Cowpea is widely grown in the humid tropics as staple and is largely affected by genotype by environment interaction (GEI). Data obtained from field trials were subjected to genotype (G) by environment (E) interaction (GEI Biplot) analysis and was applied to examine the nature and magnitude of GEI and quantify their effects on cowpea performance in seven experimental trials in a rainforest and derived savanna agroecologies of south-west Nigeria. Results showed that genotype x environment interactions effects were significant on cowpea growth and yield characters. The differential performance of cowpea varieties as early- and late-rainy season crops at both locations were attributable to variability in the soil, weather and biotic factors of the test environments. Determination of winning genotype(s) and yield ranking across environments showed that cowpea varieties depicted differential performance for the test environments and hence the interaction was crossover type. Varieties IT97K-568-18, IT97K-568-18 and Oloyin Brown are high yielding while IT96D-610 and IT98K-205-8 are poor. Oloyin Brown and IT98K-573-2-1 won in Akure 1, 2, 3 and 4 and Ado 1 while IT97K-568-18 won in Ado 2 and Akure 5. IT96D-610 and IT98K-205-8 did not win in any environment. The best performing varieties, Oloyin Brown, IT97K-568-18 and IT98K-573-2-1 combined both high yield and stable performance across test environments and were characterized as ideal genotypes while most unstable variety, IT96D-610, performed poorly in test environments. It is concluded that Ado-Ekiti was best for the late rainy while Akure location was best for early rainy season cropping.

Keywords: Legumes, genotypes, soil, weather, yield, stability.

INTRODUCTION

Cowpea (Vigna unguiculata L Walp), is a food legume which plays a major role in human nutrition in the tropics. Its edible seeds provide cheap alternative source of protein compared to animal protein. Cowpea is a major grain legume crop in tropical and subtropical regions. This region is characterized by large seasonal variations in soil moisture regimes, soil and air temperatures (IITA, 2000). The humid rainforest zone of Nigeria is characterized by bi-modal rainfall distribution and variability of the average date of onset of the rains than its cessation (Agele et al., 2004). A cropping opportunity is provided by the earlier part of the rainy (first sowing) season before the rainfall is fully established. According to IITA (2000), the optimal sowing date of grain legumes including cowpea in the rainforest zone of Nigeria is at the beginning of the rains and not when rainfall has fully established while the crop's reproductive growth phase particularly seed maturity falls into the short dry spell which marks the end of the first
modal rainfall. The dry spell is characterized by abundant sunshine and negligible cloud overcast sky. The late sowing season falls within the second mode of rainfall distribution. However, the late season (late August/early September to December), is occasioned by limiting soil moisture status, extreme high soil temperatures, high irradiance and atmospheric vapour deficits (Agele et al., 2004). There are variations in soil water and thermal regimes of the early part of the rainy season (early vegetative phase of growth) and in the later part of the late cropping season (terminal drought situation). These environmental events have profound influence on growth and yield of crops (Agele et al., 2004, Agele and Agbi, 2012).

The yielding ability of crop varieties is the ultimate result of favorable interaction of genotype with the environment. Environmental factors such as moisture content, time of sowing, air temperature and photoperiod length, soil characteristics differ across years and locations with profound influence at developmental stages while different responses and performance of genotypes observed in environment are desirable characteristic (Gauch et al., 2008). Poor yield in cowpea may be due to unavailability of high yielding and stability of genotypes along with appropriate advance agronomic management practices (Agele and Agbi, 2012). Several varieties with high seed yield potential and growth habit like early maturity were identified and evaluated in adaptation trials to study seed yield stability in different ecological zones (IITA, 2000). There is therefore great need to test adaptation among cowpea cultivars to environmental conditions of the seasons of sowing and location in the ecological zones of Nigeria.

