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Additive Main Effect and Multiplicative Interaction Stability Analysis of Grain Yield Performance in Cowpea Genotypes across Locations

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Abstract

Crops are largely influenced by climatic conditions during the growing season and therefore, minor deviation from optimal conditions can seriously threaten yield. In view of this, knowledge on the effect of environmental factors on crop growth and development could reduce the possibilities of significant yield loss. There have been statistical methods which have been developed in respect to characterizing crops but the additive main effect and multiplicative interaction (AMMI) method integrates analysis of variance and principal components analysis into a unified approach. AMMI has been used in the analysis of G × E interaction with greater precision in many crops. The objective of this study was to assess the extent of genotype x environment interaction and to select the stable cowpea genotypes in Ghanaian environments over seasons using AMMI model. Eight genotypes of cowpea released by Crops Research Institute of Ghana over two decades were selected for evaluation in two locations and two seasons using RCBD with 3 replications in forest and transitional zones of Ghana. When the mean yields of various genotypes were subjected to the AMMI model, the results showed that, a highly significant ($P < 0.001$) genotype by location and by year interaction effects for cowpea grain yield was recorded with 63.1% of the total variation attributable to environmental effects. The AMMI Bi-plot of PC1 and GGE Bi-plot gave 80.8% and 89.3% respectively. Genotype Asontem (G3) had the highest yield and was adapted to all the environments and seasons. Genotypes Asetenapa

(G1) and Soronko (G6) were however not stable with consistently low yield across all the environments. It is recommended that farmers in Forest and transitional zones of Ghana should cultivate the highly stable cowpea genotypes in order to get stable yields across environments due to climatic change.

Keywords

Stability, Genotype, Interaction, Yield, Environment

1. Introduction

Cowpea (*Vigna unguiculata* (L.) Walp) is the most important food legume in Ghana and can be grown in all agro ecological zones of Ghana since it is indigenous to Africa. The yield potential of the various varieties released in Ghana ranges from 1.5 t/ha to 2.0 t/ha with varying dates of maturity ranging from 60 - 80 days [1]. Cowpea seeds and leaves (dry weight basis) contain more than 25% of protein, minerals and vitamins in daily human diets and are equally important as nutritious fodder for livestock [2].

Due to its moderate cultivation requirements and high protein content, the crop's production in West and Central Africa in the last decades has averaged 2.6 million tons on 7.8 million hectares. This accounts for 69% of the world's production [3] while an estimated 4.5 million metric tons of cowpea is produced worldwide on 12 to 14 million hectares of land [4] [5]. According to Langyintuo *et al.* [6], world dried cowpea production as at 2010 was estimated to be 5.5 million metric tons, with Africa accounting for 94% of the production.

The cowpea grain yield and the haulm are valuable dietary proteins for most African population and their livestock [7]. According to Ravelombola *et al.* [8], cowpea grain is highly nutritious and contains about 15.06% - 38.5% protein, but it differs among cowpea varieties. In West Africa, cowpea is regarded as a major source of food for both rural and urban dwellers. The fodder is used to feed animals but fresh leaves are also used as food in most Ghanaian communities particularly the northern part of the country. Both fresh and dry seeds are used as food. Whilst the fresh pods and seeds are used as vegetables, the dry seeds are used in combination with other things for various dishes. Cowpea utilization is important in most parts of West and Central Africa since it provides a cheaper alternative to meat and serves as a "food security crop" [9] for populations that consume cowpea as traditional staple food [6]. In Ghana, the dry grains are processed into flour and dough which are used as food.

Cowpea plant is able to fix atmospheric nitrogen which helps to maintain soil fertility. It is tolerance to drought and extends its adaptation to drier areas considered marginal for most other crops [4] and due to the association with soil bacteria *rhizobia*, it serves N source to a succeeding crop [10]. The morphology of cowpea plant is such that it is able to maintain high leaf water potential or high leaf relative water content during water stress [11] which of course helps it to avoid tissue dehydration. Cowpea is considered to be a warm-season crop well adapted to many areas of the humid conditions. According to Daimon and Yashioka [12], cowpea is grown primarily under humid conditions and is regarded as a short-day warm weather crop and also adapted to high temperatures of about 20˚C - 35˚C. This clearly shows that a warm climate is essential for cowpea growth and temperatures up to 35˚C are suitable.

