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Genotype by environment interaction and yield stability of early maturing maize single cross hybrids at three locations in Southern Ghana

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A grain yield trial was conducted in three locations in Southern Ghana. The objective of the trial was to determine the effects of genotype by environment interaction on 90 early maturing hybrid maize. The trial was conducted in Fumesua, Ejura and Kpeve; representing the forest, forest-Savanna transition and coastal-Savanna transition zones respectively. The analysis of variance for grain yield demonstrated that genotypic and environmental effects were highly significant (P<0.001) while their interaction was significant (P<0.005). The genotypes contributed 34.4% of total sum of square percentage while environment contributed 31.1% of the total sum of square of the variance. The genotype main effect plus genotype × environment interaction biplot explained 85.2% of total variation of the sum of squares for grain yield. P40, P16, P78, P53, P41 P9 and P3 were identified by GGE biplot analysis as high yielding and stable genotypes while P20, P80, P22, and P15 were low yielding but very stable genotypes. On the other hand, P59, P41, P16, P26 and P50 were high yielding but not stable and was recommended that genotypes with broad range adaptability can be tested on farmers field for possible release.

Key words: Tropical maize early maturing (TZEI), Genotype × environmental interaction (GGE) biplot, hybrid, Fumesua, Ejura, Kpeve trial, environment, treatment.

INTRODUCTION

Maize (*Zea mays* L.) is the dominant staple crop grown by a vast majority of rural households in most parts of Africa, covering a total of nearly 35 million hectare that account for 20% of the total global maize area

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(FAOSTAT, 2013). It ranged as the third most important and highest industrial valued cereal in the world next to wheat and rice and is an important staple crop in most under privileged countries (Badu-Apraku et al*.,* 2010; Malik et al*.,* 2005; Khalil et al*.,* 2011). Maize can be grown over a range of agro climatic zones and its fitness to varied environments is higher than any other crop (Golam et al., 2011). The crop can be grown from latitude 58°N to 40°S, from below sea level to altitude higher than 3000 m and in areas with rainfall of about 250 to 5000 mm per annum and with growing season ranging from 3 months to about 5 months (Dowswell et al*.,* 1996, Golam et al*.,* 2011).

Its high yield potential, wide adaptability, relative ease of cultivation, processing, storage and transportation of maize has increased its potentials for combating food security challenges posed by population increase in West and Central Africa (WCA) (Badu-Apraku et al*.,* 2010). Hybrid maize varieties have caused a significant impact on crop yields for farmers on every continent since the 1930s (Bello et al., 2012). In most developing countries, maize farmers often prefer early maturing hybrid varieties because they perform better across different environments than their parents.

Multi-environment yield trial is essential in estimating genotype by environment interaction and identification of superior genotypes. Genotype by environment interaction effect on maize grain yield is usually significant due to large variation in soil and weather conditions at growing sites.

The relative performance of genotype(s) across environments has raised important and challenging issues among plant breeders, geneticists and agronomists (Babic et al*.,* 2008). The presence of genotype by environment interaction should be of great concern to maize breeders as large interaction could reduce yield and even make the selection of superior cultivars difficult (Rasul et al*.,* 2005). Kang et al. (1991) point out that selection based on yield only may not always be adequate when genotype x environment interaction is significant. He additionally proposed the use of a rank-sum method as an alternative when testing is done in diverse environments.

Importance of early maturing maize

Availability of early maturing maize will significantly contribute to rapid increase and spread of maize in WCA, especially where the short duration of rainfall had long caused stress to maize production (Boakyewaa, 2012). Chavez et al*.* (2005) worked on single cross hybrids and reported that single cross hybrids are more productive than double crosses and open pollinated varieties (OPVs). According to Badu-Apraku et al*.* (1995), annual maize yield loss from drought stress in developing countries is estimated at 15% of total production.

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

MATERIALS AND METHODS

Ninety early maturing maize single cross hybrids derived from crosses between 41 inbred lines were obtained from International Institute of Tropical Agriculture (IITA) (Table 1). The hybrids were evaluated at three locations in southern Ghana Fumesua, Ejura and Kpeve. Each of the locations experiences a bimodal rainfall pattern. Fumesua lies within the forest ecology while Ejura is a Forest-Savanna transition zone and lies between the semi-deciduous Forest and Guinea Savanna zones. The location experiences both forest and savanna climatic conditions. Kpeve is a Coastal-Savanna transition zone and is influenced by the south-west monsoons from the South Atlantic Ocean and dry harmattan winds from the Sahara Desert (Table 2).