Genotype by environment interactions are common for most quantitative traits of economic importance. Therefore, advanced breeding materials must be evaluated in multiple locations for more than one year. Genotype by environment interactions may be due to i. heterogeneity of genotypic variance across environments and ii. imperfect correlation of genotypic performance across environments. Specific adaptations can make the difference between a good variety and a superb variety. Some environmental variation is predictable, they can be attributed to specific, characteristic features of the environment such as soil type, soil fertility, plant density. Some variation is unpredictable e.g., rainfall, temperature, humidity. The stability of performance across environments may depend upon the magnitude of genotype x environment interaction. A genotype is considered to have agronomical stability if it yields well with respect to the productive potential of the test environment. Stable genotypes are defined as the cultivar that makes the smallest contribution to the genotypes x environment interaction (G x E) (Eberhart and Russell, 1996), model had been widely used to study stability parameters through genotypes x environment interaction i.e. mean seed yield and regression coefficient. The present research work deals with the determination of seed yielding ability, magnitude and nature of genotype x environment interaction and stability characteristics of six cowpea varieties tested under different environmental conditions.

Several methods of analysing GE have been reviewed (Gauch et al., 2008). Some methods, such as analysis of variance, are good at determining GE but cannot determine the pattern of the interactions. The strengths of methods of genotype by environment interaction (G x E) analysis has been debated (Yan et al., 2007; Gauch et al., 2008; Yang et al., 2009). Regression-based methods use environmental scores, which have less to do with genotype plus GE (GE) and thus explain only a small part of GE. In the recent past, statistically effective methods, such as biplots based on Principal Component (PC) analysis, have been developed for GE analysis (Gauch 1993; Crossa et al. 2002; Yan and Kang 2002). Biplot analysis is a multivariate technique that graphically displays two-way data to permit visualization of the interrelationship (Gauch 1993, 2006; Yan and Tinker 2006). The biplot is a graphical presentation of a genotype by environment two-way table (Gauch 1993, 2006, 2013). The GE biplot can be subjected to different ways of singular value partitioning (SVP) (Yan and Tinker 2006). The biplot model that is fitted to residuals after the removal of the environmental main effect (environment-centered data) is called a GE biplot (Crossa and Cornelius 1997; Yang et al., 2009). The GE biplot is useful in evaluating the genotype main effects plus the GE (Yan and Tinker 2006). This approach has been commonly used for delineating crop performance in different environments and for varietal recommendations (Yan and Tinker 2006, Yang et al., 2009).

The GGE refers to the main genotypic effect (G) and the genotype x environment interaction (GE), which are the two most important sources of variation for cultivar evaluation in a multi environment trials (Yan et al., 2007). The GE biplot displays the genotype main effect (G) and genotype by environment interaction (GE) of a genotype-by-environment dataset (Yan et al., 2000). GE biplot is specially and perfectly used for mega-environment analysis based on genetic correlation between environment and the which-won-where pattern; test environment evaluation based on their discriminating ability and representativeness; and genotype evaluation based on their mean performance and stability across a mega-environment (Crossa et al., 2002; Yan et al., 2000). However, the GE biplot is capable of capturing much of the G plus GE variation and is also useful in understanding the test environment effects required for rationalizing scarce resources in crop breeding programs (Yan and Tinker 2006).

The objectives of this study were to examine the nature of genotype by environment interaction (GEI) and to quantify
the effects of its magnitude on cowpea in seven experimental trials for three consecutive years (2013-2015) and use the GE biplots to identify superior cowpea varieties for test environments of the rainforest and derived savanna agroecologies in southwestern Nigeria.

MATERIALS AND METHODS

Materials

Six cowpea varieties (IT98K-205-8, Ife brown, IT96D-610, IT98K-573-2-1, Oloyin brown, IT97K-568-18) were planted in the early and late rainy seasons of 2013-2015 at Akure and Ado Ekiti of the rainforest and derived savanna agroecologies of south west Nigeria.

Methods

Data obtained from the field trials were subjected to genotype (G) by environment (E) interaction (GxE Biplot) analysis and was applied to examine the nature and magnitude of GEI and quantify their effects on cowpea performance in seven experimental trials. The seven environments were made up of 2 seasons (early and late rainy seasons) + 2 locations (Akure and Ado Ekiti locations) + 3 years (2013-2015).