Cowpea is adapted to different moisture availabilities in comparison to other crops [13]. It tolerates a wide variety of soils and soil conditions, but performs best on well-drained sandy loams or sandy soils.

Cowpea leaves are compound and pinnate with three leaflets each [14]. The plant can be extremely bushy or erect type with short branches and the other prostrate, spreading or sometimes twining and climbing forms with five (5) or more orders of branching with first and second order branches up to 50 cm long. The vine length can be between 120 - 180 cm [15].

Climate change may result in strong impacts on agriculture, especially on crop growth and yield. Crops are largely influenced by climatic conditions during the growing season and thus even minor deviation from optimal conditions can seriously threaten yield and therefore, knowledge on the effect of environmental factors on crop growth and development could reduce the possibilities of significant yield loss. There is the need to improve the selection of specific cultivars for growing in the target regions.

To improve the performance of new varieties, appropriate agronomic practices and trials at different agro-ecological zones are very critical for breeding and production purposes [10]. Again, to increase yield under such environments, there should be clearer understanding of the genotype, morphological, physiological and biochemical response to the environment.

Genotype by environment interaction over the years has been the primary aim in plant breeding since it assists breeders in taking steps to recommend varieties to be used by farmers. There have been statistical methods which have been developed in respect to characterizing crops with the aim of minimizing the effect of G × E interaction in selected varieties which is used to predict phenotypic responses to environmental changes. But most stability methods are not able to provide an accurate and complete varietal response pattern for interaction. The main reason of most cowpea yield improvement programmes is to check and select the high yielding and stable genotypes across several environments and seasons as well and in view of this, genotypes must be tested in diverse environments in order to assess how they can be adapted and its stability.

The additive main effect and multiplicative interaction (AMMI) method integrates analysis of variance and principal components analysis into a unified approach [16]. According to Gauch and Zobel [17] Zobel *et al.* [18] and Crossa [19], it can be used to analyze multi location trials. The AMMI model according to Gauch [20], Annicchiarico [21], Gauch and Zobel [22] and Ariyo [23], has been proven to be the suitable method for depicting adaptive responses. Again, AMMI analysis has significantly improved the probability of successful selection and therefore, it has been used to analyze G × E interaction with greater precision in many crops [23] [24] [25] [26].

Considering the three traditional models, Zobel *et al.* [18] pointed out that, analysis of variance (ANOVA) failed to detect a significant interaction component, the principal component analysis (PCA) failed to identify and separate the significant genotype and environment main effects, while linear regression models accounted for only a small portion of the interaction sum of squares. Instead, the AMMI model combines the conventional analysis of variance for genotype and environment main effects with principal components analysis to decompose the GEI into several interaction principal component axes (IPCA). Due to the biplot facility from the AMMI analysis, both genotypes and environments are plotted together on the same scatter plot and therefore, inferences about their interaction can be made [27].

The objective of this study was to determine the adaptability and yield stability of cowpea varieties using AMMI analysis to select the varieties with high performance that will make the selection of varieties that are more precise in terms of genotype × environment.

2. Methodology

2.1. Description of Experimental Sites

The study was carried out in two locations over two seasons:-the minor season from September to December, 2015 at Mampong - Ashanti and Fumesua and the major season from April to July, 2016 at both locations.

The Mampong-Ashanti (7˚N and 8˚N, 1˚24'W) experiment was conducted at the College of Agriculture Education, Akenten Appiah Menkah University of Skills Training and Entrepreneural Development, Mampong-Ashanti campus located in the forest-savannah transition agro-ecological zone of Ghana. The soil at Mampong belongs to the Bediese series of the savannah Ochrosol. The soil is sandy loam, well drained with thin layer of organic matter with characteristic deep yellowish red colour, friable and free from stones. The pH ranges from 6.5 - 7.0. It is permeable, and has moderate water holding capacity [28] [29]. The site has an altitude of 457.5 m above sea level. Mampong-Ashanti has a bimodal rainfall pattern with the major rainy season occurring from March to July and minor rainy season from September to November. Between the two seasons is a short dry spell in August. Average annual rainfall is between 1094 - 1200 mm with a temperature range of 22/23˚C-30˚C [30].