The major season stretches from April through July and the minor season from August to November (Table 2). The experiment was planted in a randomized complete block design (RCBD) with two replications at each location. Each hybrid was planted in a single row plot measuring 5 m in length with an inter-row spacing of 0.75 m and within row spacing of 0.45 m. Three seeds were planted per hill and thinned to two seedlings to obtain a target plant population density of approximately 60,000 plants ha^{-1}. The experiment was protected by two-guard rows of Dorke SR, to control border effect. Pre-emergence and post emergence chemical weed control was done with an application of Gramoxone and Atrazine respectively. Hand weeding was also done when necessary to control weeds during the growing period. NPK 15-15-15 fertilizer was applied at the rate of 30 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} as basal fertilizer at two weeks after planting and top-dressed with additional N at 60 kg N ha^{-1} at four weeks after planting.

Data collection and analysis

Data were collected on other agronomic parameters but only data from grain yield were used in data analysis. Grain yield (kg ha^{-1}) was calculated using the following formula:

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

The analysis of variance (Steel and Torrie, 1980) for grain yield for each location and across locations was conducted using Statistical Analysis System version 9.2 (SAS, 2003). Least significance

Table 1. Ninety maize single cross hybrids evaluated for grain yield at three locations in Southern Ghana during the 2012 growing season.

Entry No.	Code	Entry Name	Entry No.	Code	Entry Name
1	P1	TZEI-9 X TZEI-12	46	P46	TZEI-19 X TZEI-46
2	P2	TZEI-24 X TZEI-23	47	P47	TZEI-36 X TZEI-20
3	P3	TZEI-48 X TZEI-20	48	P48	TZEI-14 X TZEI-15
4	P4	TZEI-4 X TZEI-2	49	P49	TZEI-12 X TZEI-9
5	P5	TZEI-3 X TZEI-1	50	P50	TZEI-34 X TZEI-46
6	P6	TZEI-2 X TZEI-19	51	P51	TZEI-1 X TZEI-19
7	P7	TZEI-9 X TZEI-11	52	P52	TZEI-22 X TZEI-48
8	P8	TZEI-41 X TZEI-47	53	P53	TZEI-33 X TZEI-19
9	P9	TZEI-41 X TZEI-30	54	P54	TZEI-39 X TZEI-22
10	P10	TZEI-11 X TZEI-15	55	P55	TZEI- 9 X TZEI-10
11	P11	TZEI-46 X TZEI-34	56	P56	TZEI-25 X TZEI-27
12	P12	TZEI-10 X TZEI-11	57	P57	TZEI-22 X TZEI-20
13	P13	TZEI-32 X TZEI-5	58	P58	TZEI-14 X TZEI-16
14	P14	TZEI-38 X TZEI-35	59	P59	TZEI-22 X TZEI-45
15	P15	TZEI-12 X TZEI-13	60	P60	TZEI-19 X TZEI-48
16	P16	TZEI-35 X TZEI-19	61	P61	TZEI-33 X TZEI-2
17	P17	TZEI-39 X TZEI-34	62	P62	TZEI-12 X TZEI-20
18	P18	TZEI-22 X TZEI-20	63	P63	TZEI-22 X TZEI-18
19	P19	TZEI-39 X TZEI-36	64	P64	TZEI-28 X TZEI-14
20	P20	TZEI-45 X TZEI-47	65	P65	TZEI-2 X TZEI-34
21	P21	TZEI-36 X TZEI-34	66	P66	TZEI-34 X TZEI-22
22	P22	TZEI-17 X TZEI-16	67	P67	TZEI-36 X TZEI-38
23	P23	TZEI-11 X TZEI-12	68	P68	TZEI-2 X TZEI-22
24	P24	TZEI-13 X TZEI-17	69	P69	TZEI-27 X TZEI-19
25	P25	TZEI-35 X TZEI-16	70	P70	TZEI-18 X TZEI-46
26	P26	TZEI-25 X TZEI-23	71	P71	TZEI-36 X TZEI-35
27	P27	TZEI-48 X TZEI-45	72	P72	TZEI-14 X TZEI-17
28	P28	TZEI-42 X TZEI-47	73	P73	TZEI-27 X TZEI-14
29	P29	TZEI-31 X TZEI-18	74	P74	TZEI-36 X TZEI-33
30	P30	TZEI-9 X TZEI-15	75	P75	TZEI-31 X TZEI-7
31	P31	TZEI-47 X TZEI-34	76	P76	TZEI-22 X TZEI-46
32	P32	TZEI-17 X TZEI-15	77	P77	TZEI-42 X TZEI-30
33	P33	TZEI-39 X TZEI-30	78	P78	TZEI-34 X TZEI-7
34	P34	TZEI-41 X TZEI-46	79	P79	TZEI-33 X TZEI-3
35	P35	TZEI-30 X TZEI-47	80	P80	TZEI-46 X TZEI-47
36	P36	TZEI-11 X TZEI-9	81	P81	TZEI-41 X TZEI-22
37	P37	TZEI-27 X TZEI-9	82	P82	TZEI-33 X TZEI-46
38	P38	TZEI-36 X TZEI-22	83	P83	TZEI-25 X TZEI-14
39	P39	TZEI-13 X TZEI-10	84	P84	TZEI-34 X TZEI-3
40	P40	TZEI-36 X TZEI-39	85	P85	TZEI-19 X TZEI-18
41	P41	TZEI-45 X TZEI-34	86	P86	TZEI-48 X TZEI-16
42	P42	TZEI-12 X TZEI-15	87	P87	TZEI-10 X TZEI-12
43	P43	TZEI-30 X TZEI-31	88	P88	TZEI-18 X TZEI-26
44	P44	TZEI-4 X TZEI-3	89	P89	TZEI- 24 X TZEI-12
45	P45	TZEI-23 X TZEI-15	90	P90	TZEI-38 X TZEI-36