At maturity, the yield parameters of 100 seed weight, days to 50% flowering, shoot biomass and seed yield were collected and subjected to analysis of variance following stability parameters on variety, environment and variety x environment. This statistical analysis enables the determination of varietal stability in performance under the environmental conditions of the locations evaluated. Grain yield data were subjected to combined analysis of variance using SAS GLM (SAS, 2004) to examine the main effects of the environment (E) and genotypes (G) and their interactions (GE) variances. Further partitioning and analysis of the GE was computed using the GGE model (Yan, 2001). The Gollub’s (1968) F-test showed that the two principal components of the biplot were significant and thus could explain much of the variation (67%) in the two-way data (Zobel et al. 1988; Gauch 2006). Therefore, the GGE biplot was constructed using the first two principal components (PC1 and PC2) derived from yield data subjected to environment effects (Yan et al., 2000, Yan and Tinker 2006). The GGE-2 biplot analysis was conducted using Genstat Software version 13 (Genstat 2010).

The GGE biplot model used was described by Yan et al. (2000), Yan and Hunt (2001) and Yan (2002) as:

\[ Yij - \mu - \beta j = \lambda 1 \xi i \eta j 1 + \lambda 2 \xi i 2 \eta j 2 + \epsilon ij \quad \ldots \ldots \quad (1) \]

where \( Yij \) is measured mean yield of the \( i \)th genotype \( i(1,2,\ldots,n) \) and \( j \)th environment \( j(1,2,\ldots,m) \), \( \mu \) is the grand mean, \( \beta j \) is the main effect of environment \( j \), \( \mu + \beta j \)

being the mean yield across all genotypes in environment \( j \), \( \lambda 1 \) and \( \lambda 2 \) are the singular values (SV) for the first and second principal component (PC1 and PC2), respectively, \( \xi i1 \) and \( \xi i2 \) are eigenvectors of genotype \( i \) for PC1 and PC2, respectively, \( \eta j1 \) and \( \eta j2 \) are eigenvectors of environment \( j \) for PC1 and PC2, respectively, \( \epsilon ij \) 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 in to the genotype and environment eigenvectors.

Singular value partitioning was implemented by:

\[ gi1 = \lambda 1 f 1 \xi i1 \text{ and } eij = \lambda 1 1 - f 1 \eta ij \quad \ldots \ldots \quad (2) \]

where \( f1 \) is the portion factor for PC1. The \( f1 \) can range between 0 and 1. To visualize relationship among genotypes, the GGE biplot based on genotype metric (that is, \( f=1; \text{S.V.P}=1 \) is appropriate and environment metric (\( f=0; \text{S.V.P}=2 \))

If the data were environment-standardized, the common formulae to generate the GGE biplot was as follows:

\[ Yij - \mu - \beta j \cdot s j = gi1 e 1 j + eij k i = 1 \quad \ldots \ldots \quad (3) \]

where \( s j \) is the standard deviation in environment \( j \), \( i=1, 2,\ldots, k, g i1 \text{and } e 1 j \) are PC1 scores for genotype \( i \) and environment \( j \), respectively. In the present study we used environment standardized model, Equation (3).

The GGE-2 biplot model used was described by Yan et al. (2000), Yan and Hunt (2001) and Yan (2002) as:

\[ Yij - \mu - \beta j = \lambda 1 \xi i1 \eta j 1 + \lambda 2 \xi i2 \eta j 2 + \epsilon ij \quad \ldots \ldots \quad (1) \]

where \( Yij \) is measured mean yield of the \( i \)th genotype \( i(1,2,\ldots,n) \) and \( j \)th environment \( j(1,2,\ldots,m) \), \( \mu \) is the grand mean, \( \beta j \) is the main effect of environment \( j \), \( \mu + \beta j \)

being the mean yield across all genotypes in environment \( j \), \( \lambda 1 \) and \( \lambda 2 \) are the singular values (SV) for the first and second principal component (PC1 and PC2), respectively, \( \xi i1 \) and \( \xi i2 \) are eigenvectors of genotype \( i \) for PC1 and PC2, respectively, \( \eta j1 \) and \( \eta j2 \) are eigenvectors of environment \( j \) for PC1 and PC2, respectively, \( \epsilon ij \) 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 in to the genotype and environment eigenvectors.