The Fumesua (6˚43'N, 1˚36'W) experiment was conducted at the research fields of the Council for Scientific and Industrial Research - Crops Research Institute (CSIR-CRI), Fumesua, Kumasi, located in the forest agro-ecological zone. The location has an altitude of 228 m above Sea level. The soil belongs to Asuansi series with thick top layer of dark grey gritty loam to gritty clay loam. It is of the humid forest from Ferric Acrisol [31]. The pH ranges between 6.0 - 7.5.

Fumesua also has a bimodal rainfall pattern with the major rainfall season occurring from March to July and the minor rainfall season from September and December [30]. The average annual rainfall is 1650 - 1727 mm with a temperature range of 22˚C - 31˚C.

2.2. Experimental Design and Treatments

The design used for the study was a Randomised Complete Block Design with three replications.

Selected cowpea varieties released by CSIR-CRI over the period of 1990-2015 were used for the study as treatments. These were Asetenapa, Nhyira, Asomdwee, Asontem, Tona, Soronko, Hewale and Videza. The ploughed and harrowed land were levelled and marked out. The experimental plots were demarcated with pegs and ropes. Each plot measured 1.5 m wide × 3 m long with a spacing of 0.5 m between rows × 0.2 m within rows. Each plot had four rows and the two middle rows were demarcated as harvestable rows. Planting was done at Mampong-Ashanti and Fumesua on the 11th and 12th October for 2015 and 27th and 28th April respectively for 2016. Three seeds per hill were planted at a distance of 50 cm × 20 cm and depth of 3 cm. The emerged cowpea plants were later thinned to two seedlings per hill two weeks after planting and weeds were controlled manually using a hoe at 21 days after planting (DAP) and hand-picked at Four sprayings were carried out at 20, 30, 40 and 50 DAP using Cymetox EC (cypermethrine 30 g/l and dimethoate 15 g/l) for the two locations and the two seasons. A Knapsack sprayer (15 litre capacity) was used in the spraying to control pests and diseases.

2.3. AMMI Analysis

Additive Main Effects and Multiplicative Interaction (AMMI) Analysis

The data on the grain yield of 8 genotypes of cowpea in 2 year-locational environments were subjected to the AMMI analysis. The AMMI model used was

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum \lambda_n \gamma_{gn} \eta_{gn} + \rho_{ge} + \varepsilon_{ger}$$

where Y_{ger} is the yield of genotype (g) in environment (e) for replicate (r); μ is the grand mean, α_g is genotype mean deviation (thus mean minus grand mean); β_e is the environment mean deviations; n is the number of Principal Components Analysis (PCA) axes retained in the model; λ_n is the singular value of PCA axis n; γ_{gn} is the genotype eigenvector values for PCA axis n; η_{gn} is the environment eigenvector values for PCA axis n; ρ_{ge} is the AMMI residuals and ε_{ger} is the residual error.

The AMMI model makes use of ordinary ANOVA to analyze the main effects which is the additive part and Principal Component Analysis (PCA) to analyze the non-additive residual left over by the ANOVA using the method by [20]. To get the interaction, the genotype PCA score was multiplied by that of the environment. When a cultivar and the environment have the same sign on their respective first PCA axis, their interaction becomes positive, if different then their interaction is negative.

An AMMI biplot was drawn where important aspects of both genotypes and environments were plotted on the same axis in order to get the interrelationships clearly visualized and easy interpretation. In the AMMI biplot, PCA1 score is placed on the vertical axis while the yield is placed on the horizontal axis. The genotypes that appear almost on a perpendicular line had similar means and those that fall almost on the horizontal lines had similar interaction patterns.

For the interpretation of the scores; genotypes or environments with large PCA scores either positive or negative had large interactions while those (genotypes) with PCA 1 score of zero or nearly zero had smaller interaction [19]. The first two PCA axes were considered for this study. The biplot of the first two IPCA axes demonstrated the relative magnitude of the genotype by environment interaction (GEI) for specific genotypes and environments. When the genotype or environment is further away from the centre of the axis, then the GEI is large.

