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Genotype by environment interactions and phenotypic stability analysis for yield and yield components in parental lines of pearl millet *(Pennisetum glaucum* [L.] R. Br)

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Twenty-four parental lines of pearl millet and a seed parent (ZATIB) as check were evaluated in five different locations in northern Nigeria to determine their yield levels and stability across the environments. Identification of stable parental line(s) will improve the performance of resulting pearl millet hybrids. Location and genotype effects were highly significant (P<0.05) for all the parameters sampled while interaction between locations and genotypes were significant (P<0.05) for stand count, days to 50% flowering, downy mildew score, panicle length and grain yield (kg ha^{-1}). Estimates of environmental index showed that Samaru was the best performing environment while Bagauda and Panda were the poorest grain yielding environments. Most of the lines were adapted to high rainfall environment of Samaru while others showed specific adaptation to low rainfall locations; indicating the possibility of developing specific lines adapted to low and high rainfall areas. Mean grain yield ranged from 504.8 (kg ha^{-1}) for G3 (20A-2) to 1920 (kg ha^{-1}) for G24 (75B-3). G10, G14 and G15 were found suitable for favorable conditions with predictable performance as they gave high mean grain yield along with above average responsiveness (bi>1) and non-significant deviation from regression line while G13, G17 and G18 were considered suitable for poor environments. Regression coefficient and deviation from regression indicated that G23 and G24 (75A-3 and 75B-3) and ZATIB were most stable in performance across the test environments.

Key words: Genotype by environment interaction, pearl millet, parental lines, stability, yield components.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* [L.] R. Br) is an important cereal crop common in the arid and semi-arid tropical areas of the Indian sub-continent and Africa (Yadav et al., 2001). It is cultivated mainly as a grain crop across a wide range of environments around the sub-saharan Africa. In Nigeria, pearl millet is usually grown under traditional farming system, where the rainfall is between 200 to 800 mm and average yield of about 200 kg/ha (Ndjeunga et al., 2010). The main production constraints of this crop in Nigeria is unpredictable and

Table 1. Description of testing locations.

Location	Agro-ecological zone	Annual rainfall* (mm)	Soil type	Global position		
				Latitude	Longitude	Altitude (m.a.s.l)
Samaru	Northern Guinea	1050	Clay loam	11° 18'N	07° 61'E	691.7
Panda	Sudan	670	Sandy loam	11° 60'N	09° 04'E	454.1
Bagauda	Sudan	800	Loamy	11° 56'N	8° 40'E	498.7
Babura	Sahel	550	Sandy	12° 78'N	9° 00'E	387.7
Minjibir	Sudan	650	Sandy loam	12° 13'N	8° 69'E	416.1

*Long term average, m.a.s.l= meter above sea level.

variable weather conditions, low soil fertility, fragile environment, use of landraces, poor crop establishment and less availability of inputs.

Genotype-Environment (GE) interaction is extremely important in the development and evaluation of plant varieties, because they reduce the genotypic stability values under diverse environments (Hebert et al., 1995). Crop production is the function of genotype, environment and their interaction (GEI). Significant GEI results in changing behavior of the genotypes across different environment or changes in relative ranking of the genotypes (Crossa, 1990). A significant GxE interaction for a quantitative trait such as grain yield can seriously limit the efforts of selecting superior genotypes for improved cultivar development (Kang and Gorman, 1989). Understanding the relationship among yield testing locations is important if plant breeders and agronomists are to target germplasm better adapted to different production environments (Trethowan et al., 2001).

It has been observed that single crossed hybrids generally give 20 to 30% more grains than open pollinated varieties (OPV) under normal conditions (Rai et al., 2006). However, hybrids may not express its full potentials in the presence of limited environmental resources. Under these circumstances parental lines with a stable performance across changing environments, even with modest yield, are considered more relevant than high yielding lines with inconsistent performance across unpredictable crop season (Yadav and Weltzien, 2000; Ceccarelli, 1994; Joshi, 1998). Information on yield performance and stability over variable environments of pearl millet parental lines developed jointly by Lake Chad Research Institute (LCRI) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) during 1997 to 1999 has not been ascertained. Knowledge of the variability for different characters present in pearl millet parental lines is important for successful pearl millet hybrid development. A stable genotype possesses an unchanged or least changed performance regardless of any variation of the environmental conditions (Rahman et al., 2010). Several stability analyses have been proposed to determine linear relationship between genotypic performance and the environment. Eberhart and Russell (1966) proposed a method in which the environmental index is the mean performance of all the entries in an environment. A desirable genotype is one with high mean value, with regression coefficient of 1.0 and deviation from regression is 0. Such a genotype would have increased performance as the productivity of the environment improves. Tollenaar and Lee (2002) reported that high yielding maize hybrids can differ in yield stability and that yield stability and high grain yield are not mutually exclusive.