Singular value partitioning was implemented by:

\[ gi1 = \lambda 1 f 1 \xi i1 \text{ and } eij = \lambda 1 1 - f 1 \eta ij \quad \ldots \ldots \quad (2) \]

where \( f1 \) is the portion factor for PC1. The \( f1 \) can range between 0 and 1. To visualize relationship among genotypes, the GGE biplot based on genotype metric (that is, \( f=1; \text{S.V.P}=1 \) is appropriate and environment metric (\( f=0; \text{S.V.P}=2 \))

If the data were environment-standardized, the common formulae to generate the GGE biplot was as follows:

\[ Yij - \mu - \beta j \cdot s j = gi1 e 1 j + eij k i = 1 \quad \ldots \ldots \quad (3) \]

where \( s j \) is the standard deviation in environment \( j \), \( i=1, 2,\ldots, k, g i1 \text{and } e 1 j \) are PC1 scores for genotype \( i \) and environment \( j \), respectively. In the present study we used environment standardized model, Equation (3).

The which-won-where scatter biplot (for mega-environment delineation), genotype comparison biplot (for comparing genotypes based on mean yield and stability) and location comparison biplot (for identifying the most discriminating and representative locations) were generated using the appropriate SVP methods (Yan 2002).

In the scatter biplot, the polygon view displaying the which-won-where pattern was formed by connecting the genotype markers furthest away from the biplot origin such that the polygon contained all other genotypes (Yan 2002). The polygon was then dissected by straight lines perpendicular to the polygon sides and running from the biplot origin. Visualization of the mean and stability of genotypes using a genotype comparison biplot was achieved by representing an average environment by an arrow. The relative performance of cowpea genotypes was ranked. A line that passes through the biplot origin to the average environment (average genotype axis) was drawn followed by a perpendicular line that passes through the biplot origin. The line passing through the biplot origin is called the average tester coordinate (ATC). The double arrow line which is perpendicular to ATC and passes through the origin represents stability of genotypes. An ideal genotype should have the highest mean performance and be absolutely stable. The relative yield of cowpea genotypes were ranked based on length of their
projections onto perpendicular line from each genotype towards test environment axes. Rank increases as one goes to the positive end.

For the analyses of test location, the environment vectors were drawn from the biplot origin to the markers of the environment. The average environment (AE) was represented with a small arrow and a line from the biplot origin to the AE (average environment axis) was drawn followed by a perpendicular line that passes through the biplot origin. For each genotype, the grand means of all traits across environments that include yield and yield components and days to physiological maturity were calculated. This formed a two-way table of genotypes and traits means. The cross environment mean data were scaled (standardized) by dividing each trait mean value with the within-trait standard deviation, as outlined by Yan and Tinker (2006). The standardization helps to remove the different units found among different traits (Yan et al. 2000; Yan 2001). The resultant data were subjected to biplot analysis using the trait focused SVP method and the data were trait centered. The vectors were drawn to connect the specific traits from the biplot origin. The across-environment means of the seven traits studied were subjected to Pearson’s phenotypic correlation coefficient analyses using Genstat software.

RESULTS

G by E and test environment evaluation

The genotype by environment interaction (GEI) biplots analysis showed that the performance of cowpea genotypes at the test environments differed and hence the interaction was crossover type. Cowpea varieties Oloyin Brown, IT97K-568-18 and IT98K-573-2-1 combined both high mean yield and high stability performance across the test environments and could be characterized as well adapted while the most unstable variety with poor performance across locations was IT98K-205-8. The combined analysis of variance over environments showed that cowpea seed yield was significantly (p<0.001) affected by environments (E), genotypes (G) and genotype by environment interactions (Table 1). Environment accounted about 26 % of the variation while GEI explained about 60 % of the variation which is more than double of the environmental and four times of the genotypic effects of the total variation. As shown by differential yield ranking of genotypes, the GE was crossover type and test-environment that effectively identify superior genotypes were identified.