The AMMI analyses were complemented with GGE biplot analysis. The first two principal components were used to obtain GGE biplots using [32]. To generate a biplot for visual analysis of multi environment data, the singular values were partitioned into genotype and environment eigenvectors for the GGE biplot model [33] [34]. Collectively, AMMI and GGE biplots were used to assess the performance and interaction patterns of genotypes and environments and based on that, a genotype with absolute IPCA1 value close to zero indicated low interaction and was considered to be stable while genotypes with greater absolute IPCA1 values were considered to have high sensitivity to environmental changes.

3. Results

3.1. Additive Main Effects and Multiplicative Interaction (AMMI) Analysis Results

The climatic condition at the experimental site is represented in **Table 1**. From **Table 1**, it could be observed that, generally the climatic condition experienced at the experimental site in Mampong was favourable than Fumesua. The highest (154.90) rainfall was recorded in October during the minor season while the highest (113.40) rainfall was recorded in Fumesua. In the major rainy reason in 2016, the highest (185.00) rainfall was recorded in April while the highest (112.30) rainfall was recorded in March at Fumesua site. Similar trend were recorded for temperature and relative humidity. Temperature values in Fumesua site were generally higher (31˚C) than Mampong (30˚C) (**Table 1**). However, values for relative humidity were generally higher (85%) in Mampong site than Fumesua (80%) in both major and minor rainy seasons (**Table 1**).

Results of AMMI Analysis of variance of the cowpea varieties is presented in **Table 2**. From the AMMI anova, genotype (G) accounted for 24.4% of the total sum of squares (SS), environmental effects explained 63.1% while interaction

GEI explained 4.6%. All of them were significant at different levels. Genotype and Environment were very highly significant at $P < 0.001$ while interaction was significant at $P < 0.05$ indicating that all the sources of variation are important in the analysis.

The principal component analysis (PCA) on the analysis of variance suggests that IPC1 scores were significant at $P < 0.05$. However, the IPCA2 score was not significant (Table 2). The IPCA1 score explained 80.8% while IPCA2 explains 2.7%. The IPCA1 scores were far higher than IPCA 2 (Table 2). The mean squares of the fixed effects by the anova in Table 2 which considered year in each location as an environment, showed very highly significant ($P < 0.001$) differences for environment and genotype. Interaction (GEI) was highly significant at $P < 0.01$.

Table 1. Climatic condition at the experimental site in the major and minor raining season.

		Mampong			Fumesua		
Year	Month	Rainfall (mm)	Temperature (˚C)	Relative Humidity (%)	Rainfall (mm)	Temperature (˚C)	Relative humidity (%)
	September	83.80	25.40	75	30.40	29.40	41
2015	October	154.90	25.80	80	113.40	27.40	73
Minor	November	38.70	27.00	67	36.00	28.80	48
Season	December	12.00	30.10	60	10.00	31.00	49
2016	March	113.00	24.20	82	112.30	26.50	80
Major	April	185.00	23.00	85	86.40	27.90	72
Season	May	80.30	26.00	78	42.00	28.10	65
	June	62.60	27.10	70	43.00	26.40	68

Source: Ghana Meteorological Agency, 2015 and 2016.

Table 2. AMMI Anova table for the combined yield of eight genotypes.

Source	Df	SS	SS Explained %	MS
Treatments	31	17,309,763		558,379***
Genotypes	7	4,579,083	24.4	654,155***
Environment	3	11,866,665	63.1	3,955,555***
Block	8	123,984	0.7	15,498
Interactions	21	864,015	4.6	41,144*
IPCA1	9	698,236	80.8	77,582**
IPCA 2	7	142,067	2.7	20,295ns
Residuals	5	23,712		4742
Error	56	1,358,079		2442
Total	95	18,791,826		197,809

3.2. AMMI Bi-Plot for Mean Seed Yield

The AMMI Bi-plot of mean seed yield is shown in **Figure 1**. Results obtained from the GGE Bi-plot represent the first two principal components analysis (PC1 and PC2). The decomposition of the GGE matrix effects showed the first two principal components accounting for 97.5% of the variation which was caused by G + GE. The PC1 accounted for 89.3% of the total variation while the PC2 was responsible for 8.2% (**Figure 1**).

