accuracy. Gauch *et al*. (2008) questioned GGE analysis about the proportion of G + GE retained in the biplot. In other words, these authors claimed that GGE biplot always explained less G + GE than did the AMMI 2 mega-environment analysis, and sometimes, when GGE2 is suppressed in noise, the GGE biplot is even less accurate than AMMI 1 analysis. On the other hand, Yan *et al*. (2007) stated that GGE2 always explained more G + GE than AMMI 1 display resulting in a larger graph accuracy. In addition, GGE2 is a direct biplot product, while the AMMI 2 mega-environment analysis cannot be considered a true biplot because it makes use of a predicted table for "which-won-where" pattern discovery.

AMMI analysis can then be used to diagnose whether or not a specific sub-case provides a more appropriate analysis. AMMI has no specific experimental design requirements, except for a two-way data structure." Although the AMMI analysis of yield trials does not use the data on environmental factors, these factors themselves, such as precipitation, average daily, maximum and minimum temperatures, as well as, their height and amplitudes, nitrogen fertilisers, irrigation and the clay content, very often correlate with the data of the AMMI statistics (Gauch, 1992; Romagosa *et al.*, 1993).

Crossa *et al*. (1990) indicated that the AMMI model can be used to analyze the GEI and to identify the superior hybrid maize genotypes. Also, he pointed out that it can be used in the selection of the best test environments for hybrid maize genotype evaluation. Fan *et al*. (2007) showed that the GGE biplot methodology was a useful tool for identifying locations that optimized hybrid genotypes performance and for making better use of limited resources available for the maize testing programmes.

Annicchiarico (1997) stated that AMMI analysis appears particularly useful for depicting adaptive responses of small grain cereals tested over a wide range of environments. At the same time, the researcher explained that joint regression and AMMI analysis are more likely to perform alike, and provide similar results, for small grain cereals over areas where cold stress is limited.

The vast number of methods proposed to evaluate stability and adaptability are based on phenotypic analyses, where the treatments and or progenies are considered as a fixed effect of the model. However, when the objective is the choice of genotype based on progeny performance, the breeding values can be predicted through mixed models and not just estimated based on phenotypic means (White and Hodge, 1989). Smith *et al*. (2001a) stated that when genotypes and environments are assumed as random and fixed effects, respectively, in mixed models analysis, more realistic results are obtained.

In mixed model context, few alternatives for stability and adaptability study have been available. Van Eeuwijk *et al*. (1995) suggested the singular value decomposition analysis of GE as random effects in the AMMI approach. Similarly, Smith *et al*. (2001b) and Resende and Thompson (2003) presented the factor analytic multiplicative mixed model for GEI analysis considering G and GEI as random effects.

2.6 Correlation of Traits in Maize

Plant height is strongly associated with 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). Earliness and high yield were considered to be in reciprocal ratio to each other. In Hungary, Fleischmann (1974) proposed first the necessity of breaking this negative correlation. Modern varieties produce high yields despite flowering early. There is also a correlation between earliness and ear height. The higher the ear is, the later the plant matures (Surányi and Mándy, 1955), but earliness and lower ear height have no absolute reciprocal effect.

There are correlations between many other traits and plant height. The number of leaves (Allen *et al*., 1973) and the grain yield (McKee *et al*., 1974) are significantly correlated with plant height. In sweet corn, the grain yields (Tan and Yap, 1973) and ear length (Hansen, 1976) showed significant positive correlations with plant and ear height. In popcorn, the grain yield had a positive correlation and the popping expansion a negative correlation with both characters (Verma and Singh, 1979). Obilana and Hallauer (1974) found a significant correlation between plant and ear heights in unselected inbred.

Several workers have attempted to determine linkage between the characters on which the selection for high grain yield can be made. Annapurna *et al*. (1998) found that seed yield was significantly positively correlated with plant height, ear diameter, number of seeds per row and number of rows per cob. You *et al*. (1998) reported significant correlations between yield and number of rows per cob, number of grains per row and 1000-grain weight and also number of grains per row and number of rows per cob. Khatun *et al*. (1999) observed that grain yield per plant was positively and significantly correlated with 1000-grain weight, number of kernels per cob, ear weight and ear insertion height. Orlyan *et al*. (1999) found that the most important traits influencing grain yield are number of grains per row and number of grains per cob. Characters like number of grains per row, 1000-grain weight, and cob diameter and plant height are useful in improving grain yield in hybrids. Maximum correlation of grain yield was obtained with number of kernels per row followed by plant height and cob length (Gautam *et al*., 1999). Cantarero (2000) found that late sowing reduced number of ears per plant, number of grains per ear and grain yield.

The current study sought to evaluate hybrids for yield components and their correlation with certain agronomic attributes as well as genotype by environment interactions in Ghana.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Germplasm Used

Forty-five extra-early maize hybrids, including a locally released check, were used. These hybrids were obtained from the International Institute of Tropical Agriculture (Table 1).

Table 1: Description of the maize hybrids tested across three locations in 2011

Entry number	Entry name (single-cross)	Entry number	Entry name (single-cross)
1	TZEEI 1 x TZEEI 2	23	TZEEI 10 x TZEEI 22
2	TZEEI 1 x TZEEI 22	24	TZEEI 11 x TZEEI 22
3	TZEEI 1 x TZEEI 50	25	TZEEI 11 x TZEEI 24
4	TZEEI 2 x TZEEI 1	26	TZEEI 12 x TZEEI 19
5	TZEEI 2 x TZEEI 11	27	TZEEI 13 x TZEEI 6
6	TZEEI 4 x TZEEI 6	28	TZEEI 13 x TZEEI 12
7	TZEEI 4 x TZEEI 7	29	TZEEI 13 x TZEEI 22
8	TZEEI 4 x TZEEI 39	30	TZEEI 14 x TZEEI 6
9	TZEEI 4 x TZEEI 51	31	TZEEI 15 x TZEEI 8
10	TZEEI 5 x TZEEI 4	32	TZEEI 15 x TZEEI 21
11	TZEEI 5 x TZEEI 23	33	TZEEI 20 x TZEEI 39
12	TZEEI 5 x TZEEI 39	34	TZEEI 20 x TZEEI 19
13	TZEEI 5 x TZEEI 40	35	TZEEI 20 x TZEEI 21
14	TZEEI 5 x TZEEI 50	36	TZEEI 21 x TZEEI 20
15	TZEEI 5 x TZEEI 53	37	TZEEI 21 x TZEEI 39
16	TZEEI 6 x TZEEI 4	38	TZEEI 23 x TZEEI 5
17	TZEEI 6 x TZEEI 36	39	TZEEI 23 x TZEEI 6
18	TZEEI 6 x TZEEI 40	40	TZEEI 23 x TZEEI 39
19	TZEEI 8 x TZEEI 24	41	TZEEI 26 x TZEEI 24
20	TZEEI 8 x TZEEI 51	42	TZEEI 27 x TZEEI 3
21	TZEEI 9 x TZEEI 59	43	TZEEI 29 x TZEEI 26
22	TZEEI 9 x TZEEI 60	44	TZEEI 31 x TZEEI 8
45	Check (Three-way): AKPOSOE		

3.2 Evaluation of Hybrids

3.2.1 Description of the Evaluation Sites

The evaluation sites are located in the Forest, Forest transition and Transition zones of Ghana (Table 2). Fumesua is located in the Ejisu-juabeng district and Ejura is located in Sekye-dumasi district both in the Ashanti Region. Kpeve is found in the South Dayi District in the Volta region. All the locations are among the major maize testing sites in Ghana. They are also believed to be part of the major maize producing areas in Ghana.

Table 2: Description of the test locations used in the study

Location	Latitude	Longitude	Altitude (m ASL)	Mean Seasonal Rainfall *(mm)	Agro ecological zone	Soil Type
Ejura	7^0 38'N	1^0 37'E	229	599.70	Forest transition	Forest/savanna ochrosols
Fumesua	6^o 43'N	1^o 36'W	228	626.86	Forest	Ferric acrisols
Kpeve	3^0 20'N	$0^0$17'E	69	519.11	Transition	Savannah achrosols

*: Mean rainfall during April to July, 2011

3.2.2 Crop Husbandry

Genotypes were planted in 2-row plots of 5 m long and at inter-row spacing of 75 cm and within row spacing of 40 cm. Three seeds per hill were initially planted but were later thinned to two at 3 weeks after planting (WAP). Pre-emergence chemical weed control was practiced and comprised of an application of a combination of Pendimethalin [N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine] and Gesaprim [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] at 1.5 Lha^{-1} and 1.0 Lha^{-1} a.i., respectively at planting. 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 1-2 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.

3.2.3 Experimental Design and Data collection

The genotypes were planted in a Randomised complete block design with two replications at each location during 2011 growing season. The following parameters were measured in the field during the pre-harvest stage:

1. Days to Anthesis: The number of days from planting to the time when 50% of plants have tassels shedding pollen.
2. Days to silking: The number of days from planting to the time when 50% of plants have emerged silks.
3. Plant height: The height of ten plants in centimetres were randomly selected and measured with a graduated measuring stick from the ground level to the node bearing the flag leaf.
4. Ear height: The height of the ear from ground level to the node bearing the uppermost ear from the same plants from which plant heights were recorded were also measured.
5. Root Lodging: the numbers of plants that are root-lodged were scored on a scale of 1-5, where 1 = not lodged and 5 = heavily lodged.
6. Stalk Lodging: the numbers of plants that are stalk-lodged were scored on a scale of 1-5, where 1 = not lodged and 5 = heavily lodged.
7. Husk cover: Husk cover was rated on a scale of 1-5, where 1 = husks tightly arranged and extended beyond the ear tip and 5 = ear tips exposed.

The following parameters were measured during harvesting;

a. Plants Harvested: Total number of plants harvested per plot.

b. Ears Harvested: Total number of ears harvested per plot.

c. Ear Rot: Ear rot was rated on the scale of 1 to 5, where 1 = little or no visible ear rot and 5 = extensive visible ear rot.

d. Moisture: Grain moisture taken by moisture tester at harvest in percentage.

e. Field Weight: The weight of cobs per plot measured in kilograms.

The following data were calculated before the data analysis was done;

The anthesis-silking interval was computed as the difference between days to anthesis and days to silking. Number of ears per plant was obtained by dividing the total number of ears harvested by the total number of plants harvested. The grain yield in kilograms per plot recorded was converted to grain yield in tons per hectare (GYLD) at 15% grain moisture using the formula below:

variances due to each effect. The ANOVA method for estimating variance components consists of equating mean squares to their expectations and solving the resulting set of simultaneous equations as shown in Table 3.

Table 3: Form of variance analysis and expected mean square for the combined data over locations (Kang, 1994)

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

Where; β, g and r are the number of locations, genotypes and replications respectively. σ_e^2 = plot error variance, σ_g^2 = genotypic variance and $\sigma_{g\beta}^2$ = genotype x environnent interaction variance.

The following statistical analyses were performed to test the significance level of grain yield of the genotypes, locations and their interactions:

• Separate trial analysis for each location - This was done for the three separate trials planted across the three locations during 2011 growing season.

• The combined analyses of the trials (across locations) were done in order to determine differences between genotypes across locations and also to determine whether there was a significant difference among locations.

3.4 Correlations among traits

The degree of relationship between any two parameters was determined. Pearson coefficients of correlation were calculated using the hybrids' least Square means for all parameters to determine associations. Two-sided test of correlations different from zero were used to determine their significance. Correlation coefficients range in values between -1 and +1; a perfect negative relationship and a perfect positive relationship respectively.

3.5 Identification of superior hybrids

In an effort to identify superior hybrids to be used for commercial production, a rank sum was calculated by ranking the hybrids' performance in grain yield, days to silking and days to anthesis, ASI, ear height, plant height, stalk lodging, root lodging and ears per plot. The ten best hybrids will be selected based on the rank sum values calculated by summing the ranks of each of the 45 hybrids.

3.6 The models for a GGE biplot

The model for a GGE biplot (Yan, 2002) based on singular value decomposition (SVD) of first two principal components is:

$$\mathbf{Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}} \quad [1]$$

where Y_{ij} is the measured mean of genotype i in environment j, μ is the grand mean, β_j is the main effect of environment j, $\mu + \beta_j$ being the mean yield across all genotypes in environment j, λ_1 and λ_2 are the singular values (SV) for the first and second principal component (PC1 and PC2), respectively, ξ_{1i} and ξ_{2i} are eigenvectors of genotype i for PC1 and PC2, respectively, η_{j1} and η_{j2} are eigenvectors of environment j for PCl and PC2, respectively, ε_{ij} is the residual associated with genotype *i* in environment *j*. PC1 and PC2 eigenvectors cannot be plotted directly to construct a meaningful biplot before the singular values are partitioned into the genotype and environment eigenvectors. Singular-value partitioning is implemented by,

4.0 RESULTS

4.1.1 Trial at Ejura

The ANOVA showed that, differences among genotypes were highly significant ($P < 0.01$) for grain yield. From the values of the percentage sum of squares the contributions of genotypes were highest (98.62 %) followed by other factors under error (1.36 %) and blocks (0.02 %), shown in Table 4. Thus, genotypes contributed significantly to the variation. This indicates the prevalence of fairly optimum environmental conditions during the growing season. Grain yields ranged between 0.85 t/ha to 7.21 t/ha and the mean grain yield was 3.37 t/ha. The TZEEI 14 x TZEEI 6 showed good performance and emerged as the best hybrid with an average yield of 7.21 t/ha. TZEEI 14 x TZEEI 6 (7.21 t/ha), TZEEI 1 x TZEEI 22 (7.025 t/ha), TZEEI 5 x TZEEI 4 (6.515 t/ha), TZEEI 5 x TZEEI 40 (6.49 t/ha) and TZEEI 12 x TZEEI 19 (6.45 t/ha) emerged as the best five grain yielders respectively. The check AKPOSOE (4.49 t/ha) ranked as the 18th best hybrid (Appendix 1). The following hybrids were the poor five grain yielders; TZEEI 11 x TZEEI 22 (1.13 t/ha), TZEEI 9 x TZEEI 59 (1.11 t/ha), TZEEI 1 x TZEEI 2 (1.075 t/ha), TZEEI 10 x TZEEI 22 (1.075 t/ha) and TZEEI 5 x TZEEI 53 (0.85 t/ha). Among the testing sites the general performances of the genotypes were low at Ejura as compared to the other two locations (Figure 1).

Table 4: Mean squares and percentage of variance components for grain yield of the 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

Source of variation	DF	Locations					
		Ejura		Fumesua		Kpeve	
		MS	% SS	MS	% SS	MS	% SS
Block	1	0.10	0.02	1.49	0.47	6.70	1.20
Genotype	44	9.26**	98.62	6.69**	92.36	11.37**	89.42
Error	44	0.13	1.36	0.52	7.17	1.19	9.38
Total	89		100.00		100.00		100.00
CV %		10.60		19.30		22.80	

** P ≤ 0.01

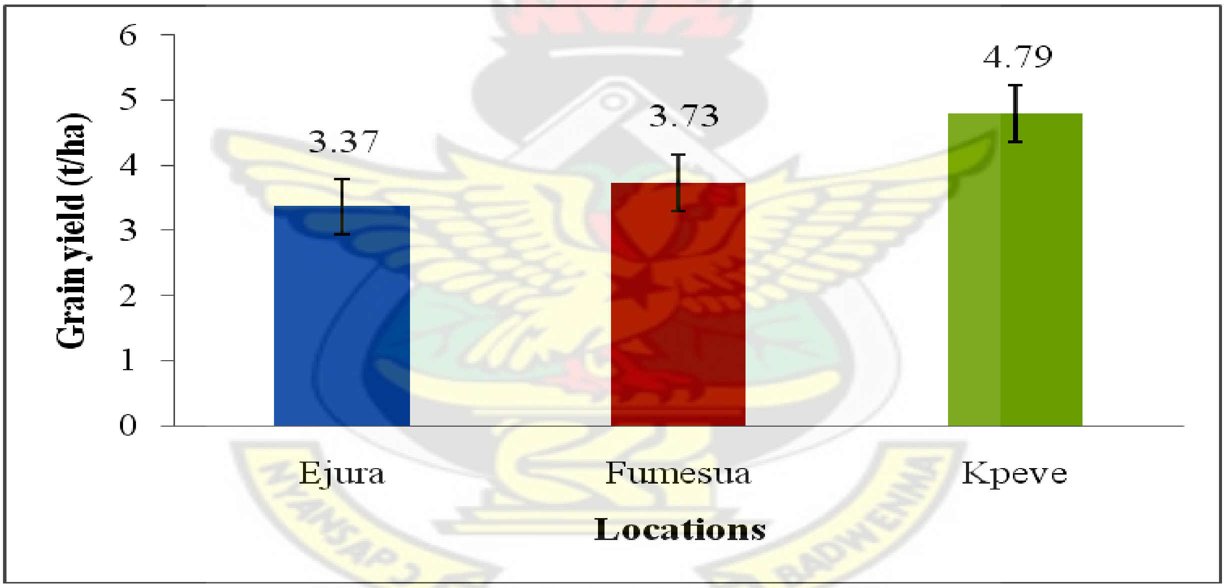

Figure 1: Mean grain yield (t/ha) of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

4.1.2 Trial at Fumesua

From this trial the variations among genotypes were found to be highly significant (P < 0.01) for grain yield. From the values of the percentage sum of squares the contributions of genotypes were highest (92.36 %) followed by other factors under error (7.17 %) and blocks (0.47 %), shown in Table 4. This can be an indication that genotypes contributed significantly to the variation. Grain yields ranged between 7.79 t/ha to 1.32 t/ha. The mean grain yield was 3.73 t/ha. Based on grain yields TZEEI 5 x TZEEI 4 (7.79 t/ha) ranked first followed by TZEEI 20 x TZEEI 19 (7.43 t/ha), TZEEI 5 x TZEEI 39 (7.33 t/ha), TZEEI 29 x TZEEI 26 (6.42 t/ha) and TZEEI 13 x TZEEI 22 (6.18 t/ha) as the best five hybrids respectively. The check AKPOSOE (4.70 t /ha) ranked as the 17th best hybrid (Appendix 1).