Yield and stability performance of cowpea varieties

Fig. 1 to 8 present polygon view of six genotypes under seven environments from which a ‘which-won-where’ pattern was observed. The ranking of cowpea genotypes based on both mean yield and stability relative to an ideal genotype in test environments are presented in Fig. 1. Cowpea varieties IT98K-573-2-1, IT97K-568-16 and Oloyin Brown in that order, when placed in the center of the concentric circle were considered as ideal genotypes (most stable across test environments) having highest mean yield across the test environments. Other genotypes based on distance from ideal genotype which were ranked unfavourable as they were most far from the ideal genotype were Ife Brown and IT98K-205-8, IT96D-610.

Ranking genotypes relative to the highest yielding environment

The two locations Akure and Ado Ekiti, used to evaluate cowpea genotypes and their ranking as presented in the figures. The relative yield of cowpea genotypes were ranked based on length of their projections onto perpendicular line from each genotype towards test environment axes. Rank increases as one goes to the positive end. Hence, Three genotypes, IT98K-573-2-1, IT97K-568-568-18 and Oloyin Brown were regarded as the best yielding genotype had yields above average, while other genotypes yielded below the average performance. Figure 1 shows the results of six tested cowpea varieties and their yield performance in the test environments. The result shows that IT98K-205-8 performed best in Akure 5 (75.9kh/ha) while Ife Brown and IT96D-610 performed best in Ado 2 (87.4kg/ha) and Akure 1 (54.8kg/ha). Cowpea variety IT98K-573-2-1, Oloyin Brown and IT97K-568-18 performed best in Ado 1 (108.2,148.6, 83.5kg/ha). In contrast, IT98K-205-8 gave the poorest yield in Ado 1 (13.4kg/ha) while Ife Brown, IT96D-610, IT97K-573-2-1, Oloyin Brown and IT97K-568-18 gave the poorest performance in Ado 4 (9.4, 9.2,15.8,13.4 kg/ha) respectively. IT96D-610 gave the poorest mean yield among the tested cowpea varieties (33.7kg/ha) while the best performing variety with the highest mean yield was Oloyin Brown (58.8 kg/ha).The highest yielding environment for all tested varieties was Ado 1. Most of the varieties were unstable across all environments, however, Oloyin Brown, IT97K-568-18 and IT98K-573-2-1 were fairly stable. The result depicted that the performance of cowpea genotypes were different at different testing environments. (Different winners at different environments) due to the existence of large GE interactions as revealed by different yield ranking of genotypes.

Genotype Evaluation Based on GEI Biplots

The first two principal components for mean performance and stability among grain yield (PC1 and PC2) of the GGE explained 84 % with PC1 = 69.5 and PC2 = 14.7 of the GGE sum of squares using environment standardized model. Cowpea varieties, IT97K-568-18, IT98K-573-2-1 and Oloyin Brown are high yielding, in contrast, Ife Brown, IT98K-205-8 and IT96D-610 were generally poor yielding varieties (Fig. 1 and 2). Although, Oloyin Brown and
IT98K-573-2-1 are high yielding varieties while Ife Brown and IT98K-205-8 are poor yield varieties and unstable Oloyin Brown and IT98K-573-2-1 performed best in Akure 1, Akure 2, Akure 3, Akure 4 and Ado 1 while IT97K-568-18 performed best in Ado 2 and Akure 5. However, Ife Brown, IT98K-205-8 and IT96D-610 did not win in any of the tested environments (Fig. 3). Cowpea variety had the shortest days to attain 50% flowering and mature earlier. Although, IT98K-205-8 and Ife Brown are unstable, they had the shortest days to attain 50% flowering and mature earlier among the tested varieties. Oloyin Brown, IT98K-568-18 took longer days to attain 50% flowering and are late maturing varieties. The which-won varieties analysis is presented in Fig. 4. IT96D-610 won in Akure 1 and Ado 2 while Ife Brown and IT98K-573-2-1 won in Akure 3,IT96D-610 won in Ado 2 and Akure 1,Oloyin Brown won in Akure 2 while IT98K-205-8 won in Akure 4, Ado 1 and Akure 5 and is early maturing. Cowpea varieties IT98K-573-2-1, IT97K-568-18 and IT96D-610 are high yielding as they gave the highest seed number across environment (Fig. 5). In contrast, Ife Brown and IT98K-205-8 are unstable with poor seed producing abilities across environments. Oloyin Brown and IT98K-573-2-1 won in, Ado 2, Akure 2, Akure 3, Akure 5 and Akure 1 and similarly, IT97K-568-18 won in Akure 4 (Fig. 6). Cowpea varieties Oloyin Brown, IT98K-205-8 and IT98K-205-8 produced heaviest seeds while in contrast, Ife Brown, IT96D-610 is unstable across all environments (Fig. 7). In terms of seed weight, cowpea varieties of Oloyin Brown, IT97K-568-18 and IT98K-573-2-1 won in Akure 3, Akure 5 and Ado 1 respectively while Ife Brown won in Akure 1 (Fig. 8).