3.3. Best Four AMMI Selections Based on Best Grain Yield Genotype in Each Environment

The best four AMMI selections based on best grain yield genotype in each environment is presented in **Table 3**. The additive main effect and multiplicative

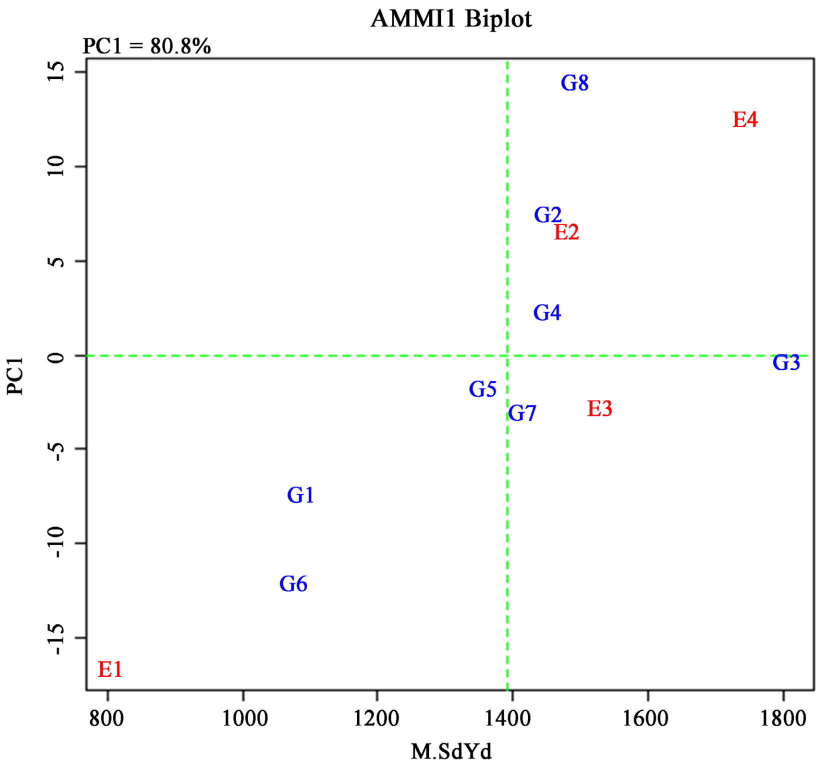

Figure 1. AMMI Biplot of Mean Seed Yield of Eight Cowpea Varieties. (G1-Asetenapa, G2-Asomdwe, G3-Asontem, G4-Hewale, G5-Nhyira, G6-Soronko, G7-Tona, G8-Videza)

Table 3. First four AMMI selection based on best grain yielding genotype in each environment.

Environment	Mean grain yield (kg/ha)	Score	Rank			
			1	2	3	4
FUM2015	808	16.525	Asontem	Tona	Hewale	Nhyira
MAM2015	1531	2.692	Asontem	Videza	Asomdwee	Tona
FUM2016	1485	−6.654	Asontem	Hewale	Videza	Asomdwee
MAM2016	1746	−12.563	Asontem	Videza	Asomdwee	Hewale

interaction analysis identified four highest yielding genotypes in each of the four environments. At Fumesua 2015 which was the least environment, four genotypes namely Asontem, Tona, Hewale and Nhyira. In environment Mampong 2015, Asontem, Videza, Asomdwee and Tona were selected as the top genotypes. Fumesua 2016 top genotypes were Asontem, Hewale, Videza and Asomdwee. In the highest favourable environment (Mampong, 2016), genotypes Asontem, Videza, Asomdwee and Hewale were selected.

GGE Bi-Plot Analysis of "What-Won-Where" and Environment View for Mean Seed Yield of Eight Cowpea Varieties

Figure 2 represents GGE Bi-plot environmental view for mean seed yield. From figure, it could be deduced that the average environment axis cuts through from the PC2 through the origin to the concentric circles. The average environment axis (AEA) relates to the ideal environment. From the bi-plot (Figure 2), it indicates that E4 is located close or in the direction of the ideal environment indicating the largest PC1 scores. E2 and E3 were located around the average environment with relatively high PC1 scores. However, E1 fell outside the concentric circles and moved away from the direction of the average environmental axis indicating low PC1 score.

