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Determine the Relationship between the Performance of the Maize Varieties and Their Multi-Environment Status

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Authors' contributions

This work was carried out in collaboration between all authors. Author CAD designed the study, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Authors JSA and JNB are supervisors who reviewed manuscript and made the necessary corrections. Author PFR managed the performed the statistical analysis and author EOY managed data collection from the fields. All authors read and approved the final manuscript.

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ABSTRACT

Maize (*Zea mays* L.) is among the main food security crops grown in a wide range of environments in Ghana. The crop grows in a wide range of environmental conditions. In the country, grain yields of maize are considerably affected by genotype x environment interaction (GXE) and other factors. The present study was performed to analyze the genotype by environment (GXE) interaction for grain yield of fourteen varieties (maize hybrids and OPVs) and three inbred lines in three environments located at different agro-ecological zones of Ghana. Grain yield data of the fourteen released varieties with three inbred lines was analyzed using GGE biplot methods were evaluated using a Randomized Complete Block Design (RCBD) with four replications across three

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environments (Fumesua, Ejura and Wenchi). The genotype and genotype by environment (GGE) biplot models were used to assess the magnitude of GXE interaction of grain yield among test materials. Results from genotypes and GXE contributed to PC1=79.3% and PC 2= 19% of the total variation of hybrids of this trait, respectively. The present study identified genotypes such as G11 (Abontem), G14 (Dorke SR) and G1 (Entry 5) showing respectively high grain yields of 6.69, 7.17 and 5.33 t/ha across environments showed minimal G X E interaction in that order across environments but with highly susceptible. Hybrids such as G2 (Entry 6) with low grain yields of 4.76 t/ha, G3 (Entry 70) (5.11 t/ha), and G13 (Akposoe) (5.22 t/ha) showed relatively low yields which are useful genetic resources for breeding because of other traits. Experimental hybrids with high grain yield in this study are good candidates for direct production or future hybrid development in Ghana.

Keywords: GXE interaction; GGE biplot; hybrid; maize and OPVs.

1. INTRODUCTION

Maize is an important staple crop for millions of people in Sub-Saharan Africa [1]. The application of quantitative genetics in maize breeding enables the development of superior genotypes whose genetic parameters have been estimated thus maximizing the gains from selection [2]. This also enables the identification of pleiotropic effects which largely contribute to the genotypic variation with regard to quantitative traits [3]. The maize genotype possesses different kinds of gene actions that interact differently in the inheritance of the various plant attributes. Maize crop also grows on a wide range of environmental conditions with regard to water balance, solar radiation, and temperatures [4]. This differential response of maize germplasm to these varied agro ecological zones (AEZ) contributes to the genotype by environment interaction (GEI) which often hampers the identification of high yielding and stable maize hybrids [5]. The GEI interaction variance can be controlled by increasing the number of test environments.

Multi-condition trails are directed to assess yield dependability execution of hereditary materials under shifting ecological conditions [6-8]. A genotype developed in various situations will much of the time demonstrate critical vacillations in yield execution. These progressions are impacted by the diverse ecological conditions and are referred to as genotype by condition (GE) connection [9]. Be that as it may, GE cooperation diminishes the hereditary advance in plant rearing project through limiting the relationship amongst phenotypic and genotypic values [10]. Subsequently, GE collaboration must be either abused by choosing predominant genotype for every particular target condition or kept away from by choosing generally adjusted and stable genotype crosswise over an extensive variety of situations [11].

It has been recommended that GGE biplot investigation was a valuable strategy for the examination of GE connections [12-16] and had been abused in the assortment assessment of wheat [7,17], Maize [13] and soybean [8]. Regardless of how a dependability parameter is estimated, a standout amongst the most basic inquiry is whether it is nonspecific? In the event that the trademark estimated by the parameter is non-hereditary, it isn't heritable and, in this manner, selection for such a parameter is unbeneficial [18,19]. Different creators have demonstrated that strength records are non-specific and thus heritable [20,21,19,22]. Consequently, the objective of the study was to; (i) evaluate the best Variety and Mega-Environments Adapted, (ii) evaluate the mean grain yield and yield Stability, (iii) determine the correlation between environment and determine the discriminating ability and representativeness of environment.