The following hybrids were the poor five grain yielders; TZEEI 4 x TZEEI 6 (1.95 t/ha), TZEEI 1 x TZEEI 2 (1.93 t/ha), TZEEI 11 x TZEEI 22 (1.80 t/ha), TZEEI 13 x TZEEI 12 (1.66 t/ha) and TZEEI 4 x TZEEI 51 (1.32 t/ha)

4.1.3 Trial at Kpeve

The differences among the genotypes were highly significant ($P < 0.01$) for grain yield. From the values of the percent sum of squares the contributions of genotypes were highest (89.42 %) followed by other factors under error (9.38 %) and blocks (1.2 %), (Table 4). Thus, variations among the performance of the hybrids were greatly caused by differences among their genotypes. Grain yields ranged between 1.56 t/ha to 9.64 t/ha. The mean grain yield was 4.79 t/ha. The highest yielding hybrid at this location was TZEEI 15 x TZEEI 8 (9.64 t/ha). The hybrids TZEEI 15 x TZEEI 8 (9.64 t/ha), TZEEI 2 x TZEEI 11 (8.74 t/ha), TZEEI 29 x TZEEI 26 (8.64 t/ha), TZEEI 5 x TZEEI 4 (8.43 t/ha) and TZEEI 5 x TZEEI 40 (8.25 t/ha) were the top five hybrids based on their grain yields respectively. The best yielder TZEEI 15 x TZEEI 8 out-yielded the check AKPOSOE by 47.71 % (Appendix 1). The following hybrids were the poor five grain yielders; TZEEI 15 x TZEEI 21 (2.37 t/ha), TZEEI 21 x TZEEI 39 (2.37 t/ha), TZEEI 4 x TZEEI 51 (2.1 t/ha), TZEEI 26 x TZEEI 24 (1.87 t/ha) and

TZEEI 13 x TZEEI 12 (1.555 t/ha). Kpeve was the highest grain yield producing location (Figure 1).

The relative performance of the following seven hybrids were similar across either two of the three locations; TZEEI 4 x TZEEI 39, TZEEI 5 x TZEEI 39, TZEEI 6 x TZEEI 40, TZEEI 13 x TZEEI 6, TZEEI 13 x TZEEI 22, TZEEI 23 x TZEEI 39 and TZEEI 31 x TZEEI 8 (Figure 2 and Appendix 1).

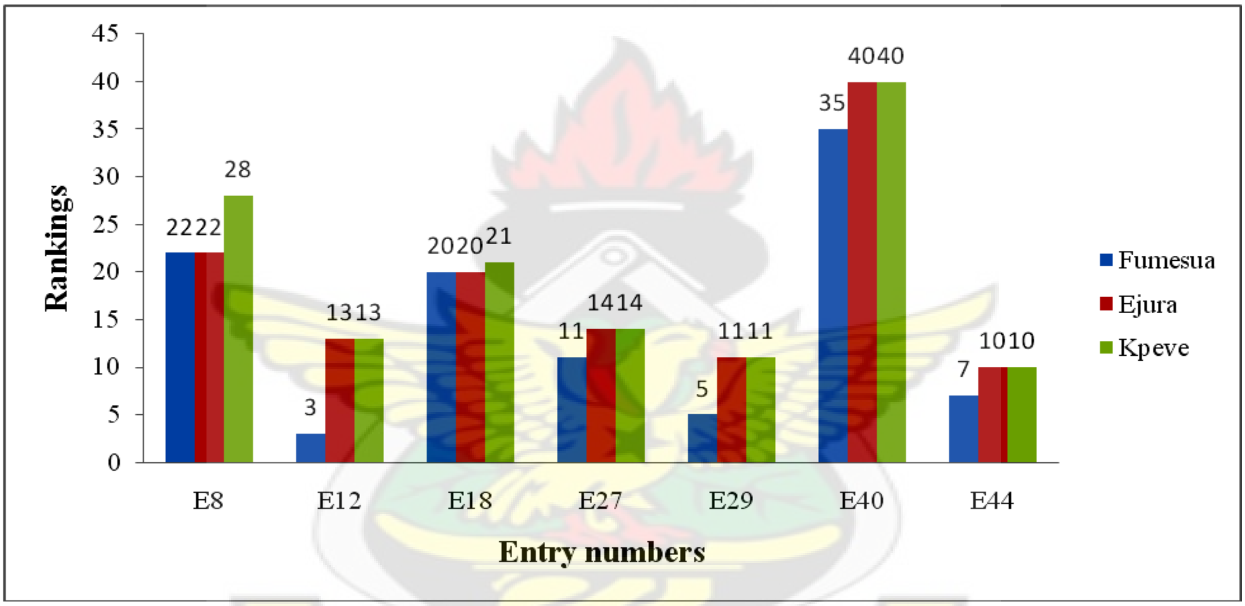

Figure 2: The relative rankings of hybrids with similar performance across either two of the three locations.

4.2 Means of growth and yield characters across locations

4.2.1 Grain yield

The combined ANOVA indicated that the differences among locations (L), genotypes (G) and their interactions (GLI) were highly significant ($p < 0.01$). The proportions of the total variance attributable to the genotypes were the highest (79.16 %) followed by other factors under error (25.79 %), location (7.044 %), G x L (7.37 %) and block (0.03 %), respectively (Table 5). The mean grain yield of the hybrids evaluated at the three locations was 3.96 t/ha (Appendix 2). Relatively 42.22 % of the 45 hybrids evaluated produced above mean grain yield (Figure 3), grain yields ranged between 7.58 t/ha and 1.76 t/ha. The best yielding hybrid, TZEEI 5 x TZEEI 4 (7.58 t/ha), out-yielded the check AKPOSOE (4.74 t/ha) by 37.47 %. In addition, TZEEI 5 x TZEEI 4 (7.58 t/ha) out-yielded the rest of the hybrids. The poorest yielding hybrid; TZEEI 4 x TZEEI 51 (1.76 t/ha) was out-yielded by the check by 76.78 % (Appendix 2). The best and worst five grain yielders are shown in Figure 4 below.

Table 5: Combined analysis of variance with the proportions of the total variance attributable to the sources of variation for grain yield of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

Source of variation	DF	MS	% SS
Block	1	0.42	0.03
Genotype	44	25.00^{**}	79.16
Location	2	48.93^{**}	7.04
Genotype x location (G x L)	88	1.16^{**}	7.37
Error	134	0.66	6.39
Total	269		
CV %	20.50		

** $P \leq 0.01$

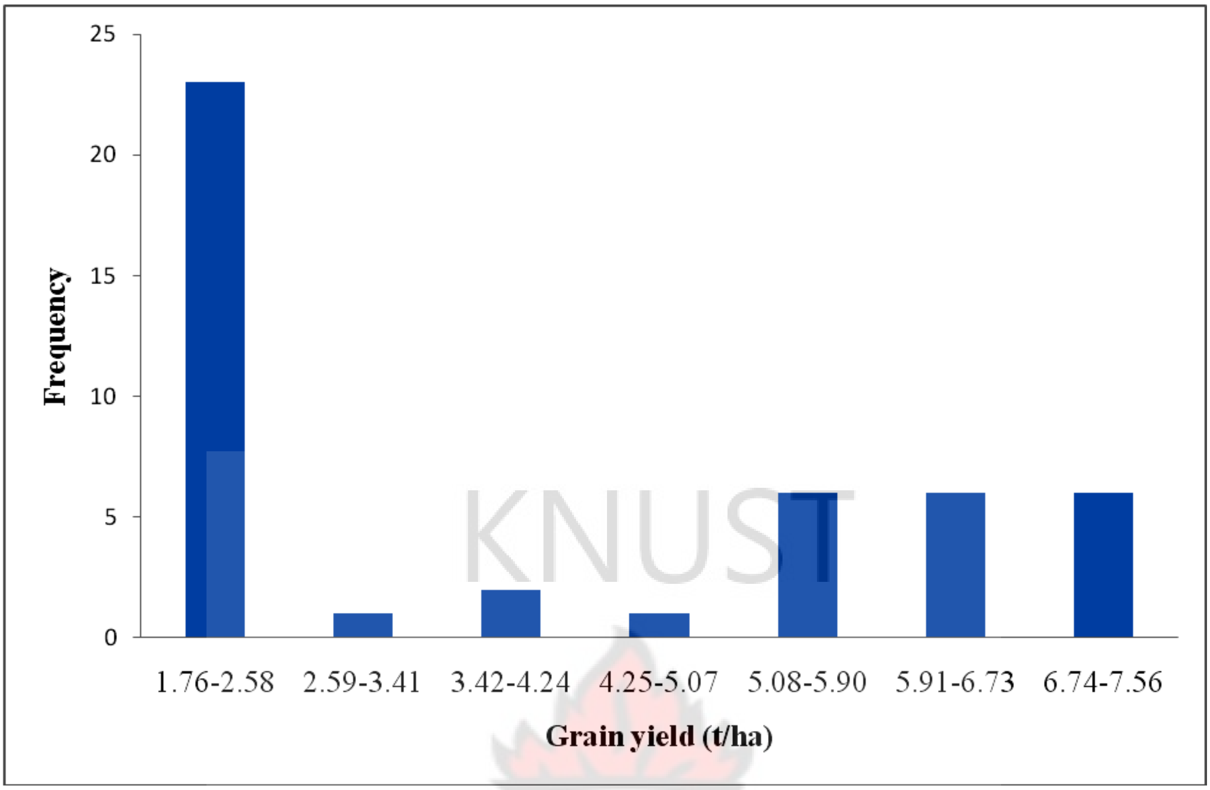

Figure 3: Frequency distribution of grain yield (t/ha) of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

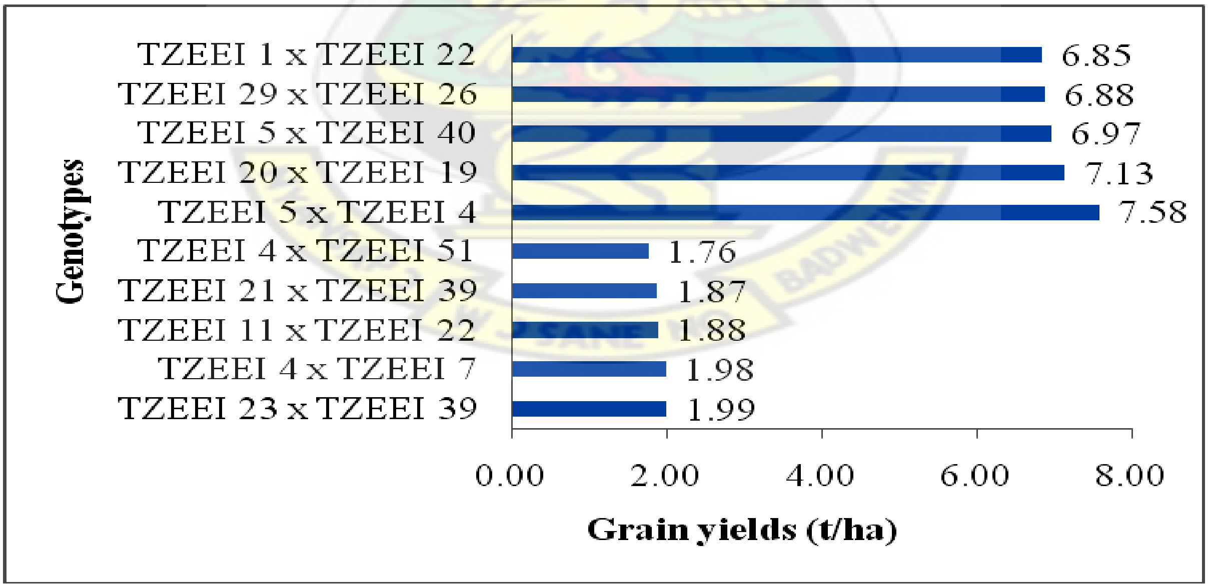

Figure 4: The best and worst five hybrids based on grain yield (t/ha).

4.2.2 Days to silking

There were highly significant differences ($p < 0.01$) among locations (L), genotypes (G) and their interactions (GLI) for days to silking. The mean square value for location was higher than genotype and genotype by location interactions (Table 6). Days to silking of hybrids ranged between 42 to 49 days. The mean day to silking was 46.03 days (Appendix 2). TZEEI 20 x TZEEI 19 recorded the lowest day to silking of 42 days. The frequency distributions of mean days to silking for the 45 hybrids evaluated are presented in Figure 5. The names of the top and bottom five hybrids for days to silking are presented in Figure 6 below.

Table 6: Mean square values of the combined analyses of variance for days to silking, days to anthesis, ASI and plant height (cm) of the 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

Source of variation	DF	Mean squares			
		DYSK	DA	ASI	PLHT
Block	1	13.33	37.04	11.62	4983.70
Genotype (G)	44	15.20^{**}	19.25^{**}	3.52^{**}	2343.80^{**}
Location (L)	2	335.83^{**}	160.83^{**}	369.64^{**}	39893.10^{**}
Genotype x loc (G x L)	88	6.56^{**}	6.22^{**}	2.57^{ns}	222.70^{ns}
Error	134	3.44	3.02	2.00	225.40
CV %		4.00	4.00	51.40	8.50

** $P \leq 0.01$ and ns = not significant

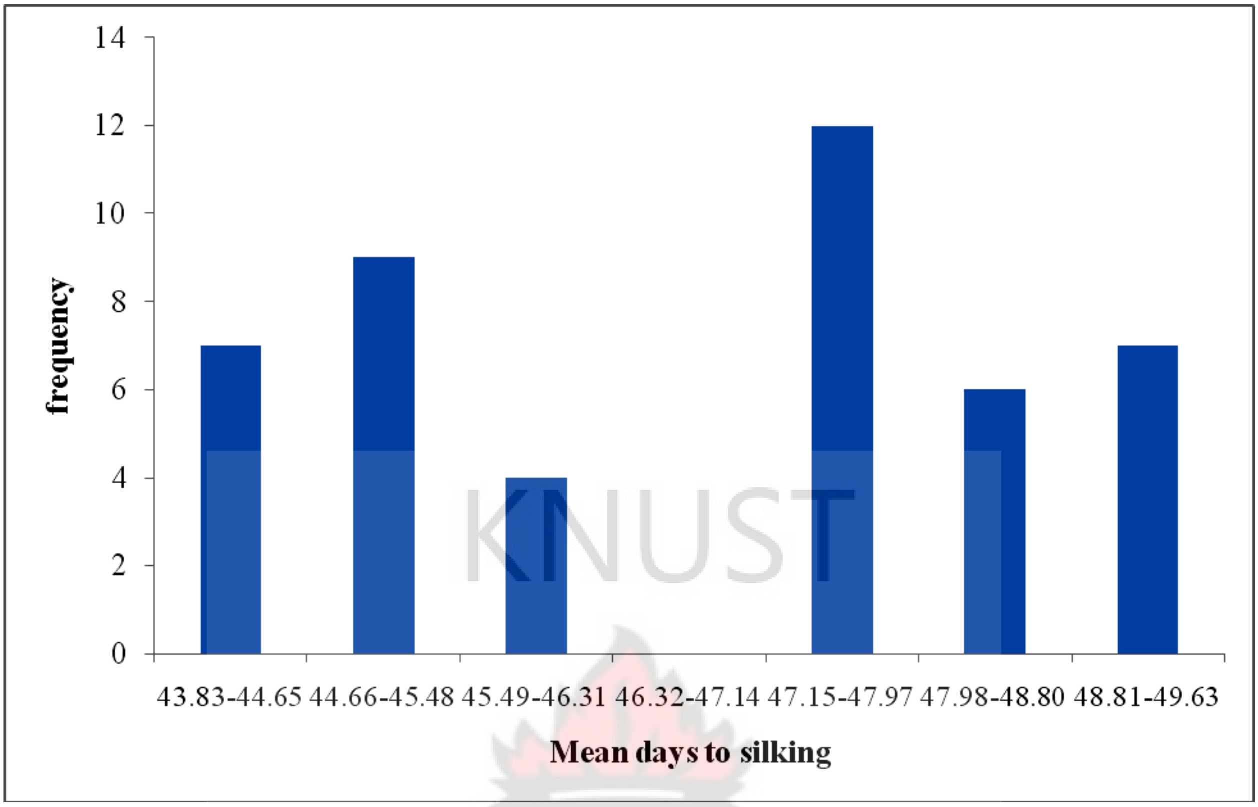

Figure 5: Frequency distribution of mean days to silking of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