A "what-won-where" polygon view of the relationship between genotypes and

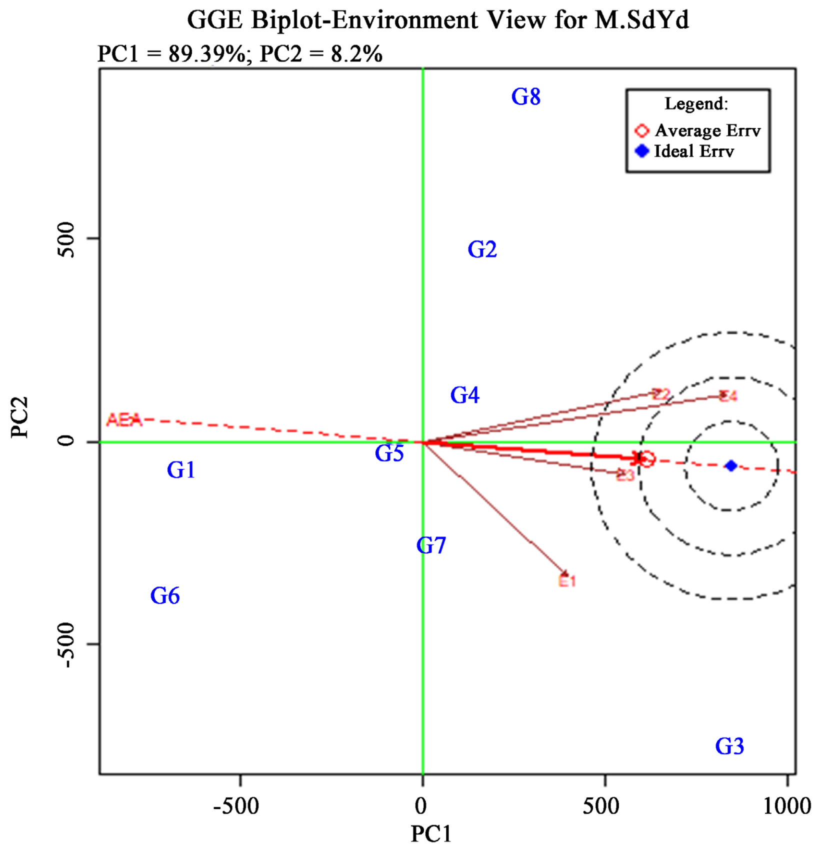

Figure 2. GGE Biplot of Environmental View on Mean Seed Yield of Eight Cowpea Varieties. (G1-Asetenapa, G2-Asomdwe, G3-Asontem, G4-Hewale, G5-Nhyira, G6-Soronko, G7-Tona, G8-Videza)

environment is presented in **Figure 3**. From **Figure 3**, it could be seen that the bi-plot explained a total of 97.5% for the variation observed. Out of this, 89.3% was explained by the first principal component (PC1), while the second principal component (PC2) explained 8.2%. Genotypes G3, G8, G6, and G1 (Asontem, Videza, Soronko and Asetenapa), respectively were situated at the corners of the polygon of "what-won-where" which indicates that these genotypes are tilted in particular environments. Out of these genotypes, G3 was the highest yielding in all the test environments. Genotypes G2, G4, G5, and G7 (Asomdwe, Hewale, Nhyira and Tona) respectively were clusted almost at the middle or centre of the "what-won-where" polygon.