2. MATERIALS AND METHODS

2.1 Experimental Designs and Study Area

Two evaluation studies (major and minor season) were carried out in a year for two years at all the three locations; Fumesua, Ejura and Wenchi. Each of the individual lines was raised in a randomized complete block design pattern (RCBD) in 4 lines of 5 m row length with spacing of 75 x 40 cm during 2015 and 2016 (major and minor season). There were four replications according to the PPV and FRA guidelines [23].

2.2 Plant Materials and Study Area

Fourteen released maize varieties used in the above experiments were used as shown in Table 3. and three inbred lines were evaluated at research sites as shown in Table 4. for the

Tables 1. Analysis of soil samples from the three locations of the research

Locations	*Wenchi*		*Fumesua*		*Ejura*	
	0-15 cm	*15-30 cm*	*0-15 cm*	*15-30 cm*	*0-15 cm*	*15-30 cm*
pH	5.27	4.27	3.64	3.47	3.99	4.24
Total Nitrogen (%)	0.07	0.06	0.11	0.07	0.11	0.07
Organic Carbon (%)	2.23	2.07	3.03	2.47	2.67	2.43
Organic Matter (%)	3.84	3.57	5.22	4.26	4.6	4.19
Ca (Cmol/Kg)	8.4	19.8	42.4	30.8	13.2	5.4
Mg (Cmol/Kg)	0.6	5	2.6	4.6	4.8	1.8
K (Cmol/Kg)	0.24	0.17	0.36	0.28	0.18	0.16
Na (Cmol/Kg)	0.18	0.37	0.94	0.8	0.67	0.6
Al (Cmol/Kg)	0.5	0.33	0.5	0.67	0.67	0.33
H (Cmol/Kg)	0.3	0.22	0.33	0.33	0.5	0.21
P (mg/Kg)	18.16	21.69	53.47	32.28	9.33	5.79
SAND (%)	90	90	80	84	88.24	87
CLAY (%)	6.12	6.12	10	10	4	4
SILT (%)	3.88	3.88	10	6	7.76	9
Textural Class	Fine sand	Fine sand	Sandy Loam	Loamy fine sand	Fine sand	Loamy fine sand

(2015-2016) period of the research at Fumesua, Ejura and Wenchi in Ghana.

2.3 Land Preparation, Planting and Fertilizer Application

The land was slashed, sprayed with glyphosate and harrowed at Fumesua. At Ejura and Wenchi the land was ploughed and harrowed. Soil samples were taken for routine analysis at the Kwame Nkrumah University of Science and Technology, Department of Agroforestry, Kumasi. The soil nutrients levels at all the research location are shown in (Tables 1). NPK (15-15-15) 2 bags / acre two weeks after and top dress with sulphate of ammonia 1 bag/acre 4-6 weeks after planting.

2.4 Plot Size and Plant Population

Plot size was 1271.0 square meters at each location. Seeds were sown at three to four seeds per hill and seedlings were thinned at 14 days after sowing (DAS) to two plants per hill.

2.5 Weed Control

Weeds were controlled with manual hand – hoeing and a selective herbicide (Nico Plus - 200 ml, Atrazine-200 ml and 2,4-D Amine. (720 g/L) - 60 ml per 18 liters knapsack sprayer, application was done two weeks after planting). Plots were weeded as and when necessary.

Table 2A. List of genotypes/ varieties, environment used and its codes

Genotype/Variety	Code
Entry 5	G1
Entry 6	G2
Entry 70	G3
Okomasa	G4
Honampa	G5
Obatanpa	G6
Etubi	G7
Enibi	G8
Abeleehi	G9
Mamaba	G10
Abontem	G11
Dodzi	G12
Akposoe	G13
Dorke SR	G14
Aburohemaa	G15
Omankwa	G16
Tintim	G17

Table 2B. Environment/Locations and codes used for the GGE

Environment	Code
Fumesua	E1
Ejura	E2
Wenchi	E3

Table 3. Rainfall Figures from Ejura, Wenchi and Fumesua (2014-2016)