In general, yield and yield stability evaluation among the cowpea varieties showed that the varieties differed in their adaptability and stability of yields in the test environments (location, season). However, varieties Oloyin Brown expressed high yield potential in the study areas. The test environment and location effect fell into two sections where most of the tested varieties where not stable while others were found suitable and ideal to the tested environments. In the biplot analysis, Ife Brown, IT98K-205-8 and IT96D-610 were vertically distant apart; however, they did not fall close to the horizontal line. This implies that these varieties lack stability but could be of high yield potential in favourable environments. Based on the analysis, Oloyin Brown, IT97K-568-18 and IT98K-573-2-1 were well adapted to high yielding environments.

**DISCUSSION**

The genotype by environment interaction analysis demonstrated that cowpea varieties responded differently to environmental conditions of the study area. The combined analysis of variance showed highly significant differences among varieties, environments and varieties by environment interactions for grain yield. The stability study indicated that among the tested varieties, most were found unstable. The result further gave credence to the fact that cowpea grain yields were affected by environment and their interactions. The results showed that IT97K-568-18, IT97K-568-18 and Oloyin Brown are high yielding while IT96D-610 and IT98K-205-8 are poor yielding. The result also indicated that Oloyin brown and IT98K-573-2-1 won in Akure 1, Akure 2, Akure 3, Akure 4 and Ado 1 while IT97K-568-18 won in Ado 2 and Akure 5. However, varieties IT98K-205-8 and IT96D-610 did not win in any environment. In contrast, IT98K-573-2-1, IT97K-568-18 and Oloyin brown showed high yield potential in favourable environments. The differences among varieties in terms of direction and magnitude along the X-axis (yield) and Y axis (IPCA1 scores) are important. In the biplot display, cowpea varieties in environment that appear almost on a perpendicular line of a graph had a similar mean yields and those that fall almost on a horizontal line had similar interaction (Crossa et al., 1990). Genotypes or environments with large negative or positive PCA scores denoted high interactions, while those with PCA1 scores near zero (close to the horizontal line) have little interaction and vice versa across environments (Crossa et al., 1990). In the biplot, the varieties Ife Brown, IT98K-205-8 and IT96D-610 were vertically distant apart; however, they did not fall close to the horizontal line. This implies that these varieties lack stability but could be of high yield potential in favourable environments. The greater the PC scores, the more specifically adapted is a genotype to certain environments while the more the PCA scores approximate to zero, the more stable or adapted the genotype is in the environments tested. The genotype main effect plus GE biplot showed that the cowpea varieties Oloyin brown, IT97K-568-18 and IT98K-573-2-1 combined both high yield and had high stability performance across the test environments in addition to other desirable agronomic traits. These varieties can be characterized as well adapted to the test environments. The most unstable varieties with poor performance across location was IT96D-610 and IT98K-205-8. Evaluation of cowpea yield stability showed that the varieties differed in
and passes through the origin represents stability of genotypes. An ideal genotype should have the highest mean performance and be absolutely stable (Yan and Kang, 2003). The relative adaptation of genotypes was studied and genotypes were ranked based on length of their projections onto the axes. Rank increases as one goes to the positive end (Yan et al., 2000). The genotype comparison biplot showed that the most stable and high-yielding genotype are Olayin Brown, IT97K-568-18 and IT98K-573-2-1. These three genotypes yielded higher and were more stable than the commercial variety, Ile Brown. Based on their stability and high yield from these varieties were outstanding in the two locations and environments. Such varieties will display stability and outstanding yield performance in high yield environments, which is highly desirable. Genotypes Olayin Brown, IT97K-568-18 and IT98K-573-2-1 were comparable in yield to Ile Brown, other varieties did not perform well Ile Brown was ranked least in terms of performance and stability. The top three genotypes which performed well in specific environments, could be targeted to those environments to maximize grain yield.