difference test ($P \leq 0.05$) was used to determine the level of significance among the treatment means and environments.

Table 2. Test environments used in the yield trial of ninety maize single cross hybrids.

Location	Latitude	Longitude	Altitude	Rainfall (mm)	Ecology
Fumesua	6° 43'N	1° 36W	228	142.4	Forest
Ejura	7° 24'N	1° 21E	229	117.4	Forest savanna transition
Kpeve	3° 20'N	0° 17E	69	121.5	Coastal transition

Rainfall data from April to August 2012.

GGE biplot analysis

The GGE biplot software (Yan, 2001) is a polygon that is used to enable visualization of three important aspects: (i) the genotype x environment relations as represented by the which-won-where pattern; (ii) the interrelationships among test environments, which enabled the identification of better environments for evaluation of maize and of least performing environments that can be dismissed and (iii) the interrelationships among genotypes, which facilitated comparison among genotypes and genotype ranking on both mean yield and stability (Yan and Hunt, 2001) and is recovered through this formula

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

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 PC I and PC2, respectively, ε_{ij} is the residual associated with genotype *i* in environment (Yan, 2002).

RESULTS AND DISCUSSION

Result from the evaluation conducted for individual location showed that there were significant differences among genotypes for grain yield (Table 3) and between locations (Table 4). At Fumesua, grain yield was generally moderate for all entries and ranged from 1366 to 6278 kg ha^{-1}. Low grain yields were observed at Ejura with yields ranging from 579 to 5269 kg ha^{-1}. There was an invasion of spittle bugs in Ejura which seriously affected yields. Moreover, there was cessation of rainfall at flowering which resulted in less soil moisture during grain filling period. This resulted in poor synchronization, subsequently affecting seed set. A similar observation was made by Denmead and Shaw (1960). They further mentioned that drought stress reduces yields by 21% when it occurs during grain filling and by 50% flowering. The result indicates that the order of response of genotypes at the three locations varied (Table 5).

In their work, Dehghani et al. (2006) reported that cropping season, rainfall and temperature had significant effects on the yield of barley and also contributed to large interactions.

GGE biplot analysis of grain yield and stability

The biplot analysis was based on environment-focused singular value partitioning (SVP = 2) and genotype-focused singular value partitioning (SVP = 1). This allowed visualization of the relationships among genotypes and among environments. The principal component axis (PCA1) explained 69.1% of total variation; while PCA2 explained 16.1%.