Location	Month	January	February	March	April	May	June	July	August	September	October	November	December
	2014	29.4	24.5	87.6	87.6	153.2	365.8	81	74.8	214.2	82.2	39.3	0
Ejura	2015	16.2	63	129.5	96.2	131.5	185.1	163.9	98.5	132.2	191.4	48.6	0
	2016	0	92.1	48.5	105.6	133.7	58.5	122	51.8	199.1	210.1	11.3	1
	2014	107	18.7	63.9	217.6	150.4	122.9	54.3	84.7	368.4	232.3	64.2	0
Wenchi	2015	0	59.9	63.5	85.5	148	79	112.1	49.7	109.1	101.4	44.6	0
	2016	0.8	26.2	143.1	116.7	215.2	189	85.6	47.3	211.2	171.6	7.1	18.4
	2014	65.8	22.7	65.4	129.3	161.5	257.1	54.2	77.5	117.6	153.1	108.6	0.3
Fumesua	2015	0	28.4	174.4	215.9	230.1	224.6	118.3	13.2	52.4	157.2	43.6	5.4
	2016	2.8	0	90.1	85.7	149.3	90.9	134.9	496.5	214.31	194	67.6	15.6

Table 4. Maximum and Minimum Temperature from Ejura, Wenchi and Fumesua (2014-2016)

Location		January		February		March		April		May		June		July		August		September		October		November		December	
	Year	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Ejura	2014	34.2	20.1	34.6	22.4	34.8	23.7	34.5	24.2	31.5	23.5	31.5	22.9	31.3	22.5	29.8	22.7	32.6	22.8	32.4	23.2	33.5	23.2	34.4	18.9
	2015	34.4	20.2	35.4	24.2	35.6	24.1	34.7	24.5	32.5	23.9	31.7	23.2	31.6	22.9	30.6	23.0	33.0	23.0	32.6	23.4	33.9	23.6	33.7	19.3
	2016	35.1	21.7	38.1	23.8	35.5	24.9	35.4	25.1	34.6	24.6	32.0	23.4	31.0	23.4	30.6	23.2	31.4	23.4	32.6	23.4	35.0	24.1	35.3	23.1
Wenchi	2014	33.6	21.4	35	22.5	34.6	22.9	33.2	22.7	31.7	22.8	30.7	22.2	29.2	21.7	28.5	21.5	28.8	21.5	30.9	21.9	31.6	22.4	32.8	21.4
	2015	33.6	19.8	34.3	22.6	35.4	22.6	34.3	22.4	32.8	22.1	30.6	21.9	31.6	22.8	28.9	22.5	30.1	22.4	31.1	22.2	32.3	22.3	33.2	20.2
	2016	34.2	20.5	36.8	22.0	35.0	22.1	33.7	22.4	32.4	21.8	30.2	21.3	29.1	22.0	29.0	21.9	29.4	22.0	30.8	21.9	33.2	22.9	33.1	22.1
Fumesua	2014	31.9	22.9	32.2	22.1	32.6	22.8	31.7	23.7	30.8	23.3	29.6	22.4	27.3	22.3	27.7	21.4	28.0	22.1	30.7	22.3	31.1	22.5	30.8	22.1
	2015	32.0	19.2	33.4	21.8	33.8	22.7	32.4	22.6	31.2	22.6	29.5	22.3	28.6	21.9	27.9	21.7	29.5	22.0	30.8	22.3	32.0	22.0	32.4	20.4
	2016	32.7	21.1	35.4	23.3	34.4	23.5	32.8	24.1	28.1	23.0	30.3	22.2	27.9	22.0	27.4	21.7	30.0	22.1	30.7	22.3	31.6	22.4	32.5	21.5

Table 5. Analysis of variance for Seeding emergence of maize varieties conducted Ghana at 3 locations in 2015 and 2016 (* p < 0.05; ** p < 0.01)