The nature of the GE estimates as indicated by significant genotype main effect and suggest differential responses of the genotypes and the need to identify high-yielding and stable genotypes across the test environments. In the locations (agroecological zones) of study, there are differences in predictable factors (soil characteristics) and unpredictable factors (temperature and rainfall). The presence of GE that is several folds larger than the genotypic main effects indicates substantial differences in genotypic responses across locations. Bernardos (2002) asserted that when the GE is substantial it should not be ignored; the causes must be identified (Yan and Kang 2002) and the GE should be addressed. Most of the GE variation in this study was due to predictable factors (location-intrinsic factors) rather than unpredictable factors (years). In this study, the GE could be attributed to differences in soil types, rainfall patterns, and temperatures as well as various pests found in specific locations. Under such circumstances, predictable factors can be managed, but modifying the environment to suit the crop will further constrain the resource-poor farmers. The cheaper option is to develop cowpea varieties adapted to the target environments. However, because the locations have no clearly defined boundaries, farmers need to have informed choices of variety to grow. The development of varieties with broad adaptation is more important rather than location-specific varieties. Multi environment analysis using GE biplot produces best polygons to view or visualize the genotype x environment interaction pattern (Yan and Kang, 2003). Visualization of the ‘Which-won-where’ pattern in the polygon view is helpful to estimate possible existence of different mega-environments in the target environment (Yan and Rajcan, 2002; Yan et al., 2000; Yan and Tinker, 2006). Hence, Akure and Ado Ekiti can be considered as separate location for cowpea variety evaluation and recommendation. A similar result has been documented for soybean by Aslaw et al. (2009).

The cowpea genotypes were evaluated across environments. The results showed that the seven environments were best predicted by the first two PCAs based on Gollob’s F-test (Zobel et al., 1988). Therefore, a biplot with two PCAs was used to describe the GGE. Yan (2000) reported that the first two PCs captured the most useful variation in a biplot. When the GE is larger than the genotype main effect, ignoring the interaction is not recommended (Yan and Kang 2002). In our study, the GGE biplots explained 67 % of the total GGE sum of squares, while G plus GE explained over 50 % of the total variance. The results of the environments showed that the environments are discriminating of the genotypes Thus, Olayin Brown, IT97K-568-18 and IT98K-573-2-1 were the most discriminating of the genotypes. Hence, Akure and Ado Ekiti were more representative environments for cowpea multi location trials and ideal for selecting cowpea genotypes for the south west Nigerian agroecologies. The success of different genotypes in different environments shows the existence of crossover genotype by environment interactions (Yan and Tinker 2006). The environments overlap suggesting the absence of a clear pattern of GEs. The existence of crossover GE suggests that cultivar evaluation and recommendation based on any single location is unreliable because there is differential performance of varieties across locations (Yan and Kang 2002). The existence of crossover interactions also suggests the need to reduce or exploit GE. For crossover genotype by environment interaction, Yan and Kang (2002) suggested that cultivar evaluation should be based on mean performance and stability. The results of the evaluation of the Test Environments showed that the presence of GE in cowpea (discriminating ability of the location; Yan and Tinker 2006) justifies undertaking the multi-location and multi-year trials. Therefore, environmental analysis will help to better understand the testing environments and possibly help reduce the cost of genotype evaluations (Yan and Kang 2002). The large GE effect suggests the possible presence of different environments with different winner genotypes (Yan and Kang, 2003). Similar result was obtained for soybean in Nigeria by Jandong et al. (2011). These reports depicted that the performance of crop genotypes which may be different at different testing environments (different winners at different environments) may be due to the existence of large GE interaction. Test environments have different winner genotypes. This situation complicates selection process and cultivar recommendation in breeding programs (Comstock and Moll, 1963, Yan et al., 2007). Existence of significant and large GE in legumes such as cowpea in Africa has been reported (Aslaw et al., 2009; Gurmu et al., 2009; Tukamuhabwa et al., 2012; Bueno et al., 2013).
CONCLUSIONS