Based on the availability of a commercially exploitable cytoplasmic-nuclear male-sterility (CMS) system LCRI, Maiduguri along with ICRISAT embarked on pioneer research of developing commercial pearl millet hybrids using indigenous germplasm and converted lines. This study was therefore, designed to examine the yield levels and stability in performance of pearl millet parental lines with a seed parent across different locations in northern Nigeria.

MATERIALS AND METHODS

The study was conducted during the 2000 rainy season at five different locations comprising of Samaru, Panda, Bagauda, Babura and Minjibir. These locations represent the diverse agro-ecologies of the major pearl millet growing regions of northern Nigeria (Table 1). Twenty-four pearl millet parental lines developed jointly by LCRI, Maiduguri and ICRISAT, Kano along with one seed parent (ZATIB) used as check were laid out in randomized complete block design (RCBD) with 3 replications. The experimental unit was a four-row plot of 5 m long, spaced at 0.75 m apart and intra row spacing of 0.5 m. Inorganic fertilizer (NPK 15:15:15) was applied as a basal dose @ 300 kg ha^{-1}. Crops were thinned down to two plants per stand two weeks after crop emergence. It was top dressed with urea three weeks post crop emergence @ 100 kg ha^{-1}.

Data were collected from two middle rows for stand count, days to 50% flowering, downy mildew score, *Striga* count, plant height, panicle length, head weight and grain yield following the recommendation of International Board for Plant Genetic Resources (IBPGR) and ICRISAT

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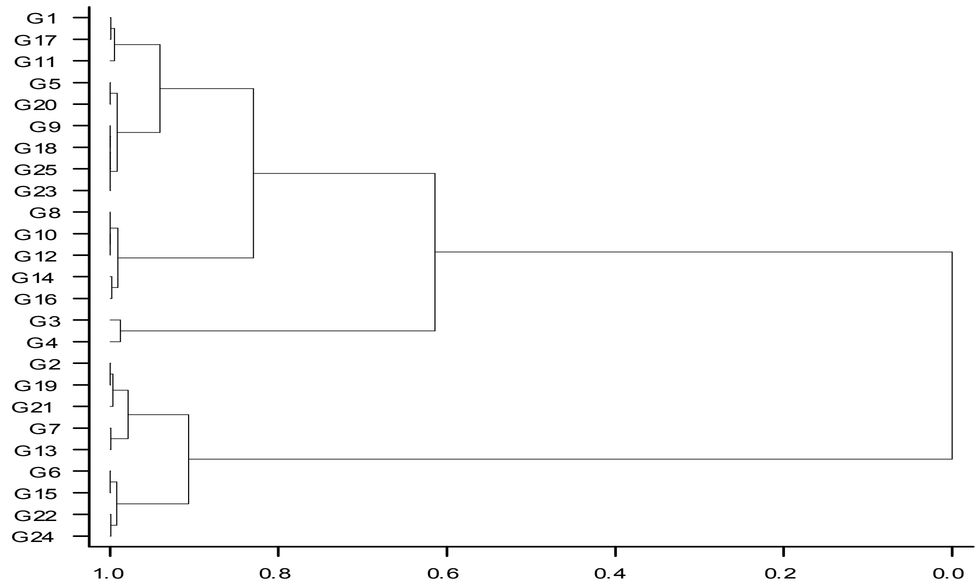

Figure 1. Dendrogram showing clustering pattern of 25 parental lines of pearl millet.

descriptor list for pearl millet (IBPGR/ICRISAT, 1993). Stability parameters were calculated according to Eberhart and Russell (1966) model. Data analysis were performed using GENSTAT, 2009 edition. Means procedure in the GENSTAT program with the option Duncan (for Duncan's multiple range test) was used in separating the means of the main effects. Cluster analysis of grain yield data was used to group the parental lines. The similarity between two lines was expressed as the squared Euclidean distance. An agglomerative hierarchical procedure with an incremental sum of squares grouping strategy known as Ward's method (Ward, 1963) was employed for the purpose of grouping genotypes. To adjust for the differences in yield levels between different locations, data for each environment were standardized to a mean of zero and standardized deviation of one as suggested by Fox and Rosielle (1982).