Source of variation	df	Mean Square
Environment (E)	2	877.3037**
Rep within Environment (R)	9	32.8075**
Year (Y)	1	8.9453
Season (S)	1	274.9650**
Genotype (G)	17	51.7546**
Year x Season	1	43.4145
Year x Genotype	16	10.6721
Season x Genotype	16	12.897
Envt x Year	2	58.6406**
Envt x Season	2	112.2046**
Envt x Genotype	33	19.9100*
Year x Season x Genotype	16	11.3244
Envt x Year x Season	2	30.4569
Envt x Year x Genotype	32	14.7313
Envt x Season x Genotype	32	13.1946
Envt x Year x Season x Genotype	32	13.3318
Pooled Error	601	12.0207
CV (%)	53.11	
Total	815	

2.6 Data Analysis

The grain yield data were subjected to combined analysis variance (ANOVA) to determine the effects of environment (E), genotype (G) and their interactions. The data were graphically analyzed for interpreting GE interaction using GGE biplot software [24]. GGE biplot methodology, which is composed of two concepts, the biplot concept [25] and GGE concept [7], was used to visually analyze the maize addition lines MET data. This methodology used a biplot to show the factors (G and GE) that are important in genotype evaluation and that are also sources of variation in GE interaction analysis of MET data [24].

2.7 Analysis of Variance

The combined ANOVA indicated a significant GE interaction. The mean squared associated with the interaction E × G ($p < 0.05$), E, R, S, G, E × Y and E × S ($p < 0.01$) was significant. The high magnitude of L (large variation) indicates that the Ghanaian region is highly variable from location to location (Table 5).

3. RESULTS

3.1 Best Variety and Mega-Environments Adapted

Utilizing diverse genotypes for various super conditions/ mega-environments in the best way to utilize the G x E cooperation and separating target situations into an important mega-environment [26]. Fig. 1.a shows a quadrilateral or trapezoidal view, indicated that the vertex variety in this study G11 (Abontem), G1 (Entry 5), G5 (Honampa) and G9 (Abeleehi). The vertex variety for every segment is the one that gave the most noteworthy grain yield for the situations that fall inside that division. Fig. 1.a, additionally distinguishes one mega environment in one part and one division comprise of two environments. The mega-environment included Ejura (E2), Wenchi (E3) and Fumesua (E1) where genotype G11 (Abontem) was the best performing a variety. The primary segment included Ejura (E1) where G11 (Abontem) was the performing best variety, and the second area/sector included Fumesua (E2) and Wenchi (E3), where G1 (Entry 5) was the genotype with the highest performance Although, the sectors (third and fourth) which did not fall within any environment, where G9 (Abeleehi) and G5 (Honampa) were the varieties with the most astounding execution/performance, they were not in the mega-environment (Fig. 1.0a).

It can be inferred that Abontem and Entry 5 genotype were generally adjusted crosswise over situations. G5 (Honampa) and G9 (Abeleehi) did not fall in any division of the environments used for the study (Table 3 and Table 4).

3.2 Mean Grain Yield and Yield Stability

The best genotype is characterized as the one that yields the most elevated yield with stable yields in all environment [15]. The best genotype is the genotype with high PC 1 scores and little PC 2 (absolute) scores, since G approaches 79.3%, one could reason that the PC 1 scores are emphatically connected with G. Accordingly PC 1 is controlled by G and PC oversaw by GE. In this examination, the G11 was nearest to the concentric focal point of the circles. Subsequently, the G11 genotype was the best of all genotypes, trailed by G14 and G1 (Fig. 1.b).

These genotypes have been distinguished as the best half and halves with high seed yield and high return strength. Normal grain yield and yield dependability were utilized to distinguish the best genotypes by various analysts in different products/crop, for instance, grain [27], corn [13] [28] and rice [16] and demonstrated that they are exceptionally viable under the most favorable conditions/best genotypes (Table 3 and Table 4).

3.3 Correlation between Environment

The vector portrayal of the GGE biplot demonstrates the common connections between environmental conditions. The point/angle between the natural/environmental vectors shows the relationship coefficient between them [7]. Fig. 1.c is the vector perspective of the GGE biplot, where the conditions are a biplot that was initially associated by lines.