The "which-won-where" patterns

From the polygon view of the GGE biplot (Figure 1), the vertex genotype can be seen as the one that give the highest yield for each of the environment in which they lie. P40 was the highest yielding hybrid at Fumesua (best hybrid across environments) followed by P78 (7th best hybrid). Meanwhile, P15, P20, P85, and P80 performed very poorly at Fumesua. P26 (14^{th} best hybrid) was the highest yielding hybrid at Ejura followed by P53 (2^{nd} best hybrid across environments) and P64, P20, P15, P80 and P14 were the poorest performing hybrid at Ejura. Meanwhile, P59 was the winning hybrid at Kpeve (5^{th} best across environment) followed by P41, P16 and P68. No environment fell into the sector where P20, P15, P80, P64, And P23 were the vertex hybrid.

From the view of the biplot (Which-Won-Where), P40 was the winning hybrid at Fumesua; P26 was the winning hybrid at Ejura, while P59 won at Kpeve because they were all close to the vertices. However, from the SAS analysis, it was observed that P41 obtained the highest yield at Kpeve. Similar observation by Yan (2002) reported that the pattern displayed by the biplot may be more vigorous than the individual data points for genotypes, because it places more weight on stability rather than rank. Furthermore, Yan and Tinker (2006) reported that the best way to determine the best genotype in a test environment is to do scaling with environment standard deviation such that all environments are given the same weight. Based on the genotype-focused scaling (Figure 1), P59 was the most

Table 3. Mean squares and percentage sum of square for grain yield (kg ha^{-1}) of 90 early maturing maize hybrids evaluated across three locations in Ghana in the 2012 growing season.

Source of variation	Degrees of freedom	Location					
		Ejura		Fumesua		Kpeve	
		Mean square	% Sum of squares	Mean squares	% Sum of squares	Mean squares	% Sum of squares
Replication	1	267158	0.1	1912966	0.7	2465962	0.5
Genotype	89	168726.5*	65.4	2026959**	71.6	3960373**	78.9
Residual	89	891492.6	34.5	783008	27.7	1034466	20.6
Total	179		100		100		100
CV (%)		26.8		19.3		17.9	
LSD		1876		1758		2020	

**P<0.001 highly significant; *P<0.05 significant.

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

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance	p>F	% Sum of squares
Replication	1	1978949	1978949	2.18	0.1406	0.5
Location	2	419665423	209832711	231.5	<0.001**	31.1
Genotype	89	464334452	5217241	5.76	<0.001**	34.4
Genotype x Environment	178	218704950	1228680	1.36	0.0121*	16
Error	269	243765185	906190			18
Total	539	1348448958				100
CV (%)		20.7				
LSD		1082				

**P<0.001 highly significant; *P<0.05 significant.

desirable genotype followed by P41 even though P41 had the highest mean yield.

Discriminative ability and representativeness of the environments

An ideal environment should both be highly differentiating of the genotypes and representative of the target environment (Tonk et al., 2011; Dehghani et al., 2006).

According to Tonk et al. (2011), the ideal environment represented by the small circle with an arrow pointing to it (Figure 2) is the most discriminating of genotypes and representative of the other test environments. The lines connecting the biplot origin with the markers for the environments are called environment vectors (Brar et al., 2010). Based on the cosine of angles of environment vectors, the three locations for grain yield were grouped into three. The presence of wide obtuse angles among the locations indicates strong cross-over genotype by environment interactions (Yan and Tinker, 2006).

Table 5. Grain yield (kg ha^{-1}) and relative ranking of early maturing maize hybrids evaluated at three locations in the forest, forest transition and coastal transition zones of Ghana in 2012.