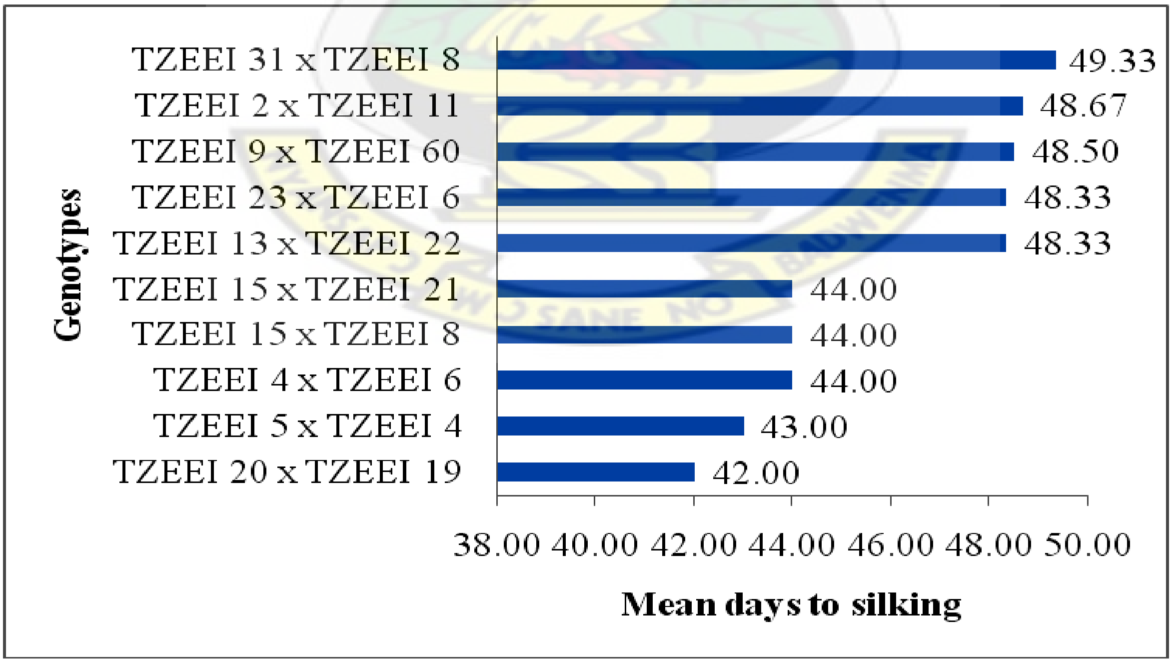

Figure 6: The best and worst five hybrids based on days to silking

4.2.3 Days to anthesis

There were highly significant differences ($p < 0.01$) among locations (L), genotypes (G) and their interactions (GLI) for days to anthesis. Location had the highest mean square value followed by block, genotype, G x L and error (Table 6). Days to anthesis of hybrids ranged between 42 to 48 days. The mean day to anthesis was 43.87 days (Appendix 2). The frequency distributions of mean days to anthesis of the 45 hybrids are shown in Figure 7. The names of the top and bottom five hybrids for days to anthesis are presented in Figure 8 below.

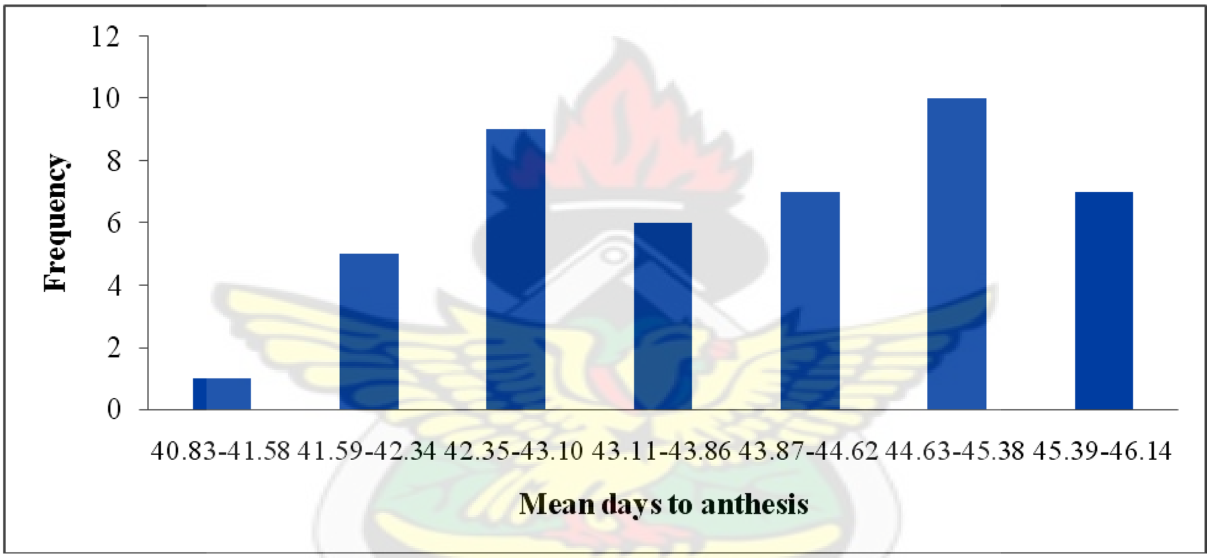

Figure 7: Frequency distribution of mean days to anthesis of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

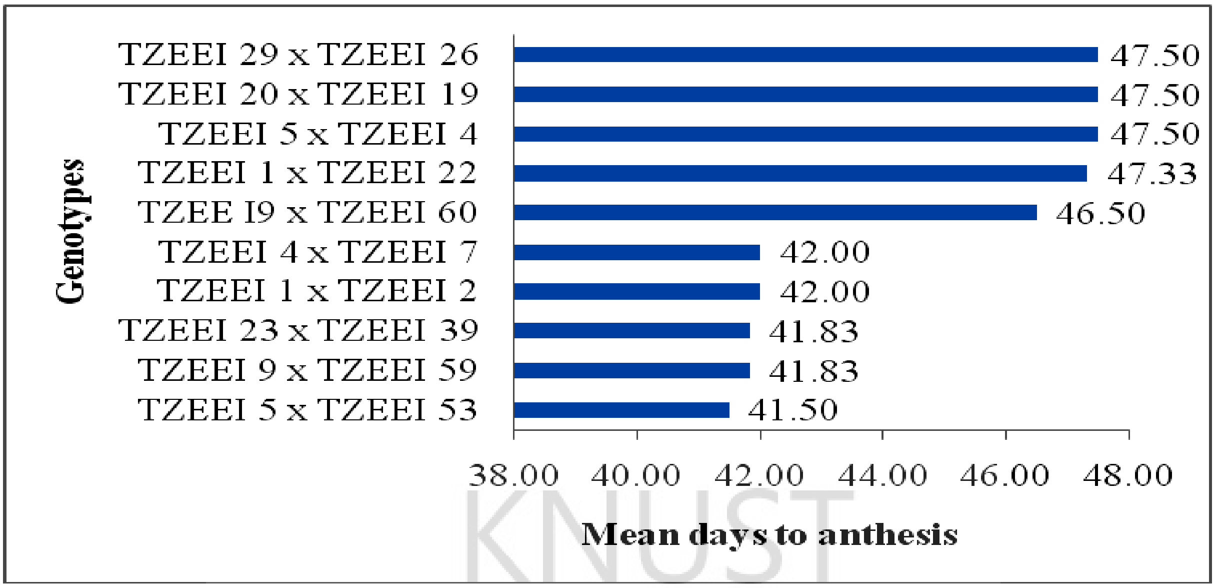

Figure 8: The best and worst five hybribs based on days to anthesis

4.2.4 Anthesis-silking interval

The combined analysis of variances across the three locations revealed highly significant differences ($p < 0.01$) among genotypes and locations. There were no significant differences for their interaction (GLI) for anthesis-silking interval. Among location, genotype and G x L, location had the highest mean square value (Table 6). ASI ranged between 1 to 4 days for all hybrids. The mean ASI was 2.90 days (Appendix 2). Only two of the 45 hybrids recorded the lowest ASI of 1 day (Figure 9). The names of the five hybrids with the smallest and largest ASI are presented in Figure 10.

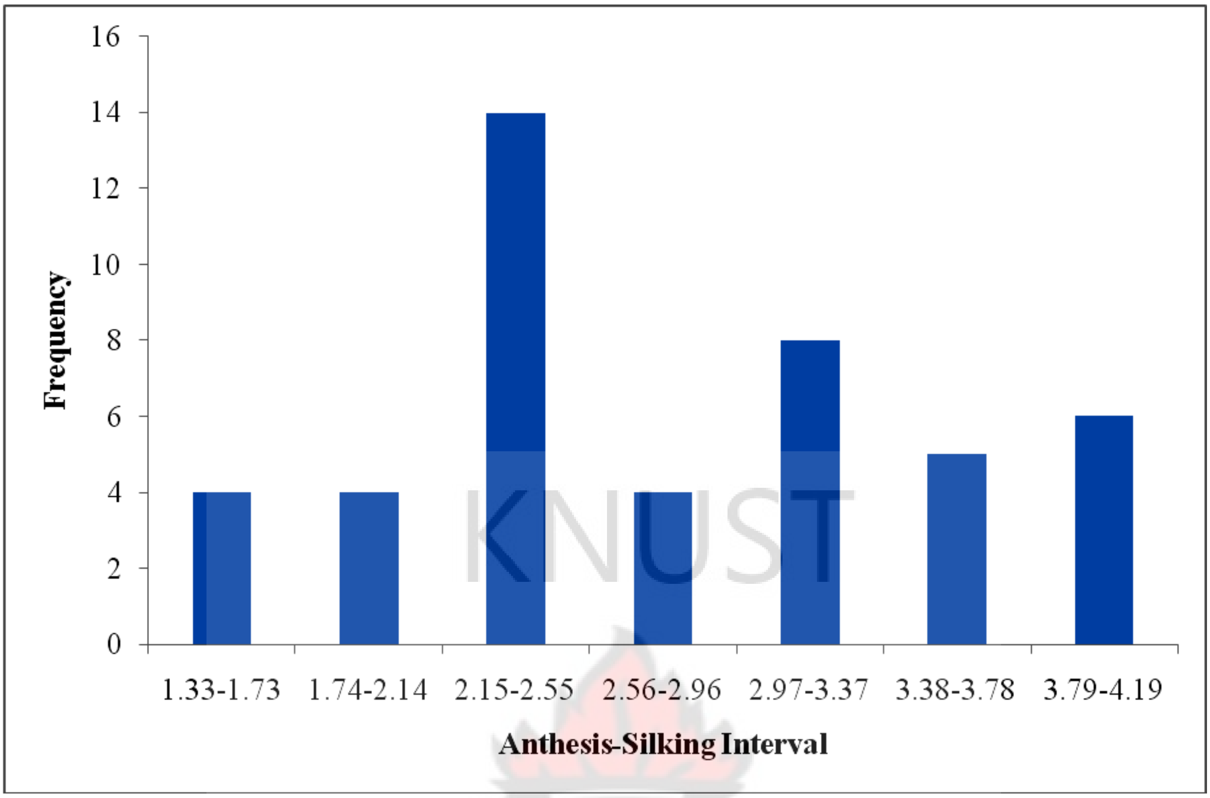

Figure 9: Frequency distribution of anthesis-silking interval of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

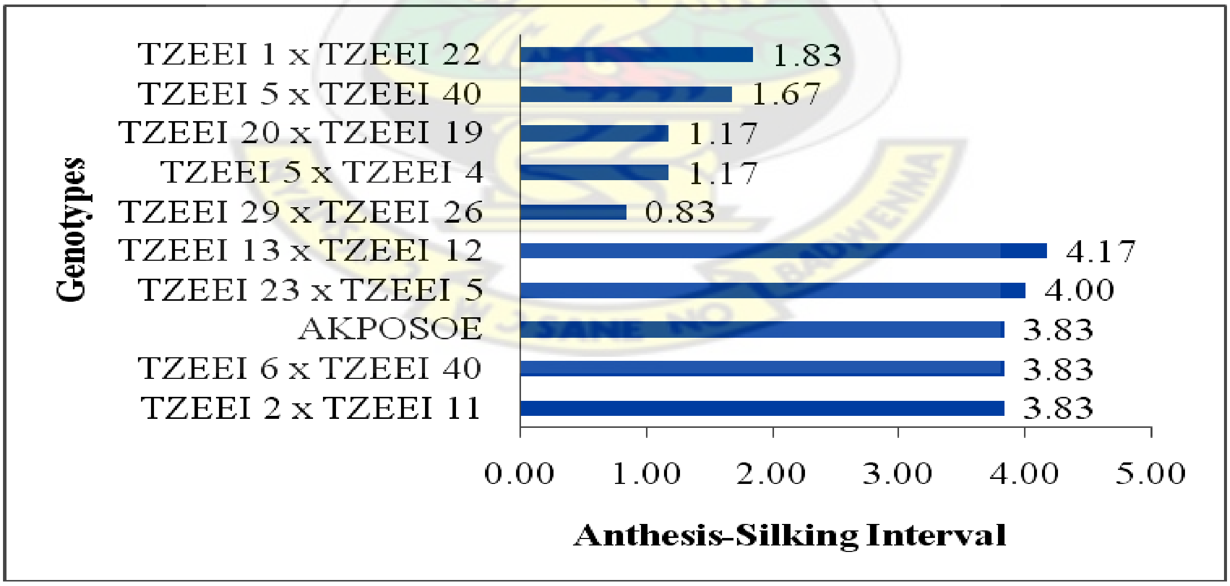

Figure 10: The best and worst five hybrids based on anthesis-silking interval

4.2.5 Plant height

There were highly significant differences ($p < 0.01$) among locations (L) and genotypes (G) for plant height. However, the differences between their interactions [GLI] were not significant. Among location, genotype and G x L, location had the highest mean square value (Table 6). Plant heights of hybrids ranged between 148.17 cm to 211.83 cm. The mean plant height was 175.61 cm (Appendix 2). The frequency distribution of plant heights of the 45 hybrids evaluated are shown in Figure 11 below. The names of the top and bottom five hybrids with the highest and lowest plant heights respectively are presented in Figure 12 below.

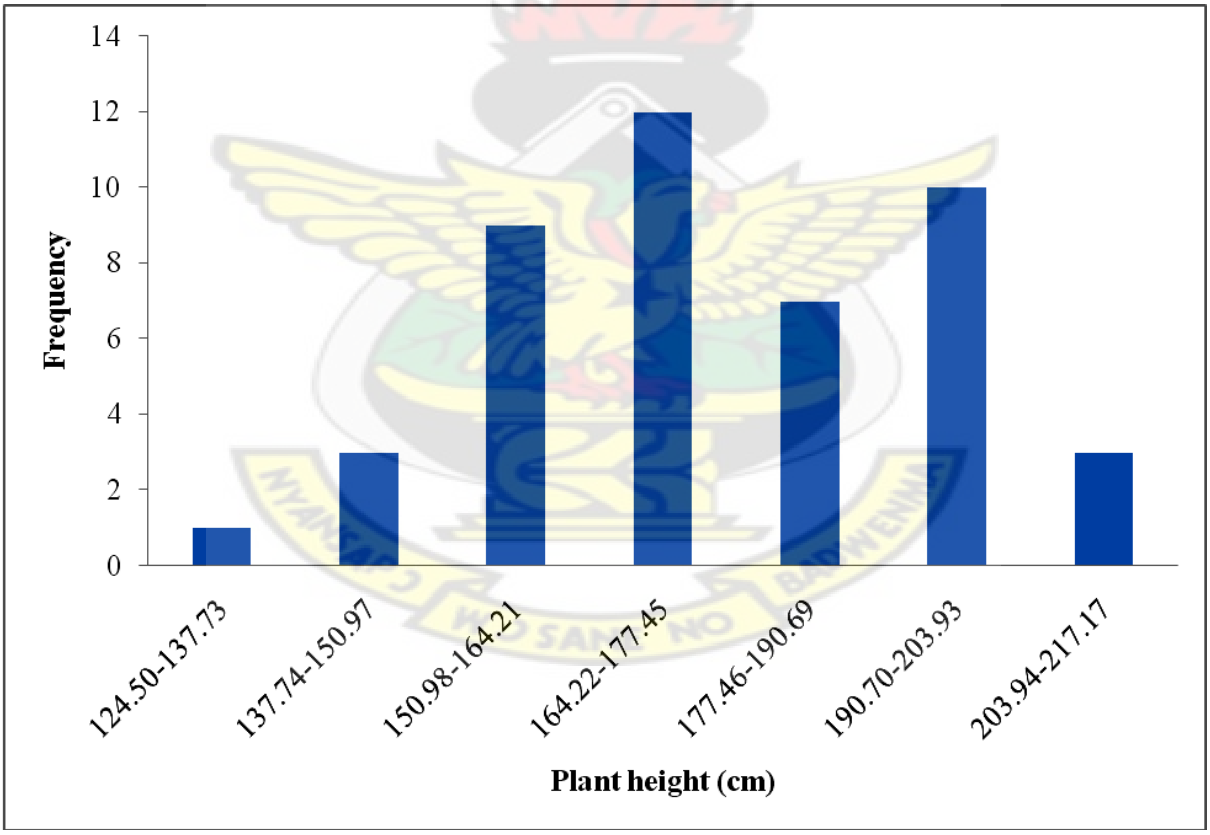

Figure 11: Frequency distribution of plant heights (cm) of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