4. Discussion

4.1. AMMI Stability Analysis

4.1.1. AMMI Analysis of Variances for the Combined Yield of Eight Genotypes

Genotype (G) accounted for 24.4%, environmental (E) effects accounted for 63.1% and their interactions (G x E) also explaining 4.6% of the total sum of squares (SS). These sources of variation were, however, significant which means that all the sources were very crucial in the analysis process. Based on the results, it could be seen that the most important source of variation is the environment

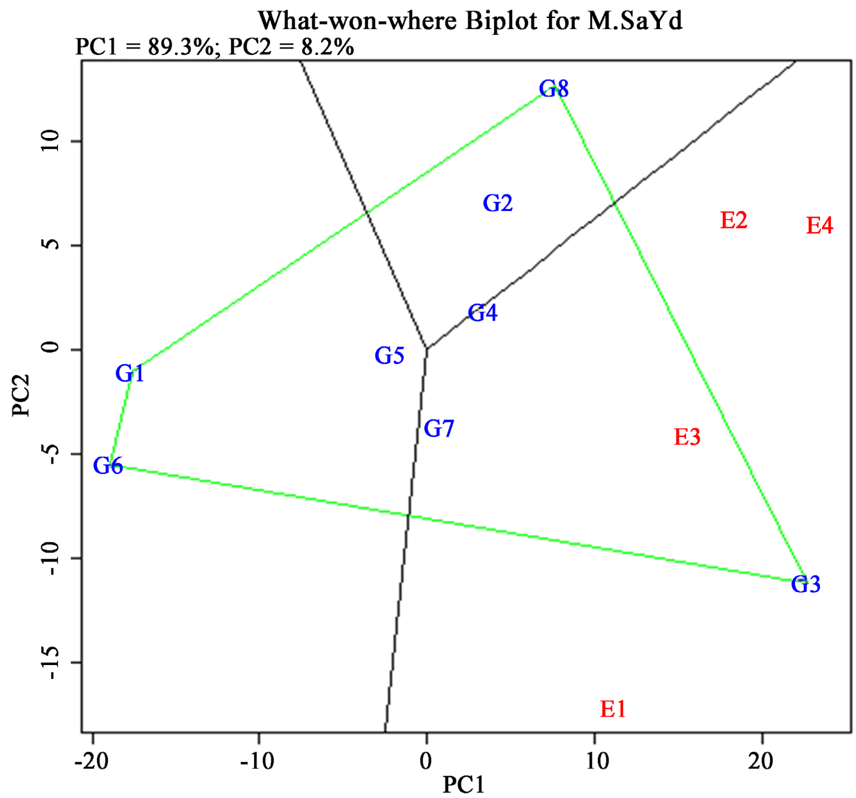

Figure 3. "What Won Where" View of the Relationship of Environment and Yield of Eight Cowpea Varieties. (G1-Asetenapa, G2-Asomdwe, G3-Asontem, G4-Hewale, G5-Nhyira, G6-Soronko, G7-Tona, G8-Videza)

(E) because it accounted for main effect due to its large contribution to the total sum of squares (SS) for the yield. This assertion is supported by [35]. The variation due to the genotype (G) was however larger than the interaction (GEI) and this is an indication that differences existing among genotypes vary across environments. This is in an agreement with [22] [36] Adjebeng-Danquah *et al.* [37] also made similar observation and related it to environment and their interaction.

When the interaction was partitioned into principal components axis, the first IPCA 1 explained 80.8% of the interaction sum of squares (SS). The second IPCA (IPCA 2) however explained 2.7% which means that there was no need to further partition the principal component since the first two (IPCA 1 and 2) clearly explained the extent of the level of significance in the source of variations. This clearly shows that the most accurate model can be predicted using the first two IPCA's. This result is in agreement with [38] that in using AMMI model, it is recommended that the most accurate model can be predicted using the first two IPCA's. Kayode *et al.* [39] however believes that genotype × environment interaction can also be predicted by further partitioning the IPCA's and not limiting it to the first two IPCA's. However, this observation contradicts the current study as the first two IPCA's showed accurate model for the AMMI.