Code	Kpeve	Rank	Ejura	Rank	Fumesua	Rank	Across	Rank
P1	5686	54	4356	15	4051	65	4698	51
P2	4874	70	3196	62	3965	67	4012	76
P3	6287	29	4247	20	5522	16	5352	15
P4	6025	24	3490	44	3267	83	4261	67
P5	6333	28	4061	26	5404	22	5266	17
P6	5520	59	4018	28	4814	41	4784	46
P7	5444	60	3913	32	4317	57	4558	57
P8	6450	24	3179	65	6072	7	5234	18
P9	6017	35	4086	24	6115	5	5406	13
P10	6992	14	4075	25	5242	27	5436	12
P11	5792	45	4653	9	4307	58	4917	36
P12	5722	50	4969	3	6159	3	5617	8
P13	4144	81	1933	85	2873	85	2983	85
P14	3848	83	1890	86	4050	66	3263	83
P15	1172	89	1044	88	1366	90	1194	89
P16	7777	4	3998	30	5774	10	5850	3
P17	5624	56	3290	56	3332	81	4082	72
P18	4863	71	3584	42	4644	47	4364	63
P19	4619	72	4570	11	5555	14	4915	37
P20	934	90	597	89	1645	89	1058	90
P21	5711	51	3905	33	5016	35	4877	39
P22	3769	84	2329	83	2862	86	2987	84
P23	2677	87	2487	82	3379	80	2847	86
P24	5788	46	3731	39	5441	20	4987	30
P25	6844	18	3415	48	4587	50	4949	32
P26	5393	61	5269	1	5478	18	5380	14
P27	7483	8	3540	43	5519	17	5514	9
P28	5852	43	3022	71	4572	51	4482	62
P29	5654	55	3423	47	4487	54	4521	58
P30	5864	42	3402	50	4763	43	4676	52
P31	5024	68	3892	34	4083	63	4333	64
P32	5145	67	4305	18	5536	15	4995	29
P33	4485	74	3886	35	3478	79	3950	77
P34	4986	69	3094	68	5847	9	4642	54
P35	6185	30	3254	59	6118	4	5185	21
P36	4602	73	4630	10	5281	26	4838	41
P37	5173	66	2828	78	3755	74	3919	79
P38	5190	65	2993	74	4741	44	4308	65
P39	6869	16	4686	8	3819	71	5125	24
P40	7661	6	4949	4	6278	1	6296	1
P41	8508	1	3681	41	5324	24	5838	4
P42	6544	21	4345	17	4952	37	5280	16
P43	4341	78	3049	70	4844	40	4078	74
P44	5573	58	4768	5	4064	64	4802	44
P45	4357	77	3193	63	4143	62	3898	80
P46	6982	15	2930	75	4204	60	4705	50
P47	4065	82	2994	73	3327	82	3462	82
P48	6524	23	3078	69	5061	32	4888	38

Table 5. Contd.

P49	**5920**	**38**	**3367**	**54**	**5178**	**29**	**4821**	**42**
P50	7551	7	3377	52	5432	21	5453	11
P51	7294	10	2700	79	5070	31	5022	27
P52	6838	19	3447	46	6082	6	5456	10
P53	7710	5	5150	2	5339	23	6066	2
P54	4469	75	3190	64	4660	46	4106	71
P55	4264	79	4216	22	5016	34	4499	61
P56	5844	44	2928	76	5448	19	4740	49
P57	3715	85	4349	16	4420	55	4161	70
P58	5742	48	2617	81	3884	69	4081	73
P59	8126	3	3203	60	6024	8	5784	5
P60	5919	39	4049	27	4810	42	4926	35
P61	5875	41	2236	84	4412	56	4174	69
P62	6056	33	3175	66	5590	13	4940	34
P63	7018	13	3391	51	3927	68	4779	47
P64	3496	86	579	90	2985	84	2354	87
P65	5692	53	3698	40	4636	48	4675	53
P66	5249	64	3280	57	4155	61	4228	68
P67	5710	52	4166	23	4525	52	4800	45
P68	8295	2	4275	19	4740	45	5770	6
P69	7021	12	3457	45	4951	38	5143	23
P70	4417	56	3197	61	3520	77	3712	81
P71	7224	11	4512	12	3830	70	5189	20
P72	6070	32	3753	28	5128	30	4984	31
P73	6810	20	2866	77	4621	49	4766	48
P74	6009	36	4017	29	4488	53	4838	40
P75	6397	26	4410	14	4855	39	5221	19
P76	7420	9	3788	36	3815	72	5008	28
P77	6354	27	3414	49	5770	11	5179	22
P78	6864	17	3993	31	6189	2	5682	7
P79	5737	49	4240	21	3783	73	4587	56
P80	1547	88	1163	87	2742	87	1817	88
P81	5332	62	3262	58	3516	78	4037	75
P82	6445	25	3756	37	3692	76	4631	55
P83	5611	57	4708	6	5026	33	5115	25
P84	5745	47	3376	53	3733	75	4285	66
P85	5888	40	3159	67	2723	88	3923	78
P86	6172	31	3349	55	5308	25	4943	33
P87	5921	37	2644	80	4963	36	4509	59
P88	5331	63	3000	72	5183	28	4505	60
P89	4172	80	4696	7	5592	12	4820	43
P90	6532	22	4453	13	4242	59	5076	26
GM	5680		3520		4594		4598	
CV (%)	18		27		19		21	
LSD	2021		1876		1758		1082	