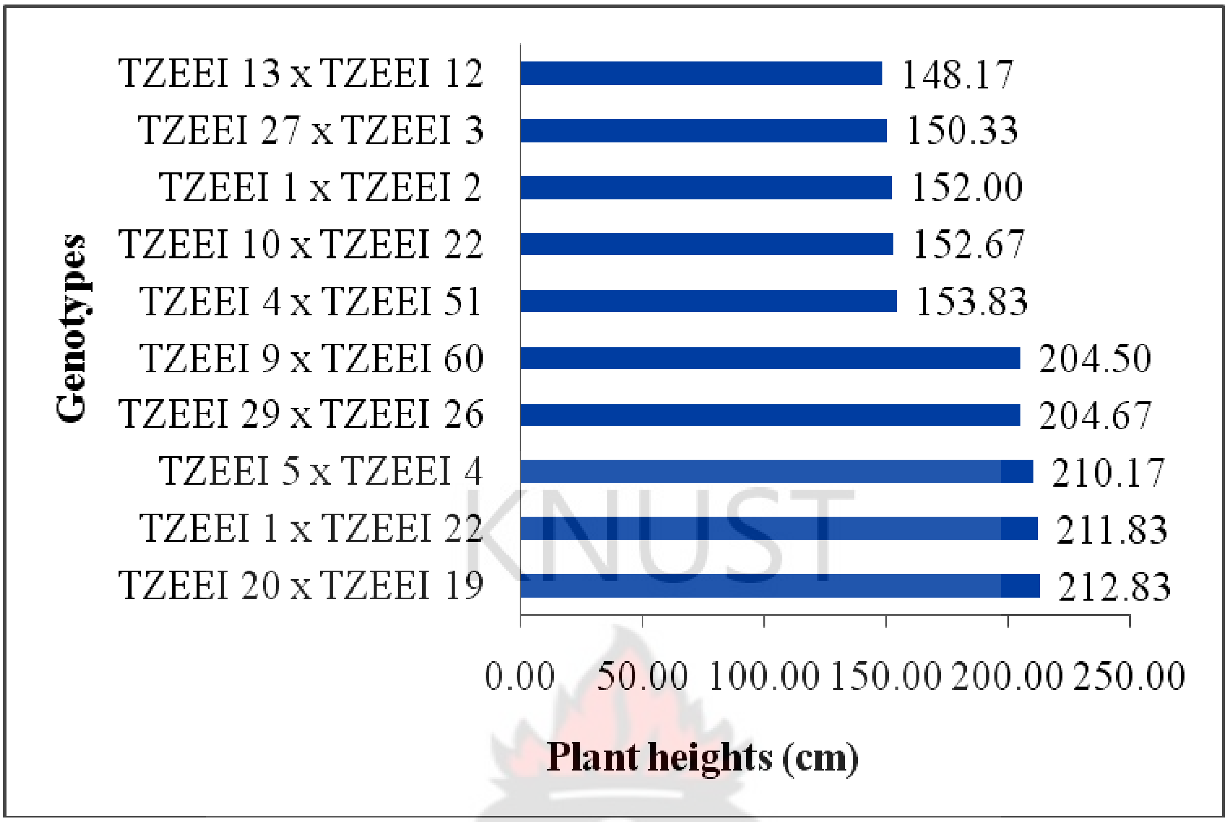

Figure 12: The best and worst five hybrids based on Plant heights (cm)

4.2.6 Ear height

The differences among genotypes (G) and locations (L) were found to be highly significant ($p < 0.01$) for ear height. Their interactions (GLI) were significant ($p < 0.05$). The mean square value was higher for location and genotype and lowest for G x L (Table 7). Ear heights ranged between 68.67 cm to 115.83 cm. The mean ear height was 87.89 cm (Appendix 2). Relatively 46.7 % of the total number of hybrids evaluated had above mean ear heights (Figure 13). The names of best and worst five hybrids for ear heights are shown in Figure 14 below.

Table 7: Mean square values of the combined analyses of variance for ear height (cm), ears per plant, root lodging and stalk lodging of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

Source of variation	DF	Mean squares			
		EHT	RLT	SLT	EPP
Block	1	1169.79	3.12	20.28	0.11
Genotype (G)	44	1436.83**	3.50**	4.69ns	0.12**
Location (L)	2	17869.73**	4.81ns	63.96**	0.10**
Genotype x loc (G x L)	88	86.20*	1.87ns	4.05ns	0.03**
Error	134	62.58	1.79	4.09	0.02
CV %		9.00	73.10	78.70	13.80

* P ≤ 0.05, ** P ≤ 0.01, ns = not significant

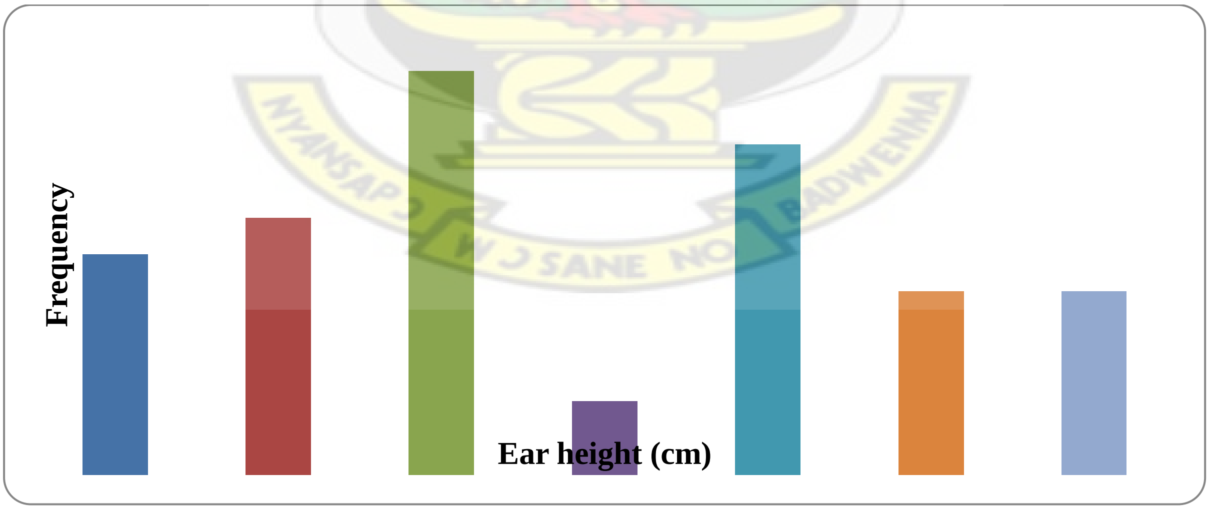

Figure 13: Frequency distribution of ear heights (cm) of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

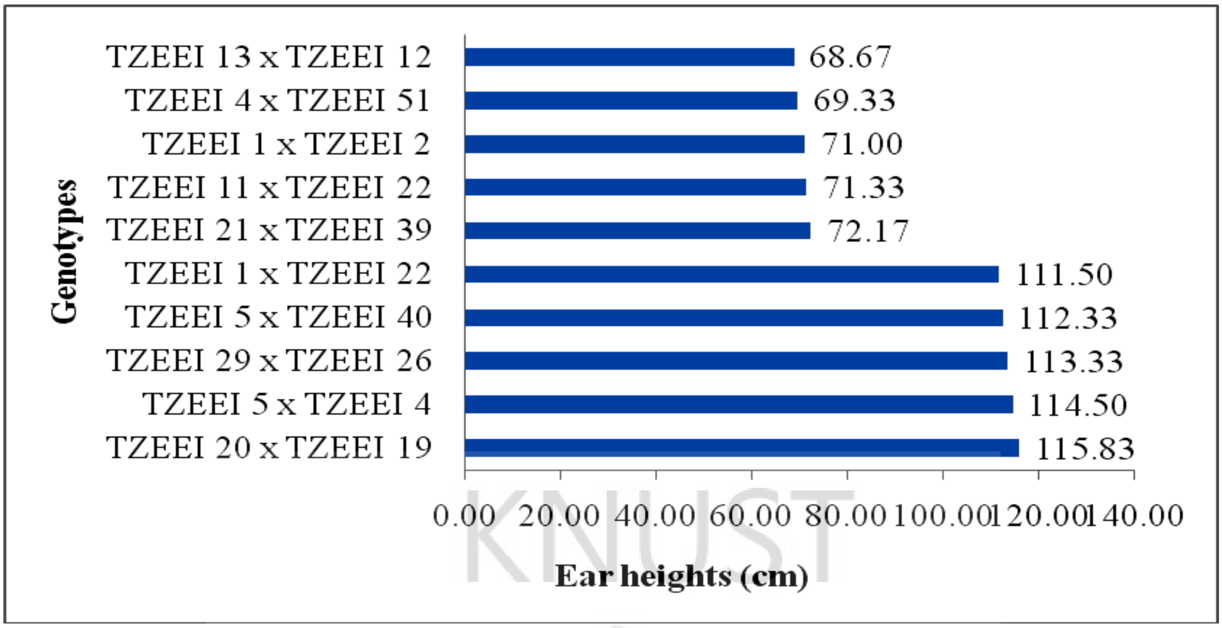

Figure 14: The best and worst five hybrids based on ear heights (cm)

4.2.7 Ears per plant

AS indicated by the combined ANOVA, the differences among genotypes (G), locations (L) and GLI for ears per plant were highly significant different ($p < 0.01$). Among location, genotype and G x L, location had the highest mean square value (Table 7). Ears per plant ranged between, 0.71 to 1.21. Mean number of ear per plant was 0.95 (Appendix 2). On the average, the hybrids evaluated had a barrenness (1-EPP) value of 0.05. Relatively all the 45 hybrids evaluated produced an ear per plant (Figure 15). The best and worst five hybrids with the highest and lowest number of EPP respectively are presented in Figure 16 below.

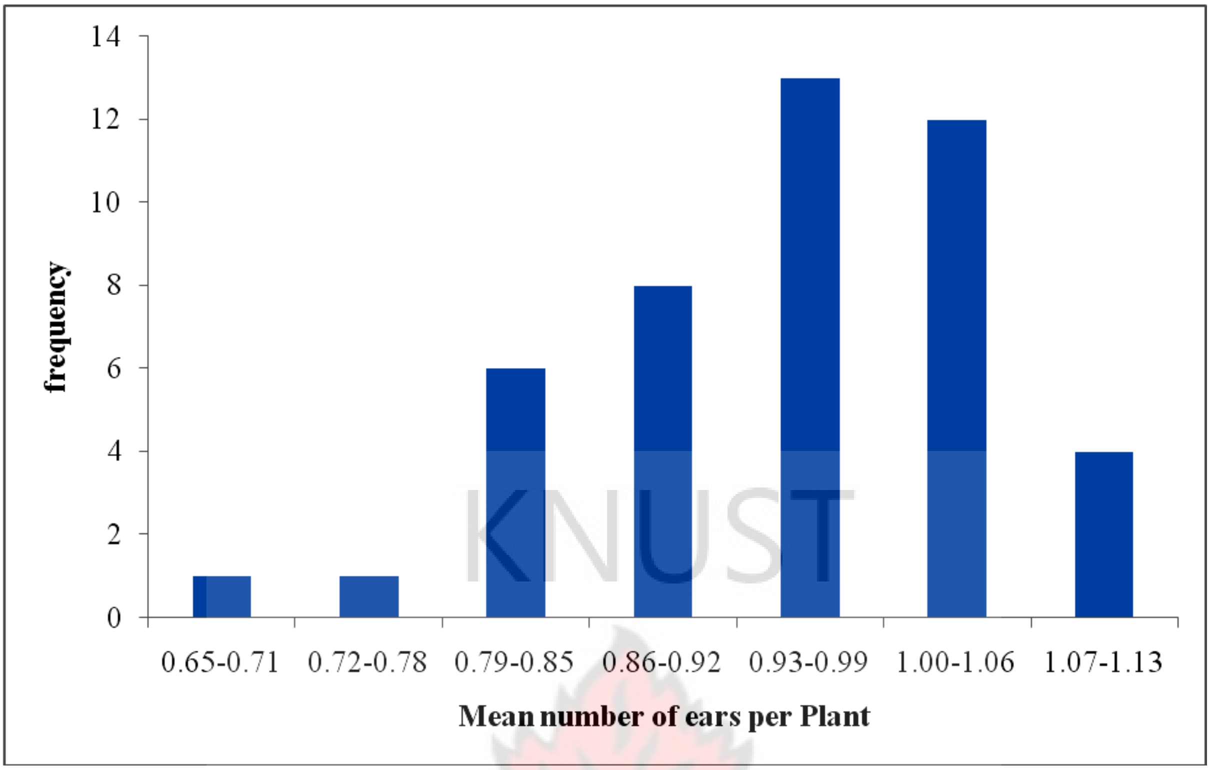

Figure 15: Frequency distribution of mean number of ear per plant of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

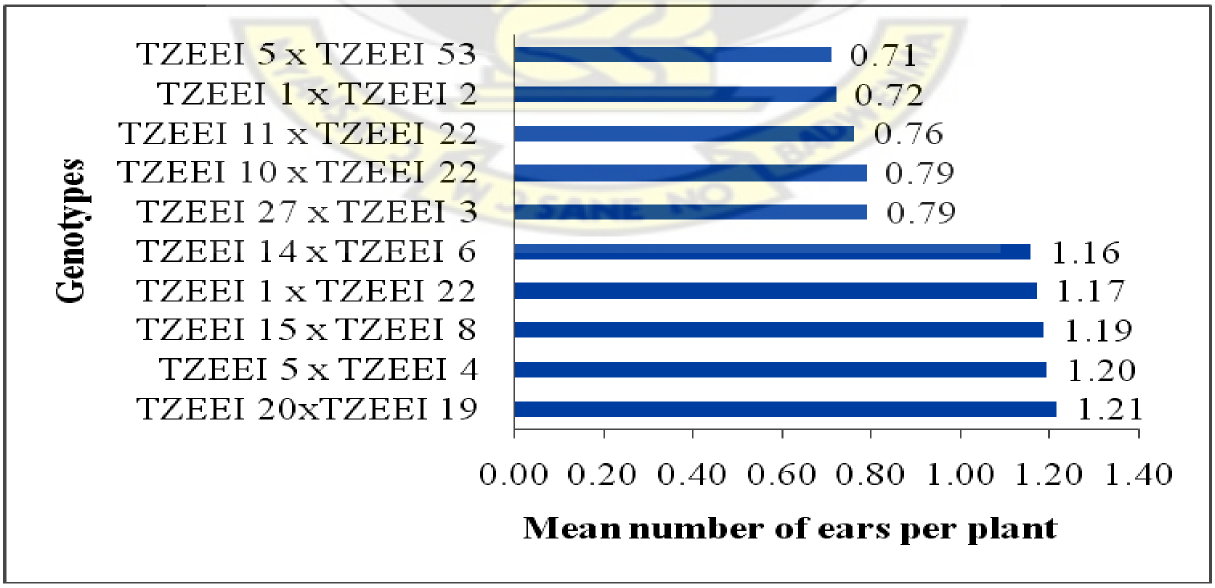

Figure 16: The best and worst five hybrids based on ears per plant

4.2.8 Root lodging

The combine ANOVA showed highly significant differences ($p < 0.01$) among genotypes (G) for root lodging. The differences among locations (L) and their interactions (GLI) were not significant for root lodging. Among location, genotype and G x L, location had the highest mean square value (Table 7). Number of root-lodged plants per plot ranged between 0 to 4 plants with a mean of 1.79 plants (Appendix 2). The frequency distribution of root-lodged plant for the 45 hybrids is shown in Figure 17. The top and bottom five hybrids for root-lodging are shown in Figure 18.

