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Genotype×environment interaction and stability analysis of soybean genotypes for yield and yield components across two locations in Nigeria

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A multilocational evaluation of 20 soybean genotypes was conducted in two distinct locations (Nsukka in Derived Savanna agro-ecology and Jalingo in northern Guinea Savanna) of Nigeria in 2015 and 2016 cropping seasons. The main objective of this study was to assess the genotype-by-environment interaction (G x E) for specific traits such as number of pods, pod weight, seed yield and yield stability. The results revealed highly significant differences among the genotypes and locations for all the traits except for seed yield. Genotype by environment interaction was not significant for all the traits except for days to 50% flowering indicating relative consistency in time of flowering among the genotypes across the locations and year. The genotype, *Ashuku* produced the highest yield in the two locations. However, the most stable genotypes across the locations were *Dadinkowa* and *Vom* while the ideal environments were Jalingo 2016 (ENV2) and Nsukka 2016 (ENV4) which produced 14.0 and 14.5 g, respectively. Similarly, Akwanga was discriminated as the overall best genotype across the two locations.

Key words: Genotype, biplot, environment, yield stability.

INTRODUCTION

The use of stable genotypes over several environments for high yield and quality characteristics is important in many crops. When genotypes are evaluated for seed yield in multilocational experiments, wide differences are commonly observed in yield performances of the genotypes over the environments. This differential yield response of genotypes from one environment to another is called genotype by environment (G x E) interaction (Jose et al., 2017). The G x E interactions is very important to the plant breeders in developing improved varieties and the introduction of new cultivar (Yan and Kang, 2003).

The ability of a genotype to demonstrate stability over a wide range of environment and its ability to yield well relative to the productive potential of a test environment is referred to as agronomic stability. Any genotype that demonstrate consistency of performance or slight variation across environment show general adaptation (Ojo et al., 2006). In a breeding programme, genotype x environment interaction effects are of special interest for

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Table 1. Agro-ecological characteristics of the experimental sites.

Location	Nsukka	Jalingo
Latitude	06° 52’ N	08° 54’ N
Longitude	07° 24’ E	11° 22’ E
Attitude (masl)	447.26	349
Agro-ecozone	Derived savannah	Northern Guinea savannah
Soil texture	Sandy clay loam	Sandy loam
Total rainfall (mm/annum)	1393.6	1137.8
Average mean temperature (0°C)	26.0	28.0
Average RH (%)	66.6	67.6

masl = meters above sea level; RH = relative humidity

identifying adaptation targets, adaptive traits and test sides.

The stability of seed yield in different crops has been statistically evaluated through analysis of G x E interaction in genotype-adaptation trails over several environments. The effective identification of superior genotypes is generally complicated by the presence of G x E interactions. A specific genotype does not always exhibit the same phenotypic characteristics under all environments and different genotypes respond differently to a specific environment.

Soybean (*Glycine max* (L). Merrill) designated as the “miracle bean” has established its potential as an industrially vital and viable oil seed crop in Nigeria. Interest in soybean production in Nigeria has increased considerably as it has the ability to fix high amount of nitrogen, thereby permitting farmers to use less fertilizer and reduce farm cost (IITA, 2014). To satisfy the demand by producers and consumers, soybean production needs to be extended to other parts of the country that were otherwise considered unsuitable or marginal for its production (Asiegbu and Okpara, 2002). This wide agro-ecological variability is the major challenge for soybean crops resulting in high genotype x environment interaction (GEI) effect. Identification of yield contributing traits and knowledge of GE interactions along with yield stability are important for breeding new cultivars with improved adaptation to the environmental constraints prevailing in the target environments. Therefore, the objectives of this study were to assess the magnitude of G x E interactions, stability of some local cultivars as well as elite soybean genotypes and thereby identify widely and/or specifically adapted genotypes under Nigerian conditions.

MATERIALS AND METHODS

The multilocational evaluation trail was carried out in 2015 and 2016 cropping seasons at two different locations: The Teaching and Research Farm, Department of Crop Science, University of Nigeria, Nsukka (Lat.06° 52’ N and Long.07° 24’ E) and the Teaching and Research Farm, Department of Agronomy, Taraba State University, Jalingo (Lat.08° 54’ N and Long. 11° 22’ E). Twenty (20) soybean genotypes comprising fifteen (15) farmers’ cultivars and five (5) improved varieties were obtained from farmers in some soybean growing states of Nigeria and the International Institute for Tropical Agriculture (IITA), Ibadan, respectively for the research.

Experimental design

The experimental design was Alpha lattice design (Patterson and Williams, 1976), which was used for the multi-location experiment. There were 10 columns and two rows per super block replicated three times and the 20 soybean genotypes were randomly assigned to each super block. The improved varieties were of early maturity class while the farmers’ cultivars are either medium or late maturity class. Each plot or column measured 1.5 x 1 m and seeds were sown at the spacing of 15 cm between stands and 30 cm between rows, resulting in 7 plants per row and 35 plants per plot (column).

Five plants were randomly selected from the two middle rows for data collection at the maturity on days to 50% flowering, plant height and yield traits such as number of pods, pod weight (g) per plant, seed yield (g) per plant and 100 seed weight (g) per genotype at harvest.

Statistical analysis

Analysis of variance (ANOVA) statistics using general linear model (GLM G x E) of SAS version 9.5 with 5% level of significance were used. The data collected were subjected to analysis of variance and GE biplot methodology as prescribed by Marjanovic-Jerumeln et al. (2011). This methodology uses a biplot to show the factors (G and GE) that are important in genotype evaluation and that are also the sources of variation in GEI analysis of yield data.