The distance between two environments measures their dissimilarity in discriminating the genotypes. Thus, the three locations fell into three apparent groups, Fumesua, Ejura and Kpeve. The concentric circles on the biplot help to visualize the length of the environment vectors, which is proportional to the standard deviation within the

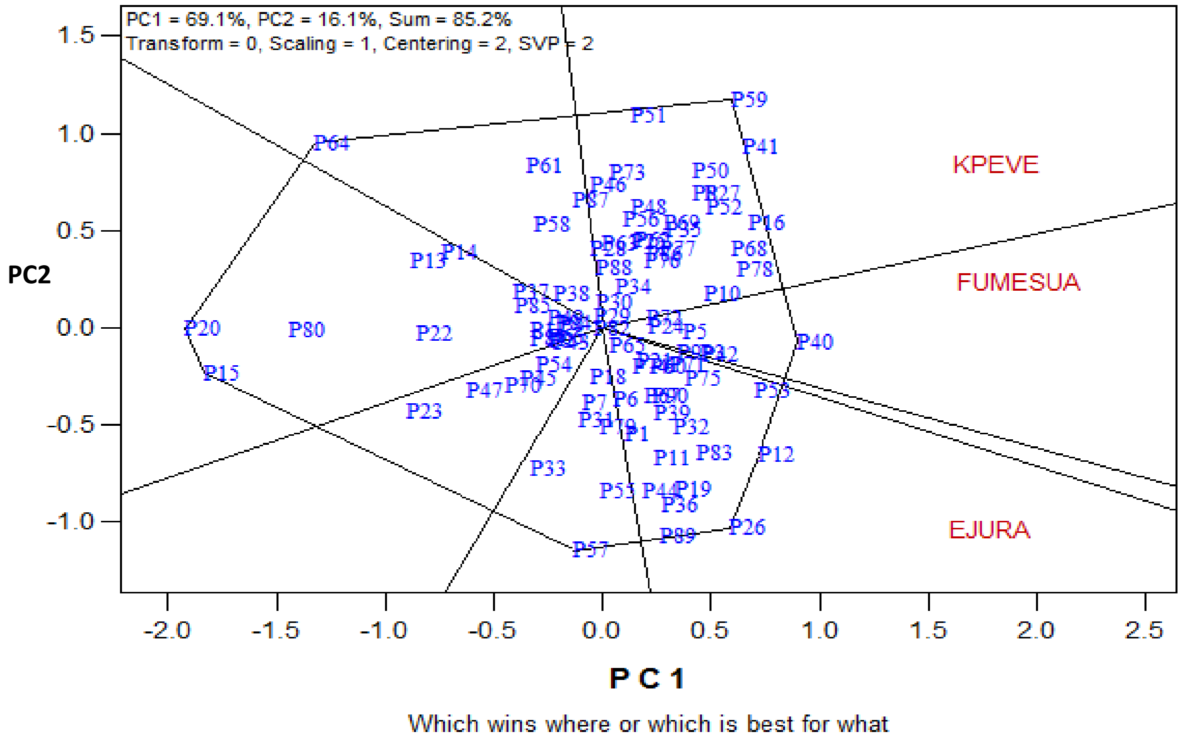

Figure 1. Which wins where or which is best for what based on a genotype by environment yield data of 90 early maturing maize hybrids evaluated in three environments in Ghana during the 2012 growing season.