Cowpea is widely grown in the humid tropics as a staple, however, in this region, it is largely affected by genotype by environment interaction (GEI), making it difficult and expensive to select and recommend new genotypes for different environments. The nature, magnitude and effects of genotype by environment interaction (GEI) on the growth and yield characters cowpea varieties in early- and late- rainy seasons, at 2 locations (Akure and Ado Ekiti) and 3 years (2013-2015) was quantified. The results depicted differential performance of cowpea genotypes at different test environments and hence the interaction was a crossover type. The GEI explained about 60% of the variation which is more than double of the environmental and four times of the genotypic effects of the total variation. Varieties Oloyin Brown, IT97K-568-18 and IT98K-573-2-1 exhibited both high yield and stability across the test environments and could be characterized as ideal while the most unstable varieties with poor performance are IT98K-205 and IT96D-610. The study identified superior cowpea genotypes for tested locations (Akure and Ado Ekiti environments) an information which denotes the value of the tested locations for future cowpea breeding activities. It is concluded that cowpea varieties produced high seed yield as early and late rainy season crops at both locations. Ado-Ekiti location was best for the late rainy season while Akure location was best for the early rainy season.

REFERENCES


APPENDIX

Table 1: Analysis of variance for grain yield (kg ha⁻¹) of six varieties evaluated at five experimental trial and two locations for three consecutive years between 2013-2015 in (Akure and Ado-Ekiti)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-value</th>
<th>%SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment (E)</td>
<td>6</td>
<td>3230932</td>
<td>538489</td>
<td>7.40</td>
<td>25.58</td>
</tr>
<tr>
<td>Genotype (G)</td>
<td>5</td>
<td>3322940</td>
<td>664588</td>
<td>9.10</td>
<td>14.87</td>
</tr>
<tr>
<td>Replicate (R)</td>
<td>2</td>
<td>2585297</td>
<td>1292649</td>
<td>17.7</td>
<td></td>
</tr>
<tr>
<td>GE</td>
<td>30</td>
<td>3747387</td>
<td>124913</td>
<td>1.77</td>
<td>59.55</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>3489186</td>
<td>348919</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>3876567</td>
<td>73143</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GE = Genotype x Environment interaction; DF = Degree of freedom; SS = Sum of squares; MS = Mean square

Figure 1. Performance and stability of seed yields among cowpea varieties in seven environments on two principal components (PC1 and PC2).
Figure 2: Polygon view of the GGE biplot showing which cowpea variety won and in which environment: seed yield

Figure 3: Performance and stability of cowpea varieties in environments of the early and late rainy season conditions on two principal components (PC1 and PC2) in terms of days to 50% flowering

Genotype by environment interactions and effects on growth and yield of cowpea varieties in the rainforest and derived savanna agroecologies of Nigeria
Figure 4: Polygon view of the GGE biplot showing which cowpea variety won and in which environment: 50% flowering date

Figure 5: The performance of cowpea varieties for stability across environments on two principal components (PC1 and PC2) in terms of number of seeds per plant
Figure 6. Polygon view of the GGE biplot showing which cowpea variety won and in which environment on two principal components (PC1 and PC2) in terms of number of seeds per plant.

Figure 7. The ranking of cowpea varieties for stability in 100 seed weight across environments on two principal components (PC1 and PC2).
Figure 8: Polygon view of the GGE biplot showing which cowpea variety won and in which environment: 100 seed weight

Accepted 20 September 2017


Copyright: © 2018. Agele et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are cited.