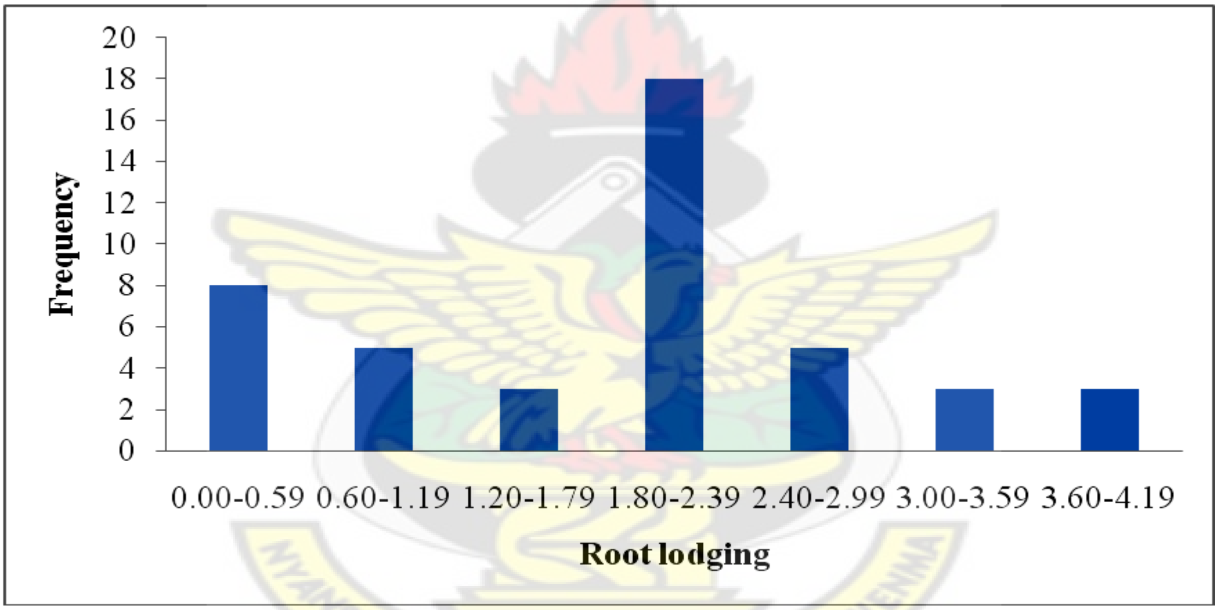

Figure 17: Frequency distribution of root lodging of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

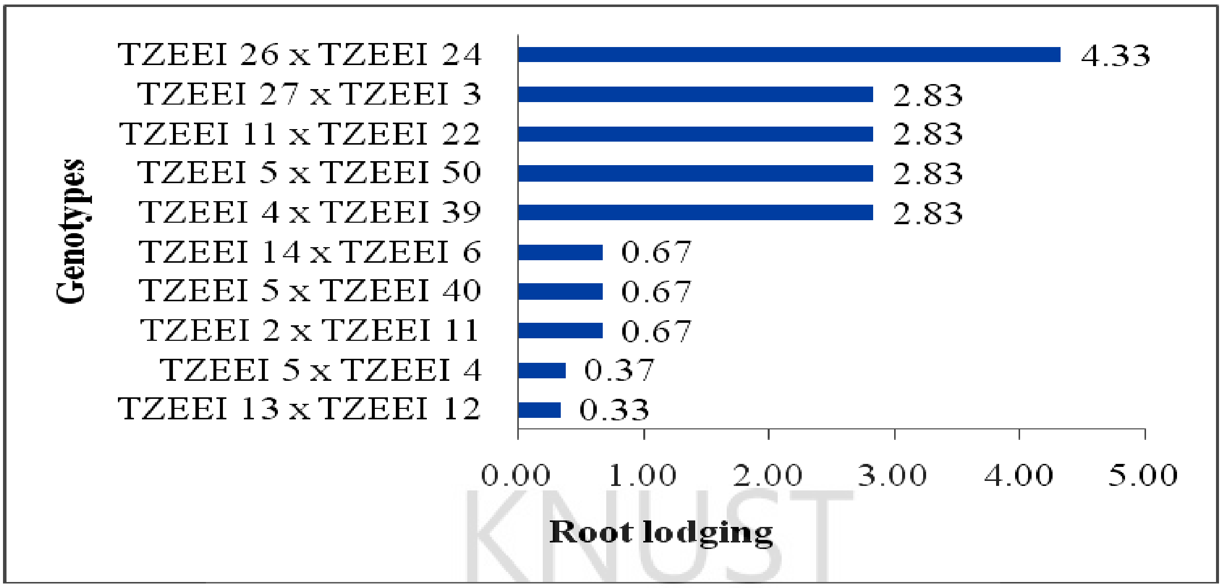

Figure 18: The best and worst five hybrids based on root lodging

4.2.9 Stalk lodging

The combine ANOVA showed highly significant differences ($p < 0.01$) among locations (L) for stalk lodging. The differences among genotypes (G) and genotype by location interaction (GEI) were not significant for stalk lodging. The mean square value for location was higher than genotype and genotype by interactions (Table 7). Number of stalk-lodged plants per plot ranged between 1 to 5 plants. The mean number of stalk-lodged plants was 2.45 (Appendix 2). Figure 19 shows the frequency distribution of number of stalk-lodged plants of the 45 hybrids. The first and last five hybrids for stalk lodging are presented in Figure 20.

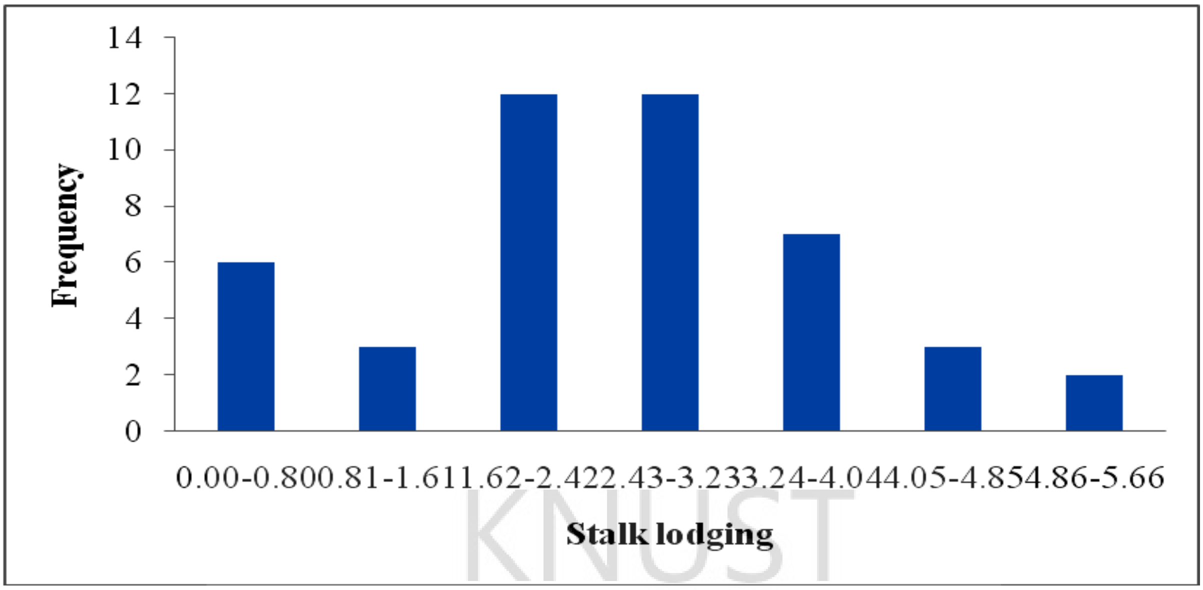

Figure 19: Frequency distribution of stalk lodging of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

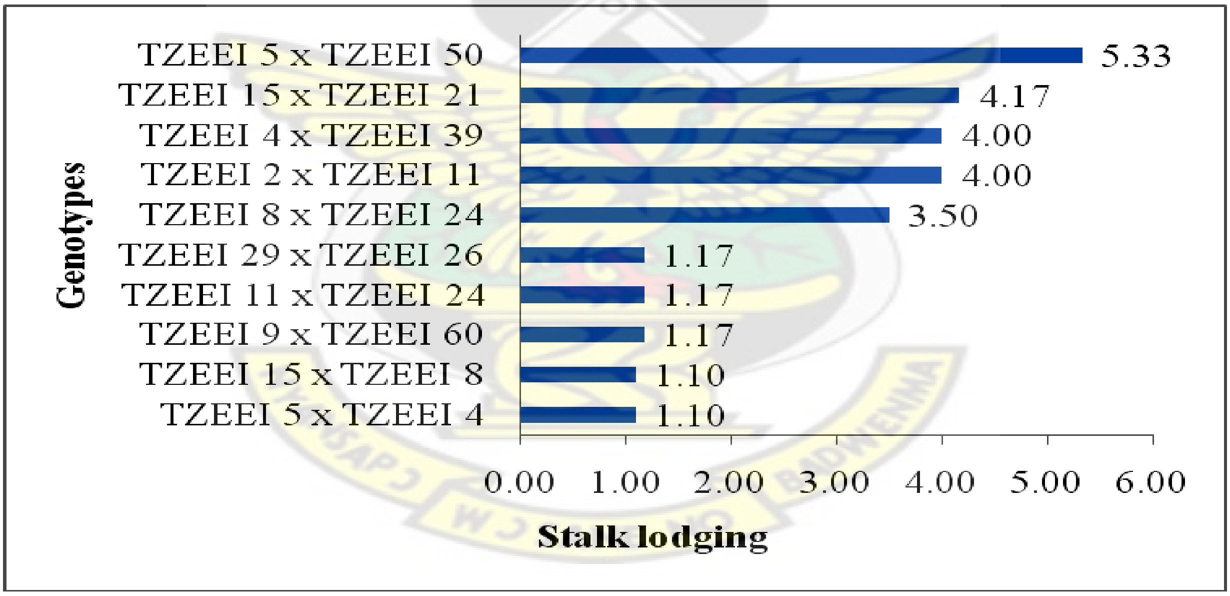

Figure 20: The best and worst five hybrids based on stalk lodging

4.3 Correlations among parameters measured

The correlation studies revealed that grain yield was positively correlated to days to anthesis, days to silking, plant height, ear height and ears per plant (Table 8). The associations were highly significant ($p < 0.01$). Plant height and ear height, days to anthesis and days to silking as well as days to silking and anthesis-silking interval were positively and significantly correlated ($r = 0.91$, $r = 0.64$ and $r = 0.40$), respectively (Table 8). The associations between grain yield and anthesis-silking interval and days to anthesis and anthesis-silking interval were weakly negative and highly significant ($p < 0.01$); $r = -0.33$ and -0.37, respectively. Similarly, root lodging and stalk lodging had a weak negative correlation with grain yield; $r = -0.26$ and $r = -0.21$, respectively. The associations were highly significant ($p < 0.01$), shown in Table 8.

Table 8: Phenotypic correlation coefficients among agronomic traits of the 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

Traits	ASI	DYSK	EPP	Yield	RLT	SLT	DA	EHT
DYSK	0.40^{**}							
EPP	-0.09^{ns}	0.42^{**}						
Yield	-0.33^{**}	0.36^{**}	0.70^{**}					
RLT	0.05^{ns}	-0.24^{**}	-0.19^{**}	-0.26^{**}				
SLT	0.30^{**}	-0.02^{ns}	0.01^{ns}	-0.21^{**}	0.04^{ns}			
DA	-0.37^{**}	0.64^{**}	0.52^{**}	0.64^{**}	-0.28^{**}	-0.24^{**}		
EHT	0.03^{ns}	0.34^{**}	0.77^{**}	0.74^{**}	-0.15^{*}	0.01^{ns}	0.31^{**}	
PLHT	0.03^{ns}	0.24^{**}	0.72^{**}	0.64^{**}	-0.10^{ns}	0.02^{ns}	0.21^{**}	0.91^{**}

* $P \leq 0.05$, ** $P \leq 0.01$, ns = not significant

4.4 Identification of superior hybrids

4.4.1 Selection index by ranking method

Rank sum values based on performance of hybrids using grain yield (t/ha), days to silking, days to anthesis, plant height (cm), ear height (cm), anthesis-silking interval, EPP, root lodging and stalk lodging are presented in Appendix 3. The rank sums revealed that TZEEI 5 x TZEEI 4, TZEEI 20 x TZEEI 19, TZEEI 29 x TZEEI 26, TZEEI 1 x TZEEI 22, TZEEI 5 x TZEEI 40, TZEEI 15 x TZEEI 8, TZEEI 14 x TZEEI 6, TZEEI 9 x TZEEI 60, TZEEI 12 x TZEEI 19 and TZEEI 5 x TZEEI 39 were the best 10 hybrids with superior agronomic performance. The hybrids below were the poorest ten; TZEEI 6 x TZEEI 4, TZEEI 23 x TZEEI 5, TZEEI 26 x TZEEI 24, TZEEI 1 x TZEEI 2, TZEEI 4 x TZEEI 39, TZEEI 13 x TZEEI 12, TZEEI 5 x TZEEI 53, TZEEI 27 x TZEEI 3, TZEEI 4 x TZEEI 51 and TZEEI 11 x TZEEI 22.

4.5 GGE biplot analysis of grain yield and stability of the 45 extra-early maturing maize hybrids.

The biplots in Figures 22, 23, and 24 were based on environment-focused singular value partitioning (SVP = 1) and is therefore appropriate for visualizing the relationships among genotypes. In Figure 21 where relationships among environments were desired, the biplot was based on genotype-focused singular value partitioning (SVP = 2) and is therefore appropriate for visualizing the relationships among environments. The principal component (PC) axis 1 explained 92.7 % of total variation; while PC2 explained 4.1 %. Thus, these two axes accounted for 96.8 % of the total variation for grain yield (Figure 21, 22, 23 and 24). The entry names of entry numbers used in this section are shown in Table 1. The results are presented as four sections. Section one presents the results of “which won-where” to identify the best genotypes for each environment. Section two; the results of hybrids’ performance and their stability; section three gives the relationship between the sites and the groups of environments. Section four; the discriminating power and representativeness of the test environments.

1. **The “which-won-where” patterns**

The GGE biplot is an invaluable statistical tool for examining the performance of genotypes tested in different environments. The polygon view of the GGE biplot (Figure 21) indicated the best genotype in each environment. The “which-won-where” view of the GGE biplot is an effective visual tool in mega-environment analysis (Yan *et al*., 2007). The term mega-environment analysis defines the partition of a crop growing region into different target zones (Gauch and Zobel, 1997). It consists of an irregular polygon and lines drawn from the biplot origin. The rays in Figure 21 are lines that intersect perpendicularly sides of the polygon or their extensions. Nine rays divide the biplot into nine sectors. Entry 10 was the vertex hybrid where Ejura and Fumesua fell while entry 31 was the vertex hybrid at Kpeve. Entry 34 performed very well at both Ejura (7th best hybrid) and Fumesua (2nd best hybrid). Also, entry 30 performed very well at both Ejura (1st best hybrid) and Fumesua (8th best hybrid). Entry 5 was the 2nd best hybrid at Kpeve. No environment fell into the sector where entry 41, 4, 9, 28, 15 and 37 were the vertex hybrid, indicating that these were the lowest-yielding hybrids at all or some locations. Hybrids within the polygon, particularly those located near entries 25, 1 and 27 were less responsive than the vertex hybrids.

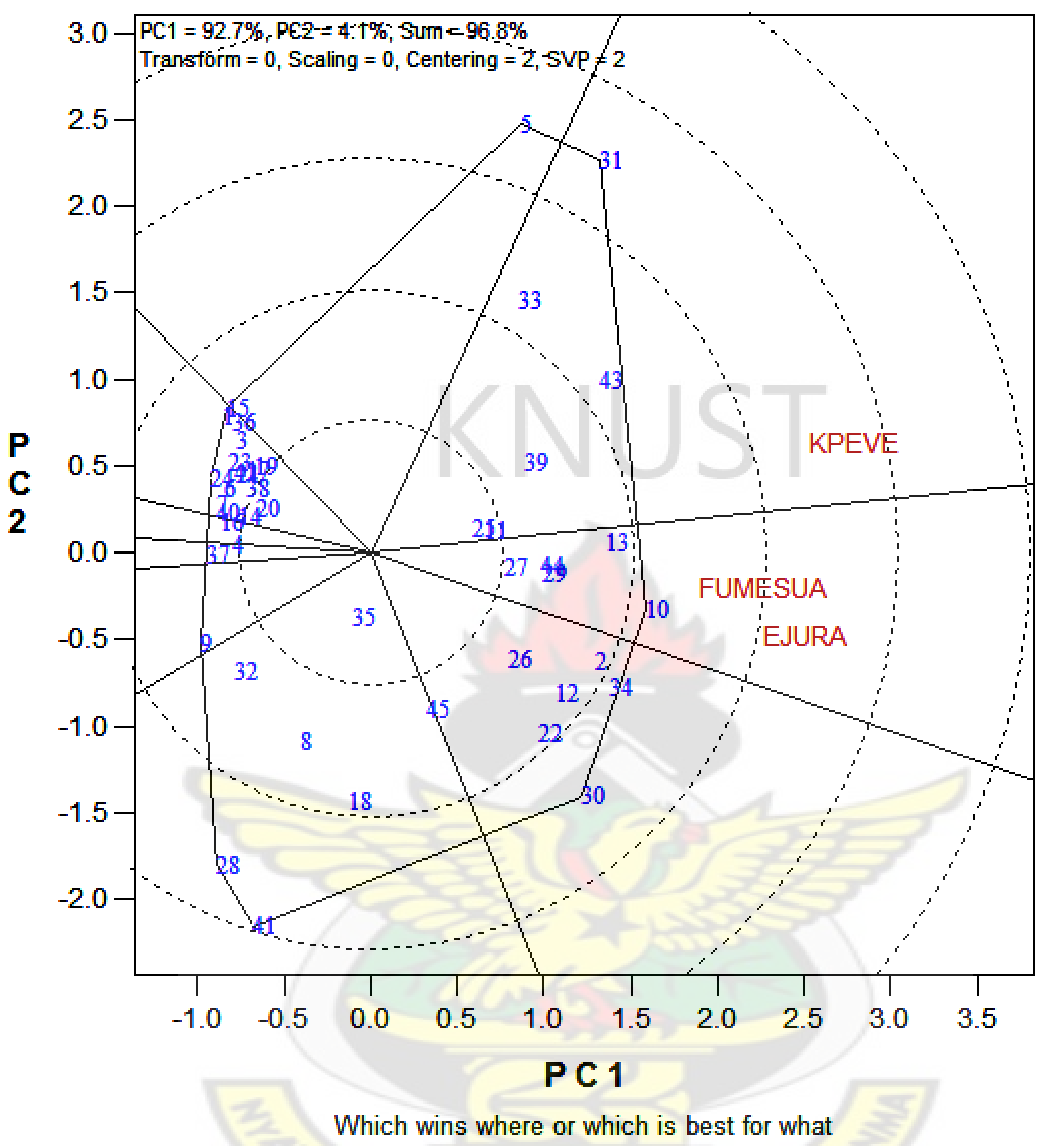

Figure 21: A 'which-won-where' or 'which-is-best-at-what' based on a genotype x environment yield data of the 45 extra-early maturing maize hybrids evaluated in three environments in Ghana during the 2011 growing season.