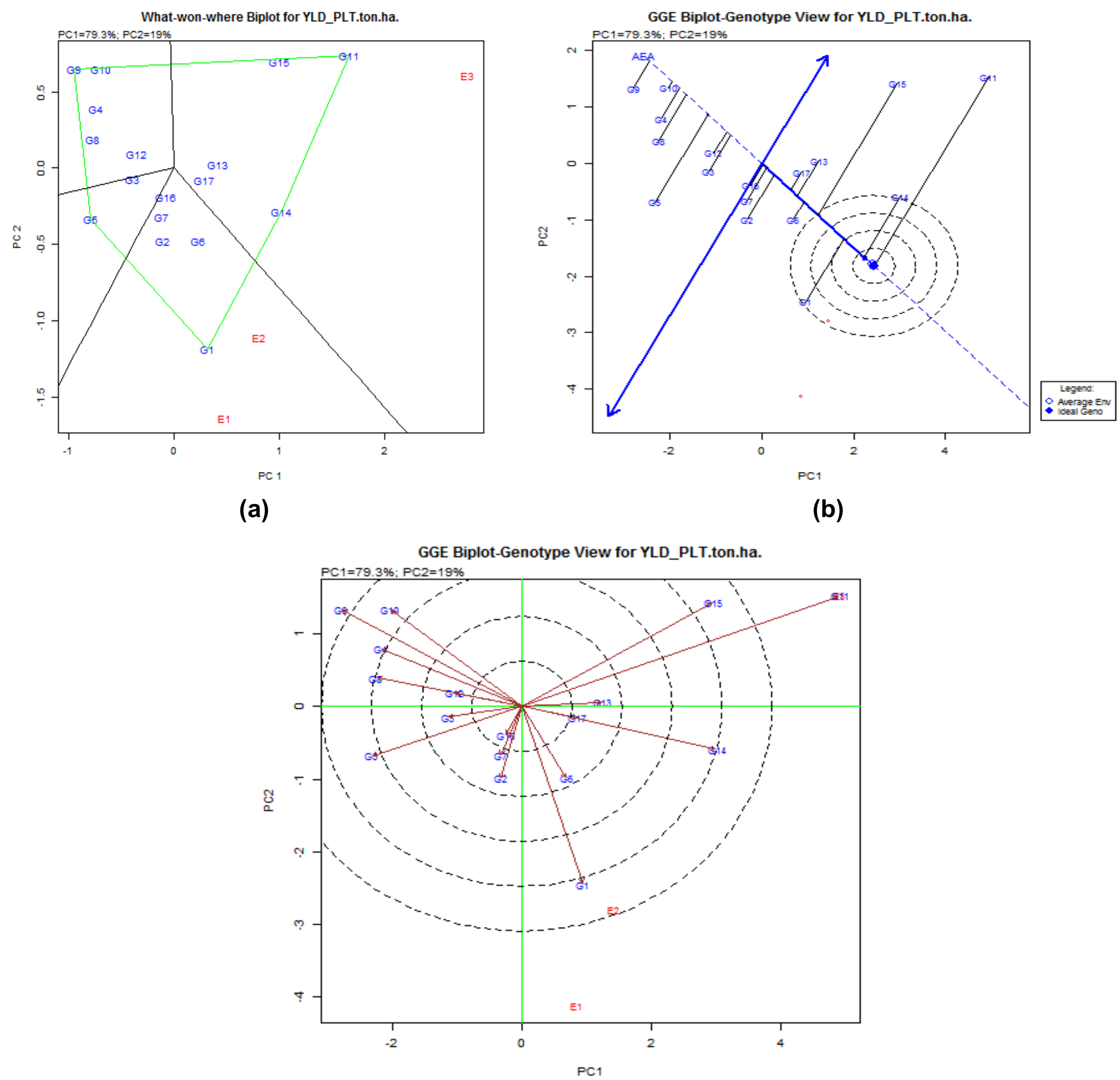

Fig. 1. GGE biplot in view of the yield information from 17 maize genotypes at three areas over a time of 2 years, (a) distinguishing proof of super conditions/ mega-environments, (b) best crossovers for normal grain yield and stability of yield and (c) gathering amongst situations and unmistakable limit and representativeness of environments /conditions

The cosine of the edge between the ecological/environmental vectors speaks to very nearly zero connections between G15 (Aburohemaa), G13 (Akposoe), G17 (Tintim) and G6 (Obatanpa) and in addition between G1 (Entry 5) and G11 (Abontem). At the point when the edge between situations is under 90 degrees, the connection coefficient between them is sure [8]. Consequently, it is normal that most situations are decidedly corresponded, aside from G15 (Aburohemaa) and G1 (Entry 5), G6 (Obatanpa), G14 (Dorke SR) (Fig. 1. c) (Table 3 and Table 4).