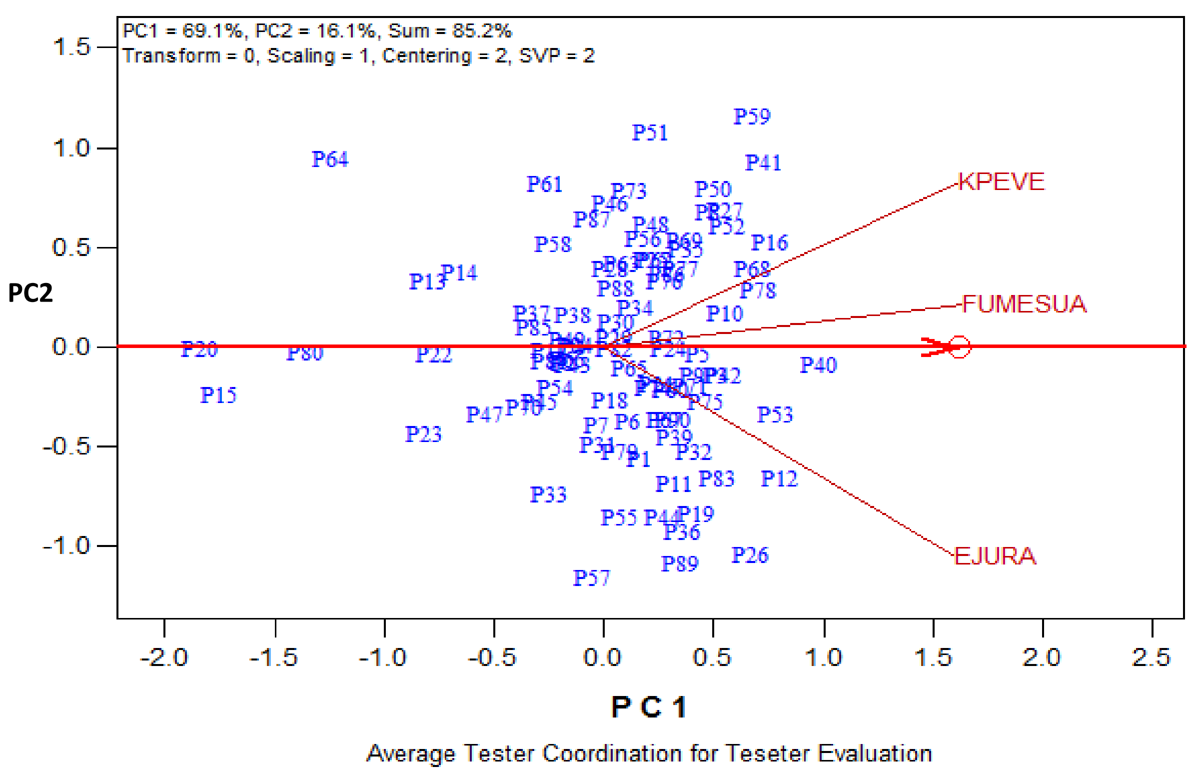

Figure 2. Discriminative ability and representativeness of test environment.