2. **Performance of hybrids and their stability across environments**

In the entry/tester view of the GGE biplot of grain yield of the 45 extra-early maturing maize hybrids evaluated in three environments in Ghana (Figure 22). The genotypes were ranked along the average-environment axis (AEC abscissa), with an arrow pointing to a greater value based on their mean performance across all environments. 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-tester axis. Based on this, 19 hybrids including the check hybrid produced above-average grain yield and may be ranked as follows:

10 > 34 = 13 = 2 = 31= 43 > 30 = 12 = 29 = 44 = 22 = 39 = 33 = 5 > 26 = 27 = 11 = 25 > 45

In the GGE biplot analysis, the AEC abscissa approximates 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-tester coordinate (ATC) y-axis double-arrow line. The greater the absolute length of the projection of a cultivar, the less stable it is (Yan *et al*., 2000; 2010). Based on this, Entries 10, 34, 2, 29 and 44 were the most stable with an above average performance, as they were located away from the AEC abscissa and had a near zero projection onto the AEC ordinate. In contrast, entries 31 and 5 were the least stable highest yielding hybrids. However, entries 24, 14, 20 and 19 were the lowest yielding but very stable hybrids. Entries 28 and 41 were not only low yielding but also among the least stable hybrids.

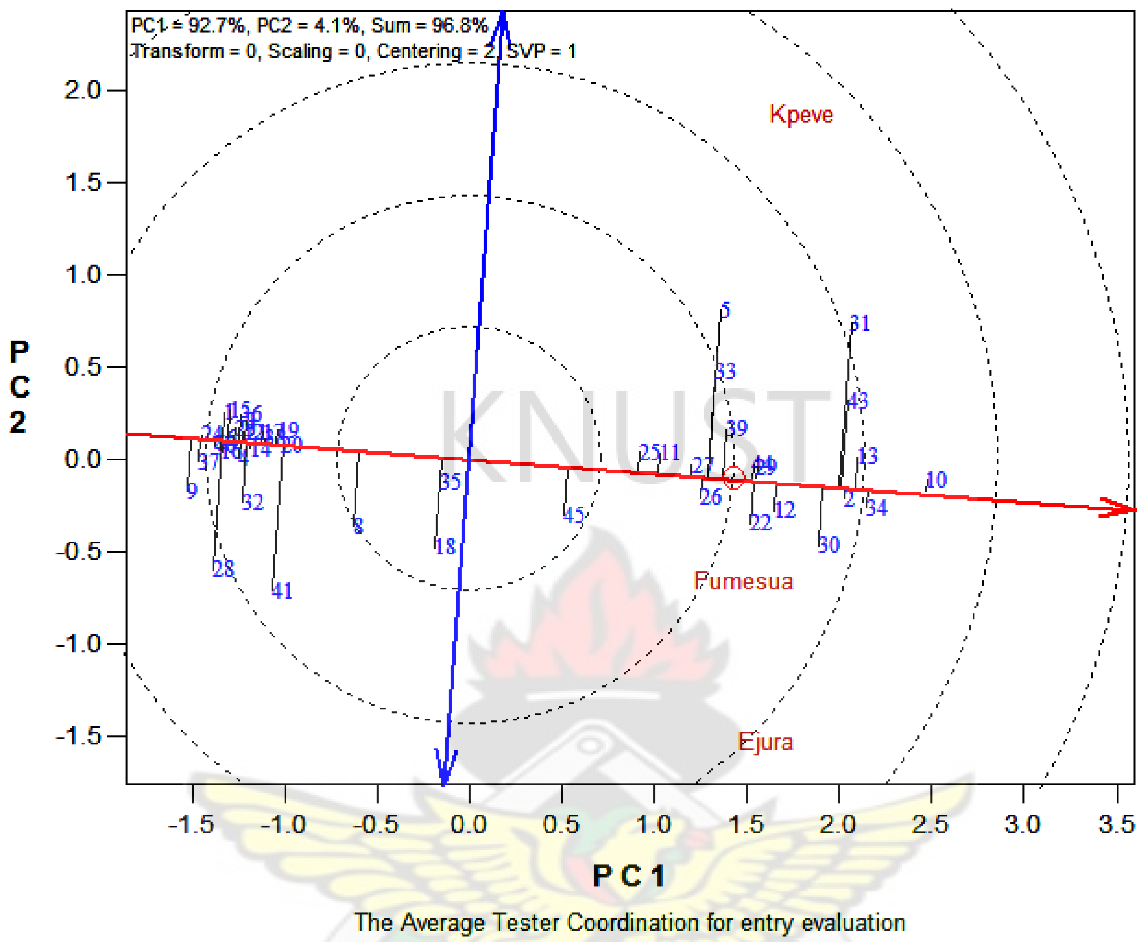

Figure 22: The 'mean vs. stability' view of the GGE biplot based on a genotype x environment yield data of the 45 extra-early maturing maize hybrids evaluated in three environments in Ghana during the 2011 growing season.

3. Interrelationship among environments

The biplot presented in Figure 23 provides the summary of the interrelationships among the environments used in the study. The lines that connect the biplot origin and the markers for the environments are called environment vectors. The angle between the vectors of two environments is related to the correlation coefficient between them. The cosine of the angle between the vectors of two environments approximates the correlation coefficient between them (Kroonenberg, 1995; Yan, 2002). The angles between Ejura and fumesua, Ejura and Kpeve and Kpeve and Fumesua were all less than 90°. The three environments were positively and significantly correlated. The correlation coefficients for Ejura and Fumesua, Ejura and Kpeve and Fumesua and Kpeve were 0.90, 0.80 and 0.80, respectively (Table 9).

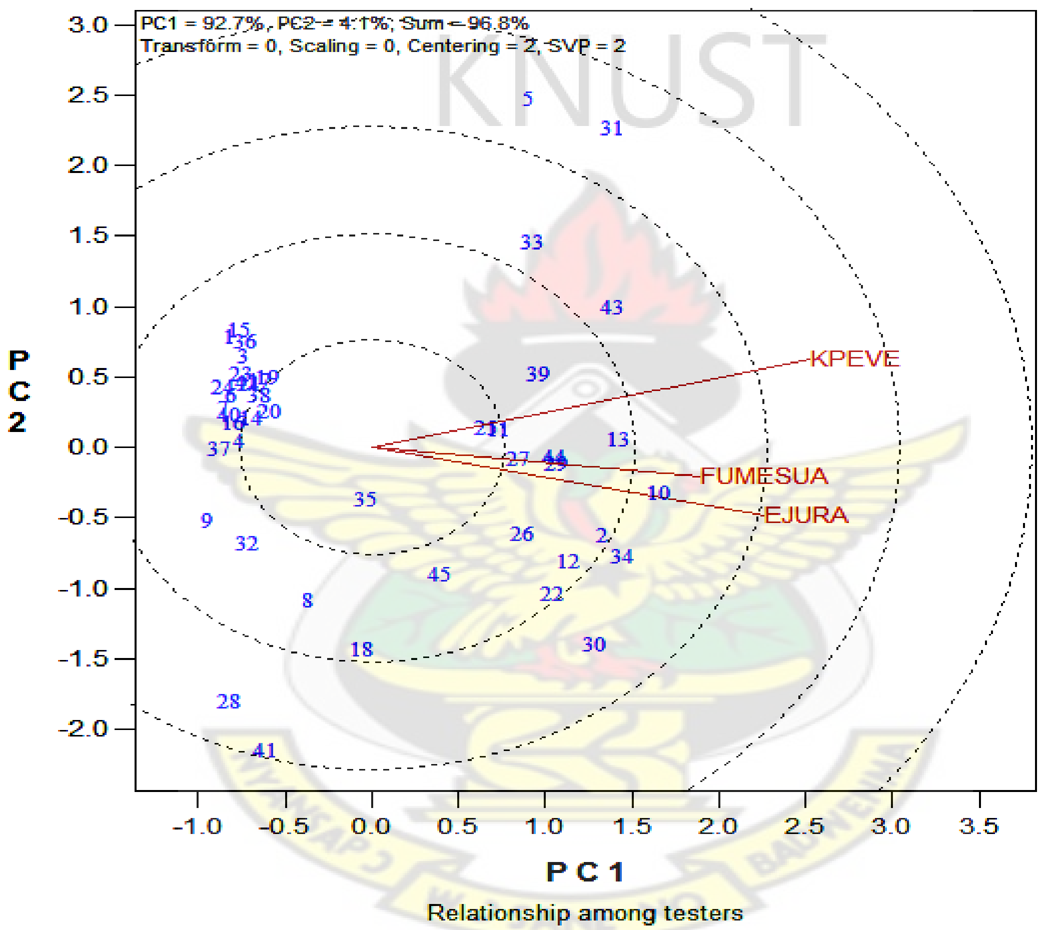

Figure 23: The biplot view showing the relationship among the 3 environments where the 45 extra-early maturing maize hybrids were evaluated in Ghana during the 2011 growing season.

Table 9: Correlation coefficients for the three environments where the 45 extra-early maturing maize hybrids were evaluated during the 2011 growing season

Locations	Ejura	Fumesua
Fumesua	0.90^{**}	
Kpeve	0.80^{**}	0.80^{**}

** P ≤ 0.01

4 Discriminating power and representativeness of the test environments

In the present study, the three test environments used were Ejura, Fumesua and Kpeve representing the Forest, Forest transition and Transition zones of Ghana. The purpose of test-environment evaluation is to identify environments that effectively identify superior genotypes in a mega-environment. The discriminating power of an environment refers to the ability of an environment to identify an ideal test environment, while the representativeness refers to the ability of a test location to represent the mega-environment (Badu-apraku *et al*., 2011a)**.** The representativeness and discriminating power view of GGE biplot analysis are presented in Figure 24. Kpeve had PC1 score greater than 2.00 and PC2 score greater than 0.50, Ejura had PC1 score greater than 2.00 and PC2 score less than -1.00 and Fumesua had PC1 score less than 2.00 and PC2 score less than 0.00. Kpeve had the longest vectors followed by Ejura while Fumesua had the shortest vector. Fumesua was at the smallest angle to the average environment axis followed by Ejura while Kpeve was at the largest angles to it (Figure 24).

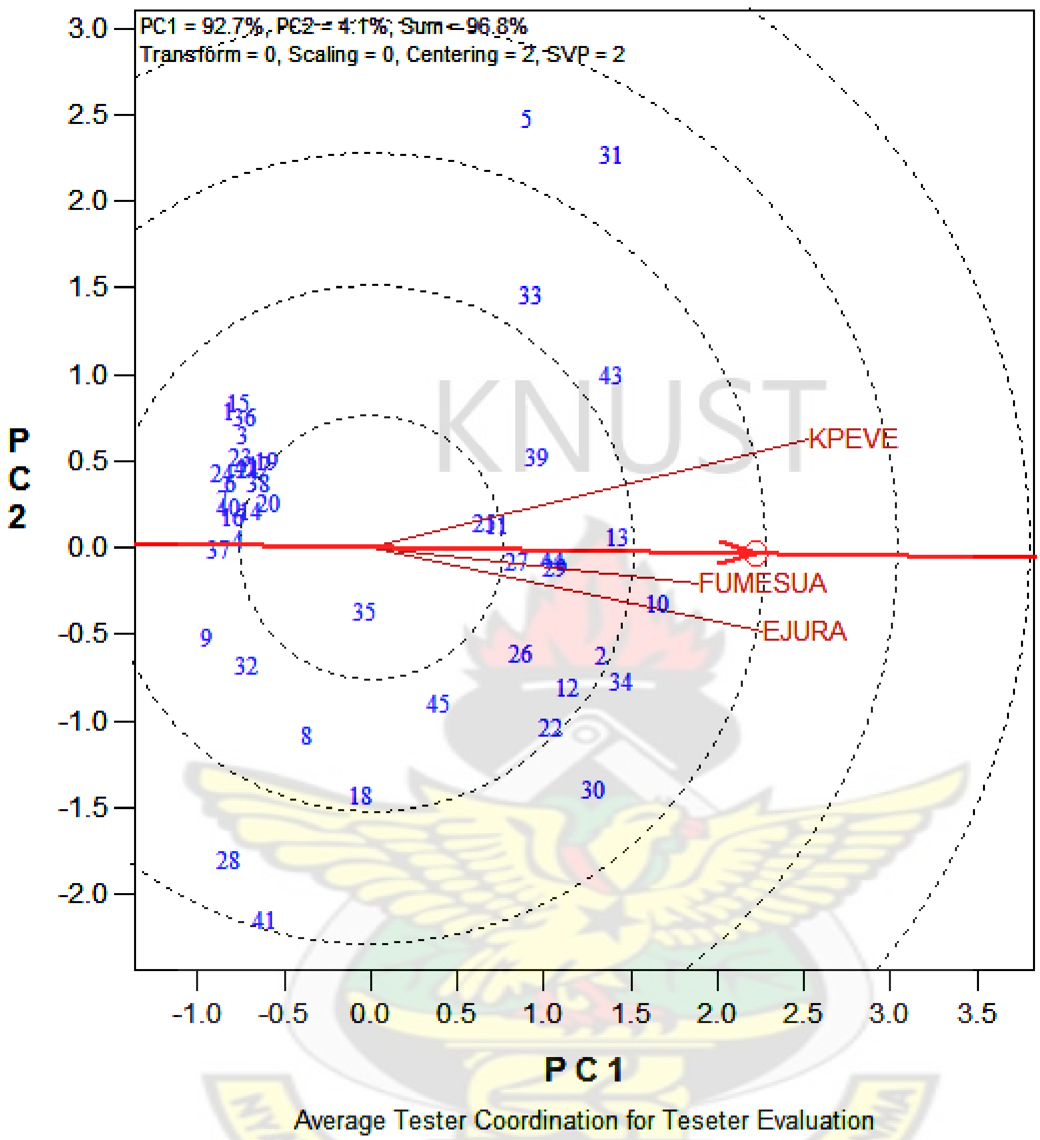

Figure 24: The 'discriminating power and representativeness' view of GGE biplot based on a genotype x environment yield data of the 45 extra-early maturing maize hybrids evaluated in three environments in Ghana during the 2011 growing season.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Performance of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

From the trials at the three locations, the values of the percentage sum of squares indicated that the contributions of genotypes were highest at Ejura followed by Fumesua and Kpeve respectively (Table 4). This reflected the existing diverse environmental conditions prevailing particularly at Fumesua and Kpeve. The sites where the experiment was conducted were different in soil type and mean seasonal rainfall. Besides, temperature and relative humidity vary among them, a fact that affects performance (Table 2). Kpeve was the highest grain yield producing location followed by Fumesua and Ejura (Figure 1). Similar result was reported by Abdulai *et al*. (2007). The basic causes of GEI have been reported to be due to differences in biochemical pathways of certain physiological processes taking place in plants. Although genotypes may be similar phenotypically, they still differ by a few nucleotide sequences. This results in differential expression of genes in different environments as reported by Langridge and Griffing (1959) for hybrid plants. GEI, which is associated with the differential performance of genotypes, tested in a number of locations and or in different years has long been recognized (Lin *et al*., 1986). In the present study, most of the hybrids evaluated showed differential ranking in performance across the three environments (Appendix 1). However, the following seven hybrids performed similarly at either two of the environments; TZEEI 6 x TZEEI 40 ranked as the 20th best hybrid at Ejura and Fumesua and 21st best hybrid at Kpeve. TZEEI 4 x TZEEI 39 ranked as the 22nd best hybrid at Ejura and Fumesua and 28th best hybrid at Kpeve. TZEEI 13 x TZEEI 6 ranked as the 11th best hybrid at Fumesua and the 14th best at Ejura and Kpeve. TZEEI 13 x TZEEI 22 ranked as the 5th best hybrid at Fumesua and 11th best hybrid at Ejura and Kpeve. TZEEI 5 x TZEEI 39 ranked as the 3rd best hybrid at Fumesua and 13th best hybrid at Ejura and Kpeve. TZEEI 31 x TZEEI 8 ranked as the 7th best hybrid at Fumesua and 10th best hybrid at Ejura and Kpeve.

TZEEI 23 x TZEEI 39 ranked as the 35th best hybrid at Fumesua and 40th best hybrid at Ejura and Kpeve (Figure 2). Among the specific locations, two hybrids showed a consistent yield advantage across the three sites; TZEEI 5 x TZEEI 4 was the highest yielder at Fumesua and was also ranked as the 3rd and 4th best hybrid at Ejura and Kpeve respectively. TZEEI 5 x TZEEI 40 was ranked as the 4th, 6th and 5th best hybrids at Ejura, Fumesua and Kpeve respectively (Appendix 1). These differential and same rankings of hybrids across the test environments demonstrated that there exists possibly in both crossover and non-crossover GEI. In addition, it showed the existence of unstable genotypes. This necessitates a closer evaluation of the genotypes according to their interactions with the environments.