3.4 Discriminating Ability and Representativeness of Environment

Fig. 1.c additionally demonstrates the segregating limit and representativeness of the test situations/environments. A proper environment/situation is one that is the most segregating among genotypes and is illustrative of every single other condition/environment [15]. In this way, G13 (Akposoe) is the most illustrative (with a short projection on the axis of the coordinates of the average tester (ATC), and G14 (Dorke SR) and G11 (Abontem) were extremely segregating (huge projection on the ATC x-axis) which recognizes them as the proper situations/environments for the differential execution of genotypes (Table 3 and Table 4).

4. DISCUSSION

Multi-environment testing (MET) is being performed to assess breeding/rearing material overall utilizing different plant reproducing programs/ plant breeding programs [7]. In MET, an extensive number of genotypes are by and large tried at various areas and in various years [17]. The advancement of genotypes that are reasonable for an extensive variety of conditions is a vital objective or raisers in most yield change programs/crop improvement programs. A genotype is considered to have a superior or better dependability of seed yield when it has a high normal grain yield, however a low level of variance in seed yield in various conditions [29]. Cultivars with a high seed yield and solidness/stability of the grain yield are distinguished by expanding sets of various genotypes in various conditions [30].

The GGE biplot additionally considers the GE and G association in the appraisal of genotypes [8]. Likewise, GGE biplot is utilized to distinguish the correct cultivars and exceptionally gainful, and the correct test conditions. The best cultivars would have an extensive score/main (PC1, high grain yield) and low essential/primary score (PC2, high soundness/ stability) [24]. Cultivars must be surveyed in the MET utilizing distinctive properties to guarantee that the best chose cultivars have satisfactory execution in factor situations in the objective territory [31]. A genotype biplot x quality/trait (GT) permits perception of genotypic connection amongst properties and understanding into the relationship that encourage the distinguishing proof of the attributes that can be utilized for aberrant determination on a coveted characteristic [26] and [32]. A GT biplot is generally performed by plotting PC1 scores against PC2. The biplot GGE strategy was utilized to assess the test situations for soybeans [8], wheat [7], [33], rice [16], grain [26] and [27], lentils [34], corn [13] [28] and typical beans [35].

5. CONCLUSION

Maize is widely grown in a wide range of diverse agro-ecologies in Ghana. It accounts significantly for food security, income generation and rural livelihood of the majority of poor smallholder farmers. However, the productivity of maize is significantly affected by GXE interaction. GXE interaction is the most important factor that causes substantial yield variations under the smallholder farming systems and among maize growing agro-ecological zones in the country. G x E is also accelerated by the outbreaks of biotic stresses and occurrence of random stresses and variability in soil fertility. Yield performance of genotypes is often confounded by GXE interaction and therefore reduces selection efficiency and response. Therefore, environments could be the primary source of GXE interaction for grain yield observed among the test genotypes evaluated in this study although it was less important in the variations of mean yield and yield stability. The present study identified genotypes such as G11 (Abontem), G14 (Dorke SR) and G1 (Entry 5) sowing respectively high mean grain yields of 6.69, 7.17 and 5.33 t/ha across environments showing minimal GXE interaction. These genotypes could be recommended for direct large-scale production in Ghana or similar environments. However, some of these hybrids were highly distinct, uniform and stable. For example, Abontem performed better across environment used in the experiment. In general, genotype by environment interaction is a big challenge for plant breeders. In this study, GGE biplot was particularly useful that revealed the magnitude of GXE interaction present in the study materials.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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