4.1.2. AMMI Biplot for Mean Seed Yield of Eight Cowpea Varieties

The graphical AMMI Biplot depicts the performance of various genotypes in relation to principal component (PC) and Mean seed yield (M.SdYd). According to Crossa *et al.* [26] genotype or environment that have large negative or positive PC scores have high interactions but those that are close to zero on the horizontal line have little interaction across environments. Such varieties are therefore considered to be more stable than those far from the line. It could be seen from biplot (**Figure 2**) that, Asontem is near zero thus fell almost on the horizontal line indicating that Asontem is the most stable genotype. Hewale, Nhyira and Tona are regarded as stable because they are also close to the horizontal line but are lower than Asontem in terms of stability. This indicates that Asontem, Hewale, Nhyira and Tona gave higher yields and are stable irrespective of environmental changes. However, genotypes that are further away tends to be sensitive towards particular environment and therefore Asentenapa and Soronko which consistently gave lower yields can thrive and produce better yields only at favourable environment with optimum supply of resources and rainfall thus such varieties were adapted to certain environments. This observation is in consonants with [36] [40]. Based on the climatic conditions prevailed in the growing period (**Table 1**), seasonal rainfall amount coupled with temperature and relative humidity levels affected the performance of some of the genotypes which thrives only in favourable conditions and therefore, little deviation from the climatic activities becomes detrimental to growth and yield.

4.1.3. Best Four AMMI Selection Based on Best Grain Yield Genotype in Each Environment

From the additive main effect and multiplicative interaction (AMMI) analysis, four highest yielding genotype in each of the four environments were identified. From the Table 3, it could be observed that for high potential environment these four genotypes in each of the environment would be an ideal crop to select to achieve the yield potential. That is to say that in each of the environment, best four genotypes which can withstand drought and other adverse environmental conditions or in an environment with optimum conditions will be ideal in order not to get yield losses of all eight genotypes. This means that farmers will have the benefit of selecting the best yielding genotypes for specific environment at any given period. Similar observation have been made by [37] selecting best four high yielding varieties in different locations and seasons for cassava. It is worth noting that, based on the best four genotypes observed, the climatic conditions influenced such genotypic responses and it could be seen that Mampong location performed better than the Fumesua.

4.1.4. GGE Biplot of Environmental View on Mean Seed Yield and GGE Biplot Analysis of "What Won Where" of Eight Cowpea Varieties

Figure 2 displays a GGE biplot-Environment views for mean seed yield ((M.sd Yd). It could be deducted from the environment and mean seed yield view that the average environment axis (AEA) begins from the PC2 through to the concentric circles to the ideal environment. Better environment means that such environment must be close to ideal which supported the growth and high yield of genotypes. It could be seen that among the four environments, E4 is above average and close to the ideal environments. E2 and E3 are just close to the average environment while E1 is regarded as very low environment because it is outside the concentric circle which falls as a good location for growth and yield of crops. Again, it could also be observed that among the genotypes, G3-Asontem is in line with the ideal environment indicating that it performed well in all the test environments with the highest yield. Similar observations have been made by [27] of graphical display of biplots of some genotypes performance by comparing-different environments.

The GGE biplot of "what won where" analysis provided graphical representation of the relationship existing among the various genotypes and the environment (Figure 3). This made clear of the genotypes performance and its stability. Asontem, Videza, Soronko and Asetenapa were found at the vertices of the polygon (Figure 3) and this is an indication that those genotypes were responsive to the environment. However, Hewale, Nhyira, Tona and Asomdwe were found close to the middle or origin and as such they were considered the least responsive to the environment and this means that those genotypes can be used for wide adaptation thus multi or different agro ecological zones. In view of this situation, in selecting same set of genotypes for assessment or recommendation for farmers, such genotypes will be representative of the environments in order to safe yield losses and cost. In this case the biplot of "what non where" with its PC scores will show the genotypes that are stable enough and can show superiority based on environments. This observation is in consonants with [27] for superior genotypes in relation to environments.

5. Conclusion

Most cowpea varieties tend to do well in certain environment and little deviations or change in environment reduces yield. However, genotypes that are resilient with inherent characteristics are able to flourish and produce acceptable yield without much yield losses. Eight cowpea varieties which were released between 1990 and 2015 were evaluated in different locations and seasons to determine which genotype will be stable based on stability measure with the changing climate. Based on the AMMI analysis, the genotypes that were adaptable and stable in terms of genotype × environment interaction among the cowpea genotypes tested were Asontem, Tona, Nhyira and Hewale.

6. Recommendation

For cowpea producers to produce enough in order to break even without running into losses due to changes in the environment, there should be a conscious effort to resort to these recommended varieties that can withstand any change due to Genotype × Environment interactions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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