From the results of the combined analysis of variance, the genotypes contributed 79.16 % of the total variation in the sum of squares for grain yield, while L and G × L sources of variation accounted for 7.04 % and 7.37 % of the total variation respectively (Table 5). This result is not consistent with the findings of Fakorede & Adeyemo (1986), Badu-Apraku *et al*. (1995, 2003) and Mohammadi *et al*. (2009), who reported that the largest proportion of total variation in multi-environment trials is attributed to locations, whereas G and G × L sources of variation are relatively smaller. The presence of large genetic variability is of the utmost importance for progress from selection for grain yield tested in different environments in multi-environment trials (Badu-Apraku *et al*., 2012). Thus, the observed large sum of square of genotypes for grain yield indicated that good progress can be made in selecting for grain yield under the different environments. The significant mean square for location showed that genetic effects were influenced by the environments, which is a consequence of environmental diversity. Similar observations were reported by Butron *et al*. (2002) in which they indicated that G x L effects for grain yield in maize were mainly due to environmental yield limiting factors such as the mean minimum temperature and relative humidity. The observed Significant G x L mean square for grain yield suggested that the locations for which the hybrids were tested comprise of a number of special environments. Hence, hybrids selected should be specifically adapted to the different environments.

The significant mean squares for location of grain yield, days to silking, days to anthesis, ASI, EPP, plant height, ear height, number of stalk and root lodging showed that the genetic expressions of these parameters were affected by environmental conditions existing at the three environments during the growing season of 2011 (Table 6 and 7). Correlation between genotypic and phenotypic values of hybrids under diverse environmental conditions is often reduced due to significant G x L (Comstock and Moll, 1963). The observed lack of significant means squares for G x L of ASI, PLHT, RLT and SLT indicated that these parameters are stable and not affected by G x L. Hence the phenotypic and genotypic correlations between these traits and grain yield are not expected to be reduced across the locations. In contrast, the significant means squares detected for G x L of DYSK, DA, EPP and EHT suggested that they are unstable and affected by G x L. Therefore, the phenotypic and genotypic correlations between these traits and grain yield could reduce hindering the evaluation of the genetic potential of the hybrids. When selections of hybrids are based on the parameters measured, such as ASI, PLHT, RLT and SLT are expected to improve the precision with which superior genotypes are identified, compared with measuring only grain yield.

5.2 Correlations among parameters measured

Plant height, ear height, days to anthesis, days to silking and EPP had a positive and significant direct contribution to yield (Table 8). Plant height had a highly significant indirect effect on yield through days to silking, days to anthesis, ears per plant and ear height with the highest effect through ear height (r = 0.91), Table 8. Similar results were reported by Afzal *et al. (*1997). Days to silking had highly significant indirect effects on yield through ears per plant, root lodging, days to anthesis, ear height and plant height with the highest effect through days to anthesis (r = 0.64).

The negative phenotypic correlations between grain yield and anthesis silking interval, root lodging and stalk lodging suggested that grain yield may be reduced by a relative increase in these traits (Table 8). Anthesis-silking interval reduced yield indirect through reduction in ears per plant (r = -0.09) as well as increasing root lodging and stalk lodging with the highest effect through stalk lodging (r = 0.3). Badu-Apraku *et al.* (2012) in a study of the assessment of reliability of secondary traits in selecting for improved grain yield in drought and low-nitrogen environments reported similar findings. The observed weak phenotypic correlations between grain yield and anthesis silking interval could be attributed to sufficient supply of moisture during the reproductive phase of growth of the hybrids (Table 2). The above observations were evident from the sums of the ranking (Appendix 3) of the performance across grain yield, days to silking, days to anthesis, ASI, plant height, ear height, root lodging , stalk lodging and ears per plant of the 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season. This reinforced the use of secondary traits in the selection of superior genotypes as compared to grain yield alone.

5.3 Identification of superior hybrids

The primary trait, grain yield, is a quantitative trait with a low heritability. Several studies have indicated that highly significant phenotypic correlations between yield and many secondary traits can be found. The use of secondary traits in breeding significantly increases breeding progress as compared to selection for yield alone (Edmeades *et al*., 1997). A superior maize hybrid must be high-yielding and also possess desirable agronomic and an end user-preferred trait which may be measured by selection index. If a hybrid fails to meet any of the above qualities, it will result in non-adoption of the hybrid by farmers and consumers. The correlation studies revealed that grain yield was positively related to plant height, ear height, days to silking, days to anthesis and EPP. This indicates that one of these traits could be use to select for the other. This was evident from the performance of the following hybrids; TZEEI 20 x TZEEI 19 (115.83 cm), TZEEI 5 x TZEEI 4 (114.50 cm), TZEEI 29 x TZEEI 26 (113.33 cm), TZEEI 5 x TZEEI 40 (112.33 cm), TZEEI 1 x TZEEI 22 (111.50 cm), TZEEI 15 x TZEEI 8 (109.00 cm), TZEEI 14 x TZEEI 6 (107.00 cm), TZEEI 5 x TZEEI 39 (106.50 cm), TZEEI 13 x TZEEI 22 (106.00 cm) and TZEEI 31 x TZEEI 8 (105.00 cm). These hybrids did not only record higher ear heights but also had the highest plant heights and grain yields as well (Appendix 2). Most hybrids with higher ASI, stalk and root lodging had lower grain yields (Appendix 2). . This was evident from the ranked scores (Appendix 3) of the hybrids below; TZEEI 6 x TZEEI 4, TZEEI 23 x TZEEI 5, TZEEI 26 x TZEEI 24, TZEEI 1 x TZEEI 2, TZEEI 4 x TZEEI 39, TZEEI 13 x TZEEI 12, TZEEI 5 x TZEEI 53, TZEEI 27 x TZEEI 3, TZEEI 4 x TZEEI 51 and TZEEI 11 x TZEEI 22. This again means that in selecting for superior hybrids, the above mentioned traits should be considered.

On the basis of the above observations; TZEEI 5 x TZEEI 4, TZEEI 20 x TZEEI 19, TZEEI 29 x TZEEI 26, TZEEI 1 x TZEEI 22, TZEEI 5 x TZEEI 40, TZEEI 15 x TZEEI 8, TZEEI 14 x TZEEI 6, TZEEI 9 x TZEEI 60, TZEEI 12 x TZEEI 19 and TZEEI 5 x TZEEI 39 in descending order (Appendix 3) have been identified as the 10 superior hybrids from this study and can be considered for commercial production. Also, the result suggested that out of the 33 inbred lines used to develop the 44 hybrids used in the study, the following 17 inbred lines may be good combiners of genes for grain yield and superior agronomic traits; TZEEI 5, TZEEI 4, TZEEI 20, TZEEI 19, TZEEI 29, TZEEI 26, TZEEI 1, TZEEI 22, TZEEI 40, TZEEI 15, TZEEI 8, TZEEI 14, TZEEI 6, TZEEI 9, TZEEI 60, TZEEI 12 and TZEEI 39.

5.4 Yield performance and stability of the 45 extra-early maturing maize hybrids.

Environmental PC1 scores were obtained in both positive and negative scores. This case exhibited that PC1 scores represent proportional genotype yield differences across environments which were caused by both crossover and non crossover GEI. Similar to PC1, environmental PC2 scores had both positive and negative scores. Kaya *et al.* (2006) and Emre *et al.* (2009) reported similar results. In the polygon view of the GGE biplot in Figure 21, the presence of two or more environments within a sector indicates that a single genotype has the highest yield in those environments. If environments fall into different sectors, it means that different genotypes won in different environments (Yan *et al.*, 2007). As observed in Figure 21, TZEEI 5 x TZEEI 4 had the highest yield at Ejura and Fumesua, while the winning hybrid at Kpeve was TZEEI 15 x TZEEI 8. This crossover G × E indicated that the target environment could be divided into different target zones. TZEEI 14 x TZEEI 6 is specifically adapted to Ejura and thus, produced the highest yield at Ejura with relatively lower yields at Fumesua and Kpeve. TZEEI 2 x TZEEI 11 was the 2nd best hybrid at Kpeve. The following hybrids, TZEEI 26 x TZEEI 24, TZEEI 21 x TZEEI 39, TZEEI 4 x TZEEI 51, TZEEI 5 x TZEEI 53, TZEEI 13 x TZEEI 12 and TZEEI 2 x TZEEI 1 were the lowest-yielding hybrids at all or some locations. Implying they should not be considered for production in any of the three environments. Souza *et al*. (2008) reported that when different genotypes have different performance in a location this can be capitalized on to maximize productivity. The entry by environment response biplot (Figure 21) may be useful for a narrow based adaptation selection. Thus, hybrid TZEEI 5 x TZEEI 4 is the most promising for production in Ejura and Fumesua and TZEEI 15 x TZEEI 8 at Kpeve.

For selection for broad adaptation in maize production, an ideal genotype should have both high mean performance and high stability within a mega-environment (Badu-Apraku *et al*, 2011a). Thus, TZEEI 5 x TZEEI 4, TZEEI 1 x TZEEI 22, TZEEI 20 x TZEEI 19, TZEEI 31 x TZEE I8 and TZEEI 13 x TZEEI 22 were the highest yielding and most stable hybrids. This implies that their rankings were highly consistent across locations. They were closest to the ideal genotype and may be considered as best hybrids. These five hybrids are suitable for production in Ejura, Fumesua and Kpeve. TZEEI 11 x TZEEI 22, TZEEI 5 x TZEEI 50, TZEEI 8 x TZEEI 51 and TZEEI 8 x TZEEI 24 were low yielding and the most stable. TZEEI 2 x TZEEI 11 and TZEEI 15 x TZEEI 8 was high yielding and the least stable and TZEEI 13 x TZEEI 12 and TZEEI 26 x TZEEI 24 had both low yielding and low stability (Figure 22). Thus, they should not be considered for production across the three locations. From the result of the interrelationship among environments (Figure 23), the smallest angle is between Ejura and Fumesua, implying there is the highest correlation between them. The approximate correlation coefficient for these two locations is 0.90. Subsequently, the smaller angle occurs between Fumesua and Kpeve. Based on the above observation, the three sites used for the study are grouped into two. Group one includes Ejura and Fumesua representing the Forest zone. Group two involves Kpeve representing the Transition zone. The classification in this study does not correspond closely to the maize agro-ecological zones identified by earlier researchers (Morris *et al*., 1999). The discriminating power and representativeness view of the GGE biplot analysis is presented in Figure 24. Since the AEC abscissa is the average-environment axis, test environments at smaller angles to the average environment axis are more representative of the mega-environment than those at larger angles to it. Therefore, the cosine of the angle between any environment vector and the average environment axis approximates the correlation coefficient between the genotype values in that environment and the genotype means across the environment (Yan *et al*. 2007). The small circle is the average-environment and the arrow pointing to it is used to indicate the direction of the AEA. The absolute length of the projection from the marker of an environment onto the ATC y-axis is a measure of its representativeness: the shorter the projection, the more representative the environment. In contrast, the absolute length of the projection from the marker of an environment onto the ATC x-axis is a measure of its discriminative ability: the longer the projection, the more discriminative the environment. Based on these requirements, Fumesua was the most representative but not discriminating. Ejura was more representative and more discriminating of the test environments. The Kpeve was highly discriminating (far away from the origin) but the least representative of the environments since it was at the largest angle to the AEC abscissa. It therefore implies that Kpeve, which had longest vector and largest angle with the AEC abscissa, cannot be used in selecting superior genotypes, but can be used effectively in culling unstable genotypes (Figure 24). Similar result was reported by Badu-Apraku *et al.* (2011b). An ideal test environment should effectively discriminate genotypes and represent their mega-environment (Yan & Rajcan 2002). This indicated that Ejura, located in the Forest transition zone, represented the ideal testing environment for these set of hybrids. This location would therefore be the most appropriate for selecting superior hybrids. The environments that have shortest vectors are less informative compared to those with longer vectors and provide little or no information on the genotypes and could therefore be excluded when choosing test environments. Thus, the shortest-vector environment Fumesua may be regarded as independent research environment and may be treated as unique and, therefore, essential research environment. Ejura and Fumesua were highly correlated in their ranking of the hybrids (Figure 24), indicating that these locations produced similar information about the hybrids. The implication is that one of these locations is redundant and could be dropped to reduce the costs of field evaluation without any loss of information. Since Fumesua was less powerful in discriminating among the hybrids, it can be dropped.

The following are the main limitations of this study;

In the present study, only two replications were used due to insufficient seeds to plant three or more replications across the test sites. Also, the reliability of performance of the 45 extra-early maturing maize hybrids was based on observations made from three environments for only one year due to financial and time constraints, which prevented the establishment of trials at more locations for more done a year.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSION

The selection process of good performing and stable genotypes is mainly complicated by the phenomenon of genotype by environment (G x E) interaction. In West and Central Africa, G x E have been reported in maize cultivars (Fakorede and Adeyemo, 1986; Badu-Apraku *et al*., 1995; 2003). The large occurrence of G x E interactions causes the relative rankings of genotypes to change from location to location and or from year to year. Hence, it is vital to have a proper understanding of the effects of G x E interactions on variety evaluation, to aid decisions on cultivar recommendations. It was with this aim that this research was conducted in three different maize growing agro-ecologies of Ghana to identify stable and high-yielding hybrids with superior agronomic performance for commercial production in Ghana during the growing season of 2011.

From this study GEI of the 45 extra-early maturing maize hybrids evaluated was found to be significant for grain yield. The presence of large genetic variability for grain yield indicated that, good progress can be made in selecting for grain yield under the different environments. Although, variability among genotypes was highly significant within and among the testing locations; locations were found to contribute greatly to the variations in hybrids' performance. This indicates that, unpredictable environmental conditions are one of the major players in selecting superior and widely adapted maize varieties under Ghanaian conditions. The observed significant genotype by location interaction effect for grain yield suggested that the locations for which the hybrids were tested comprise of a number of special environments. Hence, hybrids selected should be specifically adapted to the different environments. The presence of significant genotypic mean squares for grain yield, days to silking, days to anthesis, ASI, EPP, plant height, ear height, number of stalk and root lodging justified the use of the Multi-trait Selection method to identify the best 10 candidates for the production.

Among the hybrids evaluated; TZEEI 5 x TZEEI 4, TZEEI 20 x TZEEI 19, TZEEI 29 x TZEEI 26, TZEEI 1 x TZEEI 22, TZEEI 5 x TZEEI 40, TZEEI 15 x TZEEI 8, TZEEI 14 x TZEEI 6, TZEEI 9 x TZEEI 60, TZEEI 12 x TZEEI 19 and TZEEI 5 x TZEEI 39 were the 10 top yielders with superior agronomic qualities. Hence these hybrids can be considered as candidate varieties for commercial production. Conversely, TZEEI 6 x TZEEI 4, TZEEI 23 x TZEEI 5, TZEEI 26 x TZEEI 24, TZEEI 1 x TZEEI 2, TZEEI 4 x TZEEI 39, TZEEI 13 x TZEEI 12, TZEEI 5 x TZEEI 53, TZEEI 27 x TZEEI 3, TZEEI 4 x TZEEI 51 and TZEEI 11 x TZEEI 22 were the poorest. These hybrids performed poorer than the hybrid check (AKPOSOE) and therefore, they are not good candidates for commercial hybrid maize production. Also, the result suggested that out of the 33 inbred lines used to develop the 44

IITA hybrids used in the study, the following 17 inbred lines may be good combiners of genes for grain yield and superior agronomic traits; TZEEI 5, TZEEI 4, TZEEI 20, TZEEI 19, TZEEI 29, TZEEI 26, TZEEI 1, TZEEI 22, TZEEI 40, TZEEI 15, TZEEI 8, TZEEI 14, TZEEI 6, TZEEI 9, TZEEI 60, TZEEI 12 and TZEEI 39.

The GGE biplot analyses provided results in terms of stability and performance of the 45 extra-early maize hybrids. Based on the results of the present study, TZEEI 5 x TZEEI 4, TZEEI 1 x TZEEI 22, TZEEI 20 x TZEEI 19, TZEEI 31 x TZEEI 8 and TZEEI 13 x TZEEI 22 were the highest yielding and most stable hybrids. They were the closest to the ideal genotype and may be considered as the best hybrids. These five hybrids have the potential for production in Ejura, Fumesua and Kpeve and other locations within the same agro-ecological zones. TZEEI 11 x TZEEI 22, TZEEI 5 x TZEEI 50, TZEEI 8 x TZEEI 51 and TZEEI 8 x TZEEI 24 were low yielding and the most stable. This indicated that the performance of these hybrids would be predictable in less favourable environments. The hybrids, TZEEI 5 x TZEEI 4, were identified as the most promising for production in Ejura and Fumesua and TZEEI 15 x TZEEI 8, in Kpeve. Ejura located in the Forest transition zone, has been identified as the ideal testing environment for these set of hybrids.

6.1 RECOMMENDATIONS

This study should be repeated in other major maize growing ecological zones of Ghana such as the Coastal, Guinea and Sudan savannas for two or more years to confirm yield stability and the pattern of response of the 45 maize hybrids across locations and years. To save resources, the less superior hybrids should be excluded from future testing in other locations.

The high yielding and stable hybrids with superior agronomic performance, TZEEI 5 x TZEEI 4, TZEEI 1 x TZEEI 22, TZEEI 20 x TZEEI 19 and TZEEI 13 x TZEEI 22 should be tested extensively in on-farm trials and promoted for adoption and commercialization in Ghana.