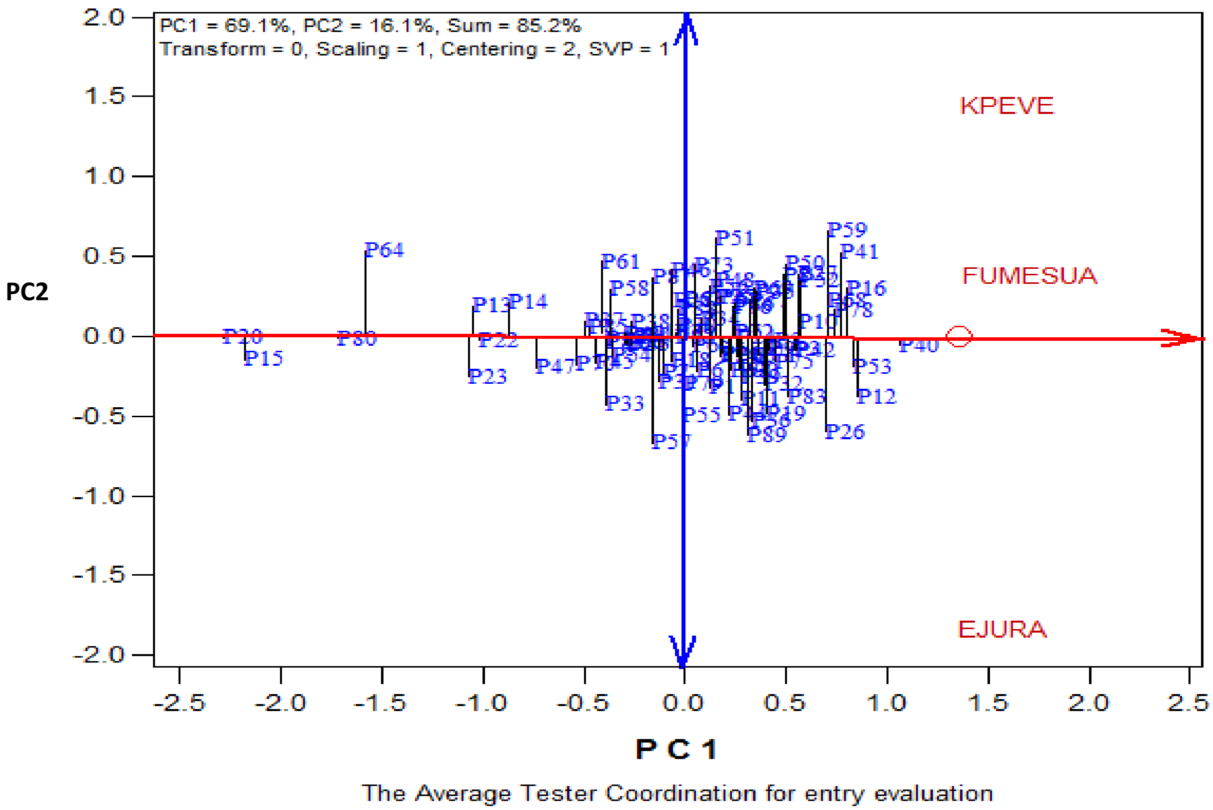

Figure 3. GGE-biplot view based on the mean performance and stability of 90 early maturing hybrids across three locations during 2012 cropping season.

respective environments and its discriminating ability of the environments (Kroonenberg, 1995). A test environment with a smaller cosine of angle with Average Environment Coordinate (AEC) was more representative than other test environments.

Hybrid performance and stability across environment

GGE biplot was used to analyze the mean performance and stability of genotypes for grain yield because of the significant interaction for grain yield alone. The performances of the hybrids and stability are observed by an average environment coordination method (Yan, 2002). This is further demonstrated by means of average PC1 and PC2 scores for all environments, and is indicated by a small circle. A line is then drawn to pass through this average environment and the biplot origin. This line is known as the average environment axis and serves as the abscissa of the average environment coordination. The biplot displayed the pattern of variability of genotypes, environment and their interactions and stability. P40, P10, P 42, P12, and P53 had high potential yield respectively and were near to ideal genotypes (Figure 3). Therefore, these were considered as stable and high yielding genotypes. On the other hand, P59, P41, P16, P26, P68, P52 and P50 were high yielding but not stable. This condition poses a serious challenge to plant breeders because the highest yielding genotype may not be preferred by farmers due to its instability across range of environments. According to Tonk et al. (2011), an ideal genotype grown in test environments should possess high mean performance and stability. Such an ideal genotype having high yield with less interaction and the greatest vector length from origin of biplot to the genotype pointers can be recommended for release. P40, P78 P12 P35 are specifically adapted to Fumesua; P26, P53, P12 and P40 are adapted to Ejura; while P41, P68, P59, P16 and P53 are specifically adapted to Kpeve.

Conclusion

From the study conducted, G × E was found to be highly significant (P<0.001) for both genotypes and environment, and significant (P<0.05) for their interaction. The combined analysis of variance revealed that genotypes contributed

34.4% of the total percentage sum of square variation in grain yield while environment contributed 31.1% of the variation. The highly significant effects revealed that environmental conditions had major effects in selecting hybrids for high grain yield and wide adaptation. From the results, 20 hybrids were identified to be high yielding. Therefore, the high yielding and stable hybrids can be tested on farm and the best could be released to farmers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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