RESULTS AND DISCUSSION

The mean square values for stand count, days to 50% flowering, downy mildew score, *striga* count, plant height, panicle length, head weight and grain yield (kg ha^{-1}) are presented in Table 2. There was highly significant (P>0.01) component of variation across locations and genotypes for all the parameters sampled indicating that the locations and genotypes were inherently variable justifying their selections for this study.

The interaction between locations and genotypes were significant for stand count, days to 50% flowering, downy mildew score, panicle length and grain yield suggesting that these parameters were considerably influenced by the environmental variations across the five locations. On the other hand locations by genotype interaction was non-significant for *striga* count, plant height, and head weight indicating that these parameters were stable across the environments. The presence of significant location by genotype interaction showed the inconsistency of performance of pearl millet parental lines across the test environments. A similar result was reported by Abebe et al. (1984) on sorghum, Khalil et al. (2010) on maize hybrids and Lothrop (1989) on maize. Baradwaj et al. (2001) stated that the significant differences among crop genotypes for grain yield indicated the necessity to group them into clusters to identify the nature of the groupings. Figure 1 is the dendrogram showing clustering pattern of pearl millet parental lines. Although, the maintainer B-lines and male sterile A-lines possess similar genetic background since they were developed from NCD2; they did not display a particular order of clustering across the three main groups formed. However, different A-lines and B-lines showed greater affinity with each other irrespective of their selection. There were instances where A/B counterparts clustered. The difference in clustering pattern among the parental lines was an indication of the variability that exists in pearl millet being predominantly cross pollinated crop.

As shown in Table 3, partitioning of genotype by environment into linear and non-linear portions for grain yield indicated that both were vital. Genotype by environment (linear) and pooled deviations were significant when tested against pooled mean square revealing that both linear and non-linear components accounted for genotype by environment interaction. The large significant genotype by environment variance suggests that the component was most important in contributing to differences in performance of genotypes across the test environments. The relatively large proportion of environment variance when compared with genotype as main effect suggests the large influence of environment on yield performance of pearl millet lines in northern Nigeria. These findings were in accordance with Kang (2002).

The estimates of environmental index (Table 4) showed

Table 3. Combined analysis of variance for grain yield in pearl millet lines used to estimate stability parameters.

Source	Df	Mean square
Genotype (G)	24	15.296**
Environment (Env) + GxEnv.	100	29.13**
Environment (Linear)	1	18.267**
GxEnv. (Linear)	24	1.062**
Pooled deviation	75	9.801**
Pooled error	250	45.5

** Significant when tested against pooled mean square at P < 0.01.

Table 4. Estimates of environmental index.

Environment	Mean grain yield (kg ha^{-1})	Environmental index (I_i)
Babura	1440.77	0.212
Minjibir	1504.4	0.276
Panda	784.88	-0.444
Bagauda	752.79	-0.476
Samaru	1669.11	0.432
SE±		0.146

that Samaru location was the best performing environment, Minjibir and Babura were medium performing while Bagauda and Panda were the poorest grain yielding environments. This variations in the environmental index showed that the performance of the genotypes varied from location to location. Samaru location was therefore the most favorable environment for realizing the yield potential of the pearl millet parental lines with the location possessing favorable environmental resources in terms of higher and longer rainfall duration as well as better soil variables. Although most genotypes were adapted to high rainfall environment of Samaru, some genotypes demonstrated specific adaptation to low rainfall locations suggesting that rainfall distribution during growing season was the determining factors for the performance of pearl millet genotype and confers either broad or specific adaptation to such locations.

According to Ghaderi et al. (1980), analysis of variance procedure is useful for estimating the magnitude of genotype by environment interaction but fails to provide more information on the contribution of individual genotypes and environment to genotype by environment interactions. To address the problem, different stability parametric procedures were employed in this study to evaluate and describe pearl millet parental lines performance and their result presented in Table 5. The individual location grain yield, mean grain yield of the genotypes across the five locations, regression coefficient and deviation from regression indicated that mean grain yield across the five locations ranged from 504.8 (kg ha^{-1}) for G3 (20A-2) to 1920 (kg ha^{-1}) for G24 (75B-3). The top five higher mean values for grain yield in descending order are G24, G21, G19, G16 and G20 with mean grain yield ranging from 1920 (kg ha^{-1}) to 1483.4 (kg ha^{-1}). These five parental lines consistently produced highest grain yield in low rainfall locations of Babura and Minjibir than in high rainfall regions. A-lines parents generally produced lower mean grain yield than their B-lines counterpart. Samaru location produced the highest overall mean grain yield of 1669.1 (kg ha^{-1}) which differed significantly from the rest locations. However, the lower rainfall locations of Babura and Minjibir produced similar mean grain yield but significantly higher than Panda and Bagauda with higher rainfall occurence. The variation in yield among parental lines across the testing location confirm the presence of genotype by environment interaction and for high yield potential indicating that specific breeding programmes are necessary for effective development of stable pearl millet parental lines in a diverse environmental conditions of northern Nigeria. This is similar to the report of Rathore and Gupta (1994) who stated that crossover interaction is substantial evidence in favor of breeding specific adaptation.