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APPENDICES

Appendix 1: Mean grain yield (t/ha) and relative ranking of the 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

		Ejura		Fumesua		Kpeve	
Entry	Entry name	Yield	Rank	Yield	Rank	Yield	Rank
1	TZEEI 1 x TZEEI 2	1.08	43	1.93	42	3.11	29
2	TZEEI 1 x TZEEI 22	7.03	2	5.74	9	7.79	7
3	TZEEI 1 x TZEEI 50	1.17	39	2.33	32	3.17	27
4	TZEEI 2 x TZEEI 1	1.46	29	2.35	30	2.75	36
5	TZEEI 2 x TZEEI 11	5.01	15	3.47	21	8.74	2
6	TZEEI 4 x TZEEI 6	1.35	33	1.95	41	2.88	35
7	TZEEI 4 x TZEEI 7	1.27	36	1.96	40	2.71	38
8	TZEEI 4 x TZEEI 39	3.18	22	2.95	22	3.14	28
9	TZEEI 4 x TZEEI 51	1.86	26	1.32	45	2.10	43
10	TZEEI 5 x TZEEI 4	6.52	3	7.79	1	8.43	4
11	TZEEI 5 x TZEEI 23	4.81	16	4.98	15	6.53	17

12	TZEEI 5 x TZEEI 39	5.29	13	7.33	3	6.72	13
13	TZEEI 5 x TZEEI 40	6.49	4	6.17	6	8.25	5
14	TZEEI 5 x TZEEI 50	1.44	30	2.44	27	2.94	34
15	TZEEI 5 x TZEEI 53	0.85	45	2.33	31	3.11	30
16	TZEEI 6 x TZEEI 4	1.33	34	2.06	38	2.68	39
17	TZEEI 6 x TZEEI 36	1.38	32	2.49	26	3.21	24
18	TZEEI 6 x TZEEI 40	3.93	20	3.67	20	3.62	21
19	TZEEI 8 x TZEEI 24	1.43	31	2.66	24	3.34	22
20	TZEEI 8 x TZEEI 51	1.49	28	2.90	23	3.20	26
21	TZEEI 9 x TZEEI 59	1.11	42	2.61	25	3.01	32
22	TZEEI 9 x TZEEI 60	6.37	6	5.42	10	6.68	15
23	TZEEI 10 x TZEEI 22	1.08	44	2.39	29	2.98	33
24	TZEEI 11 x TZEEI 22	1.13	41	1.80	43	2.71	37
25	TZEEI 11 x TZEEI 24	4.43	19	5.17	12	6.29	18
26	TZEEI 12 x TZEEI 19	6.45	5	3.90	19	6.68	16
27	TZEEI 13 x TZEEI 6	5.18	14	5.24	11	6.69	14
28	TZEEI 13 x TZEEI 12	2.77	24	1.66	44	1.56	45
29	TZEEI 13 x TZEEI 22	5.36	11	6.18	5	7.14	11
30	TZEEI 14 x TZEEI 6	7.21	1	5.75	8	7.09	12
31	TZEEI 15 x TZEEI 8	5.72	8	5.03	13	9.64	1
32	TZEEI 15 x TZEEI 21	1.94	25	2.41	28	2.37	41
33	TZEEI 20 x TZEEI 39	4.72	17	4.85	16	7.87	6
34	TZEEI 20 x TZEEI 19	6.32	7	7.43	2	7.65	8
35	TZEEI 20 x TZEEI 21	2.86	23	4.35	18	4.17	20
36	TZEEI 21 x TZEEI 20	1.18	38	2.12	36	3.22	23
37	TZEEI 21 x TZEEI39	1.21	37	2.03	39	2.37	42
38	TZEEI 23 x TZEEI 5	1.62	27	2.26	33	3.21	25
39	TZEEI 23 x TZEEI 6	5.34	12	5.03	14	7.41	9
40	TZEEI 23 x TZEEI 39	1.16	40	2.17	35	2.65	40
41	TZEEI 26 x TZEEI 24	3.43	21	2.09	37	1.87	44
42	TZEEI 27 x TZEEI 3	1.31	35	2.24	34	3.05	31
43	TZEEI 29 x TZEEI 26	5.60	9	6.42	4	8.64	3
44	TZEEI 31 x TZEEI 8	5.49	10	5.87	7	7.18	10

45	AKPOSOE	4.49	18	4.70	17	5.04	19

Appendix 2: Means of grain yield (t/ha), days to silking, days to anthesis, ASI, plant height (cm), ear height (cm), EPP, stalk lodging and root lodging of 45 extra-early maturing maize hybrids evaluated at three locations in Ghana during the 2011 growing season.

Entry	Yield	ASI	DYSK	EPP	RLT	SLT	DA	EHT	PLHT
TZEEI 1 x TZEEI 2	2.04	3.17	44.67	0.72	1.67	3.50	42.00	71.00	152.00
TZEEI 1 x TZEEI 22	6.85	1.83	45.00	1.17	0.83	1.33	47.33	111.50	211.83
TZEEI 1 x TZEEI 50	2.22	3.17	46.17	0.86	2.83	2.50	42.50	75.50	161.00
TZEEI 2 x TZEEI 1	2.19	2.67	45.50	0.83	2.83	2.83	43.00	76.50	161.00
TZEEI 2 x TZEEI 11	5.74	3.83	48.67	1.02	0.67	4.00	45.00	99.67	181.67
TZEEI 4 x TZEEI 6	2.06	2.83	44.00	0.81	2.17	2.17	42.67	75.00	158.33
TZEEI 4 x TZEEI 7	1.98	2.33	44.83	0.82	1.50	3.00	42.00	73.33	157.50
TZEEI 4 x TZEEI 39	3.09	3.50	46.67	0.92	2.83	4.00	43.50	79.00	161.83
TZEEI 4 x TZEEI 51	1.76	3.50	46.17	0.79	1.67	3.00	42.17	69.33	153.83
TZEEI 5 x TZEEI 4	7.58	1.17	43.00	1.20	0.37	1.10	47.50	114.50	210.17
TZEEI 5 x TZEEI 23	5.44	3.67	47.00	0.99	1.50	3.17	43.50	95.50	190.50
TZEEI 5 x TZEEI 39	6.45	2.67	47.83	1.14	2.00	2.83	45.17	106.50	196.00
TZEEI 5 x TZEEI 40	6.97	1.67	48.00	1.12	0.67	1.40	46.33	112.33	201.33
TZEEI 5 x TZEEI 50	2.27	3.00	44.67	0.92	2.83	5.33	43.00	77.67	164.17

TZEEI 5 x TZEEI 53	2.10	3.17	45.17	0.71	2.50	3.17	41.50	73.00	157.17
TZEEI 6 x TZEEI 4	2.02	3.33	45.33	0.85	1.83	2.17	42.67	72.83	158.33
TZEEI 6 x TZEEI 36	2.36	2.67	45.17	0.91	2.00	2.67	42.67	79.00	164.83
TZEEI 6 x TZEEI 40	3.74	3.83	46.33	0.95	2.00	3.33	42.50	82.50	177.50
TZEEI 8 x TZEEI 24	2.48	3.50	47.33	0.92	1.83	3.50	43.50	79.67	169.33
TZEEI 8 x TZEEI 51	2.53	2.50	45.83	0.92	2.33	2.83	43.00	79.33	166.33
TZEEI 9 x TZEEI 59	2.24	3.17	44.50	0.82	1.33	2.50	41.83	75.83	160.00
TZEEI 9 x TZEEI 60	6.15	2.00	48.50	1.12	1.17	1.17	46.50	103.83	204.50
TZEEI 10 x TZEEI 22	2.15	2.00	44.67	0.79	1.17	1.67	42.33	75.50	152.67
TZEEI 11 x TZEEI 22	1.88	3.17	45.17	0.76	2.83	2.83	42.17	71.33	157.67
TZEEI 11 x TZEEI 24	5.30	3.67	47.17	1.03	1.17	1.17	43.50	95.83	177.33
TZEEI 12 x TZEEI 19	5.68	1.83	48.33	1.12	1.50	1.67	46.17	101.83	195.83
TZEEI 13 x TZEEI 6	5.70	3.67	47.83	1.03	2.50	1.50	44.17	98.00	193.50
TZEEI 13 x TZEEI 12	2.00	4.17	46.33	0.84	0.33	2.33	42.83	68.67	148.17
TZEEI 13 x TZEEI 22	6.22	3.67	48.33	1.08	1.83	2.00	44.67	106.00	203.33
TZEEI 14 x TZEEI 6	6.68	1.83	48.17	1.16	0.67	2.33	46.33	107.00	199.00
TZEEI 15 x TZEEI 8	6.79	3.67	44.00	1.19	1.20	1.10	45.17	109.00	197.83
TZEEI 15 x TZEEI 21	2.24	2.83	44.00	0.87	1.83	4.17	42.17	76.17	161.67
TZEEI 20 x TZEEI 39	5.81	3.50	47.83	1.01	2.00	1.67	44.50	99.17	183.67
TZEEI 20 x TZEEI 19	7.13	1.17	42.00	1.21	1.00	1.30	47.50	115.83	212.83
TZEEI 20 x TZEEI 21	3.79	3.33	46.50	0.99	2.33	3.17	43.50	84.83	172.50
TZEEI 21 x TZEEI 20	2.17	2.67	44.50	0.84	2.33	2.67	42.50	76.00	162.00
TZEEI 21 x TZEEI39	1.87	2.67	45.17	0.83	1.17	2.33	42.33	72.17	159.33
TZEEI 23 x TZEEI 5	2.36	4.00	46.00	0.89	2.00	2.50	43.50	78.00	163.00
TZEEI 23 x TZEEI 6	5.92	3.00	48.33	1.05	1.50	1.83	45.33	102.50	186.83
TZEEI 23 x TZEEI 39	1.99	2.67	44.33	0.81	2.17	2.83	41.83	74.67	160.50
TZEEI 26 x TZEEI 24	2.46	3.33	45.33	0.87	4.33	1.83	43.00	73.17	159.67
TZEEI 27 x TZEEI 3	2.20	2.83	45.33	0.79	2.83	2.67	42.50	75.33	150.33
TZEEI 29 x TZEEI 26	6.88	0.83	44.00	1.11	1.00	1.17	47.50	113.33	204.67
TZEEI 31 x TZEEI 8	6.18	3.17	49.33	1.05	2.00	1.50	46.33	105.00	194.50
AKPOSOE	4.74	3.83	48.17	1.01	1.67	2.67	44.33	92.33	186.67
Means	3.96	2.90	46.03	0.95	1.79	2.45	43.87	87.89	175.61
CV %	20.50	51.40	4.00	13.8	73.10	78.7	4.00	9.00	8.50

L.S.D	1.61	2.31	3.67	0.26	2.65	4.00	3.43	15.65	29.70

Appendix 3: Rank sum values of hybrids based on performance of hybrids using grain yield, days to silking, days to anthesis, ASI, plant height (cm), ear height (cm), EPP, stalk lodging and root lodging of 45 extra-early maturing maize hybrids evaluated in three locations at Ghana during the 2011 growing season

Entry name	yield	rank	ASI	rank	DYSK	rank	EPP	Rank	RLT	Rank	SLT	rank	DA	ra
TZEEI 5 x TZEEI 4	7.58	1	1.17	2	43.00	2	1.20	2	0.37	2	1.10	1	47.50	43
TZEEI 20 x TZEEI 19	7.13	2	1.17	3	42.00	1	1.21	1	1.00	7	1.30	6	47.50	44
TZEEI 29 x TZEEI 26	6.88	4	0.83	1	44.00	5	1.11	10	1.00	8	1.17	5	47.50	45
TZEEI 1 x TZEEI 22	6.85	5	1.83	5	45.00	14	1.17	4	0.83	6	1.33	7	47.33	42
TZEEI 5 x TZEEI 40	6.97	3	1.67	4	48.00	37	1.12	8	0.67	4	1.40	8	46.33	38
TZEEI 15 x TZEEI 8	6.79	6	3.67	40	44.00	6	1.19	3	1.20	13	1.10	2	45.17	35
TZEEI 14 x TZEEI 6	6.68	7	1.83	7	48.17	38	1.16	5	0.67	5	2.33	20	46.33	39
TZEEI 9 x TZEEI 60	6.15	11	2.00	8	48.50	43	1.12	9	1.17	9	1.17	3	46.50	41
TZEEI 12 x TZEEI 19	5.68	16	1.83	6	48.33	40	1.12	7	1.50	17	1.67	12	46.17	37
TZEEI 5 x TZEEI 39	6.45	8	2.67	13	47.83	34	1.14	6	2.00	26	2.83	30	45.17	34
TZEEI 11 x TZEEI 24	5.30	18	3.67	37	47.17	32	1.03	15	1.17	11	1.17	4	43.50	26
TZEEI 23 x	5.92	12	3.00	22	48.33	42	1.05	12	1.50	18	1.83	14	45.33	36

TZEEI 6														
TZEEI 13 x TZEEI 22	6.22	9	3.67	39	48.33	41	1.08	11	1.83	24	2.00	16	44.67	32
TZEEI 31 x TZEEI 8	6.18	10	3.17	28	49.33	45	1.05	13	2.00	31	1.50	10	46.33	40
TZEEI 6 x TZEEI 36	2.36	27	2.67	14	45.17	16	0.91	26	2.00	27	2.67	25	42.67	17
TZEEI 9 x TZEEI 59	2.24	29	3.17	26	44.50	8	0.82	36	1.33	14	2.50	23	41.83	2
TZEEI 10 x TZEEI 22	2.15	35	2.00	9	44.67	12	0.79	42	1.17	10	1.67	11	42.33	9
TZEEI 20 x TZEEI 39	5.81	13	3.50	35	47.83	36	1.01	17	2.00	29	1.67	13	44.50	31
TZEEI 13 x TZEEI 6	5.70	15	3.67	38	47.83	35	1.03	14	2.50	38	1.50	9	44.17	29
TZEEI 5 x TZEEI 23	5.44	17	3.67	36	47.00	31	0.99	19	1.50	16	3.17	36	43.50	24
TZEEI 8 x TZEEI 51	2.53	23	2.50	11	45.83	23	0.92	22	2.33	34	2.83	31	43.00	21
TZEEI 15 x TZEEI 21	2.24	30	2.83	19	44.00	3	0.87	29	1.83	25	4.17	44	42.17	8
TZEEI 21 x TZEEI 20	2.17	34	2.67	15	44.50	9	0.84	33	2.33	36	2.67	26	42.50	13
TZEEI 2 x TZEEI 11	5.74	14	3.83	41	48.67	44	1.02	16	0.67	3	4.00	42	45.00	33
TZEEI 6 x TZEEI 40	3.74	21	3.83	42	46.33	27	0.95	21	2.00	28	3.33	39	42.50	12
TZEEI 21 x TZEEI 39	1.87	44	2.67	16	45.17	18	0.83	34	1.17	12	2.33	21	42.33	10
TZEEI 4 x TZEEI 6	2.06	37	2.83	18	44.00	4	0.81	38	2.17	32	2.17	17	42.67	15

TZEEI 4 x TZEEI 7	1.98	42	2.33	10	44.83	13	0.82	37	1.50	15	3.00	34	42.00	5
AKPOSOE	4.74	19	3.83	43	48.17	39	1.01	18	1.67	21	2.67	28	44.33	30
TZEEI 20 x TZEEI 21	3.79	20	3.33	30	46.50	29	0.99	20	2.33	35	3.17	38	43.50	27
TZEEI 23 x TZEEI 39	1.99	41	2.67	17	44.33	7	0.81	39	2.17	33	2.83	33	41.83	3
TZEEI 5 x TZEEI 50	2.27	28	3.00	21	44.67	11	0.92	24	2.83	42	5.33	45	43.00	20
TZEEI 1 x TZEEI 50	2.22	31	3.17	24	46.17	25	0.86	30	2.83	39	2.50	22	42.50	11
TZEEI 8 x TZEEI 24	2.48	24	3.50	34	47.33	33	0.92	23	1.83	23	3.50	41	43.50	25
TZEEI 2 x TZEEI 1	2.19	33	2.67	12	45.50	22	0.83	35	2.83	40	2.83	29	43.00	19
TZEEI 6 x TZEEI 4	2.02	39	3.33	29	45.33	19	0.85	31	1.83	22	2.17	18	42.67	16
TZEEI 23 x TZEEI 5	2.36	26	4.00	44	46.00	24	0.89	27	2.00	30	2.50	24	43.50	28
TZEEI 26 x TZEEI 24	2.46	25	3.33	31	45.33	20	0.87	28	4.33	45	1.83	15	43.00	22
TZEEI 1 x TZEEI 2	2.04	38	3.17	23	44.67	10	0.73	44	1.67	19	3.50	40	42.00	4
TZEEI 4 x TZEEI 39	3.09	22	3.50	32	46.67	30	0.92	25	2.83	41	4.00	43	43.50	23
TZEEI 13 x TZEEI 12	2.00	40	4.17	45	46.33	28	0.84	32	0.33	1	2.33	19	42.83	18
TZEEI 5 x TZEEI 53	2.10	36	3.17	25	45.17	15	0.72	45	2.50	37	3.17	37	41.50	1
TZEEI 27 x TZEEI 3	2.20	32	2.83	20	45.33	21	0.79	41	2.83	44	2.67	27	42.50	14

TZEEI 4 x TZEEI 51	1.76	45	3.50	33	46.17	26	0.79	40	1.67	20	3.00	35	42.17	6
TZEEI 11x TZEEI 22	1.88	43	3.17	27	45.17	17	0.76	43	2.83	43	2.83	32	42.17	7