Parental lines with superior performance in drier areas is an indication of the presence of stress tolerant potentials among the lines while on the other hand those with better performance in wetter regions have specific adaptation to favorable environment. Stability of genotypes and their performance over a set of diverse environments is of considerable importance to agronomists and plant breeders. Newly developed cultivars are usually evaluated across different environments in order to elucidate the pattern and the magnitude of genotype by environment interactions. If the interaction is present particularly for trait of interest, then it can reduce the correlation between phenotypic and genotypic values and will ultimately reduce progress from selection (Kang and Gorman, 1989). On the other hand, if the genotype by environment interaction is not prominent, a single genotype can be recommended for a wider geographical area. This approach will not only lead to increased productivity, but can also considerably reduce the input cost by developing a single variety for a wider agro-ecological zone.

Understanding the relationship among yield testing locations is important if plant breeders are to target germplasm better adapted to different production environments or regions (Trethowan et al., 2001). Two stability parameters consisting of regression coefficient “bi” and deviation from regression “S^2di” were used to evaluate some parental lines as shown in Table 5. A genotype with a unit value for regression coefficient and minimum deviation from regression is considered to be stable (Eberhart and Russell, 1966). Several of the genotypes had a significant deviation from linear regression implying that these genotypes were unstable

Table 5. Mean grain yield (kg ha^{-1}), regression coefficients (bi) and deviation mean square (S^2di) of 25 pearl millet parental lines tested across five environments.

Code	Parental lines	Babura	Minjibir	Panda	Bagauda	Samaru	Mean grain yield	bi	S^2di
G1	6A-2	313	399	203	258	1419	518.2	0.932	23.2**
G2	6B-2	1202	2136	856	721	1849	1352.6	1.188	6.7
G3	20A-2	578	220	263	200	1264	504.8	0.956	24.5**
G4	20B-2	1160	621	564	472	1162	795.8	0.746	2.7
G5	21A-1	1160	2082	424	998	1565	1235	1.169	14.0*
G6	21B-1	1720	1205	999	1101	2075	1420	1.011	10.1*
G7	23A-1	1037	1324	597	968	1929	1171	0.999	6.8*
G8	23B-1	618	714	361	443	1729	773	0.675	1.5
G9	24A-1	1283	1502	702	501	1508	1099.2	1.300	4.2
G10	24B-1	1913	1414	704	539	1729	1259.8	1.319	0.6
G11	25A-1	1732	1510	599	740	1352	1186.6	1.209	3.5
G12	25B-1	1238	758	306	535	1729	913.2	1.080	4.1*
G13	37A-1	1325	1485	771	1063	1907	1310.2	0.565	3.7
G14	37B-1	1877	1725	559	735	1685	1316.2	1.363	1.1
G15	47A-3	1082	1588	1036	480	2062	1249.6	1.150	5.9
G16	47B-3	1873	2297	1099	650	1641	1512	1.263	10.3*
G17	51A-4	1914	1917	1086	878	1397	1438.4	0.873	4.9
G18	51B-4	1455	1802	814	1287	1508	1373.2	0.609	1.6
G19	60A-2	2075	2492	1300	1088	1840	1759	0.896	19.6**
G20	60B-2	1529	2217	1056	1041	1574	1483.4	0.459	29.2**
G21	66A-2	2609	2328	1623	949	1796	1861	1.185	15.1*
G22	66B-2	963	717	753	407	2017	971.4	0.810	7.1
G23	75A-3	1311	962	546	469	1490	955.6	1.051	0.05
G24	75B-3	2363	2321	1372	1549	1995	1920	1.022	0.03
G25	ZATIB	1743	1876	1030	747	1507	1380.6	1.006	0.2
CV%							34.75		
Mean							1230.39		
SE±							0.022		

*,**Significant at 5 and 1% levels of probability respectively; suitable for optimum environment bi=1, suitable for favorable environment bi>1, suitable for poor environment bi<1.

across the environments. Parental lines G10, G14 and G15 were found suitable for favorable conditions with predictable performance as they showed high mean grain yield along with above average responsiveness (bi>1) and non-significant deviation from regression line. Genotypes G13, G17 and G18 were considered suitable for poor environments with predictable performance as they exhibited high performance for grain yield along with below average responsiveness (bi<1) and non-significant deviation from regression line. Other high yielding lines (G19 and G20) have regression coefficient of less than one, they are suitable to poor environments because of their unpredictable performance due to their significant deviation from regression line. All the top five yielders demonstrated significant mean square from linear regression except G24 (75B-3) that displayed high mean value, regression coefficient value of near unit (1.022) and deviation from regression of approximately zero (0.31), indicating that the genotype is stable, widely adapted and therefore would increase performance as the productivity of environment improves. G23 (75A-3) showed regression coefficient of 1.051 (close to unit) and deviation from regression of 0.05 revealing that the genotype is stable. G23 and G24 are A/B counterparts (75A-3 and 75B-3) possessing wide adaptation with stable performance across the test environments. The two lines can be utilized as parental lines for the development of single cross hybrids in view of their stability and high mean values. This finding is in agreement with Ezeaku and Angarawai (2006), who found that pearl millet hybrid produced with 75A-3/75B-3 possessed superior grain yield. The report of Angarawai et al. (2004) revealed that male sterile line (75A-3) produced high grain yield and was one of the lines least affected by downy mildew.

ZATIB (check) showed regression coefficient value of

Table 6. Mean values for yield and yield components of 25 pearl millet parental lines across five locations.

Traits	Babura	Minjibir	Panda	Bagauda	Samaru	CV(%)
Stand count	17.9[a]	20.0[b]	16.2[c]	13.4[d]	12.1[d]	26.77
50% flowering (days)	52[e]	60[c]	67[a]	66[b]	54[d]	6.14
Downy mildew score	1.29[b]	1.72[a]	1.22[b]	1.05[c]	1.64[a]	28.52
Striga count	1.20[a]	1[b]	1[b]	1[b]	1[b]	15.03
Plant height (cm)	176.52b[c]	196.60[ab]	164.17[c]	173.57[bc]	216.77[a]	38.85
Panicle length (cm)	32.2[b]	31.92[b]	33.45[b]	32.52[b]	36.32[a]	18.42
Head weight (kg ha^{-1})	2216.8[c]	2597.5[b]	1207.4[d]	1158.2[d]	2951.5[a]	33.99
Grain yield (kg ha^{-1})	1440.77[b]	1504.4[b]	784.88[c]	752.79[c]	1669.11[a]	35.57

Mean values having similar letter(s) are not significantly different at 5% level of probability according to Duncan Multiple Range Test.

1.006, which is closer to unity and deviation from regression of near zero (0.2). Considering the criteria of stability, ZATIB showed stability in yield across the five locations when compared to the rest of the genotypes. Tollenaar and Lee (2002) reported that high yielding maize hybrids can differ in yield stability and that yield stability and high grain yield are not mutually exclusive. Regression coefficient for grain yield across locations ranged from 0.456 to 1.362. The result further showed that 14 out of 25 pearl millet parental lines gave regression coefficient values greater than one, indicating that these lines responded to favorable environment and can produce higher yields when provided with suitable environments. On the other hand, the rest 11 lines with regression coefficient less than one responded to all environments and possess wider adaptation to varying environmental conditions. Tollenaar and Lee (2002) reported significant differences among high yielding maize hybrids for their yield stability. Gama and Hallauer (1980) detected significant hybrid x environment interaction for maize hybrids while some were reported to be stable when both stability parameters were considered. Kang and Gorman (1989) and Vulchinokova (1990) also reported significant GxE interactions for different traits of maize.

The values of yield and yield components across test locations are shown in Table 6. The result showed significant differences in response of these characters to changes in environments. Plant height, panicle length, head weight and grain yield were prominently expressed in Samaru location with the values significantly higher in this location than other locations. The rest characters varied across the locations. The differential response of various characters sampled to changing environmental conditions was also manifested in the significant genotype x environment interactions as observed earlier in this study. The lowest coefficient of variation (CV%) was observed for days to 50% flowering (6.14%), *striga* count (15.03%), panicle length (18.42%) indicating the highest precision by which they were measured and also suggest less influence by environments compared to other traits. The highest CV% was recorded for plant height (38.85%), an indication of less precision by which it was recorded as well as higher influence by the environmental variations.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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