RESULTS

The experimental sites differed in altitude, rainfall, mean temperature, relative humidity and soil texture (Table 1). Nsukka is located in the southeastern part of Nigeria while Jalingo is in northeastern part. The amounts of rainfall in 2016 in both locations were higher than those of 2015. In 2016, Nsukka had a mean rainfall of 152.98 mm against 141.04 mm in 2015. Similarly, in 2016, Jalingo had a mean rainfall of 153.94 mm against 149.14 mm in 2015. During the growing seasons, mean monthly

Table 2. Combined analysis of variance for seed yield and yield components in two years and two locations.

SV	DF	DF1	PH (cm)	NP	PW (g)	SY (g)
Year (Y)	1	39.20	999.36**	63583.17**	9208.25**	4064.80**
Location (L)	1	413.44**	752.11**	7811.29**	686.14**	156.33*
Y x L	1	63.04	1365.84**	2426.98*	516.85**	278.00**
REP (Y,L)	8	11.97	58.16*	747.42*	117.19*	65.47*
Genotype (G)	19	63.54**	240.60**	815.80**	65.73*	29.52
G x Y	19	29.04*	23.37	239.11	23.47	14.09
G x L	19	45.69*	15.61	150.84	36.79	18.62
G x Y x L	19	48.10*	31.66	279.33	37.89	17.13
Error	140	4.17	4.45	15.67	5.67	3.89

*,** = Significant at 5 and 1%, respectively, SV = source of variation, DF = degree of freedom, DF1 = days to 50% flowering, pH = plant height, NP = number of pods, PW = pod weight, SY = seed yield/plant, Y = year, L = location, G = genotype, REP= replicate

temperature was higher in Jalingo when compared to that of Nsukka; however, relative humidity was higher in 2015 than 2016 in both locations. Meanwhile, in 2016, relative humidity was higher in Jalingo (66.41%) than Nsukka (61.76%). Also, the two locations varied in soil type with the soil of Nsukka being sandy clay loam while that of Jalingo is sandy loam.

The combined analysis of variance (ANOVA) was performed to determine the effects of year (Y), location (L) and genotype (G) as presented in Table 2. Variance due to genotypes (G) were highly significant ($p<0.01$) for all the traits studied, except for pod weight. Similarly, location (L) was highly significant ($p<0.01$) for all the traits, except seed yield that was significant only at $p<0.05$. However, year (Y) effect was highly significant for all the traits with the exception of days to 50% flowering. The Y x L interactions were highly significant ($p<0.01$) for all the traits except days to 50% flowering. The G x Y interaction on the other hand were non-significant for most of the traits except for days to 50% flowering which was significant only at 5% level of probability. Also, triple interaction (G x Y x L) was found non-significant for all the traits except days to 50% flowering.

G x E is a major problem when comparing the performance of crop genotypes across environments because it reduces the efficiency of the genetic gain through selection (IITA, 2011). The mean seed yield value of genotypes averaged over environments (Table 4) indicated that the genotypes "*Ashuku*" and "*Akwanga*" had the highest and lowest seed yield of 13.0 and 8.5 g, respectively. The environments mean seed yield ranged from 4.1 g (ENV3) to 14.5 g (ENV4) and averaged seed yield over environments and genotypes is 10.1 g. ENV4 and ENV2 showed the most favorable performance for seed yield (14.5 and 14.0 g, respectively) and are rich environments. ENV3 and ENV1 were unfavorable since they presented the lowest mean for seed yield (4.1 and 7.9 g, respectively).

The best genotype across the two locations in terms of seed yield per plant is *Akwanga*. It performed best in ENV1 when compared to the other environments (Figure 1). However, the genotype *Gwantu* is the most stable genotype across the two locations. Also, *Lau* was found to be the closest to *Akwanga* in terms of seed yield per plant. As graphically revealed on the biplot, the most stable environment for the genotypes performance in terms of seed yield is ENV3 which is very close to the horizontal axis that divides the graph into the poorest (below average and the best (above average).

The general mean performance of the genotypes across the two locations revealed that *Akwanga* is leading by its impressive performance in ENV4 (Figure 2) among all the environments. On the other hand, *Dadinkowa* and *Vom* were the most stable genotypes due to their proximity to the horizontal axis. These genotypes were closely followed by *Kagoro*, *Mangu* and TGX1485-ID, respectively. The most stable environment for mean performance of the twenty soybean genotypes is ENV1 and is closely followed by ENV3.

DISCUSSION

Combined analysis of variance (ANOVA) for seed yield and yield components showed highly significant variations among environments (L) and genotypes (G) but without similar variations in genotype x environment (G x E) interaction in most of the traits with the exception of days to 50% flowering ($p< 0.05$). Significant variations were observed for days to 50% flowering among the genotypes across the locations indicating the existence of variability in the source of the genotypes. The result showed that, both the genotypes and the environmental conditions had significant influence on the yield and yield components performance of the soybean. Adugna and Labuschgne (2003) also reported significant variations among locations for days to 50% flowering in linseed. In Jalingo, soybean genotypes were taller, had more branches with longer root lengths and higher fresh and dry root weights than those in Nsukka. Similarly, seed yield and yield

Table 3. Mean of quantitative characters of 20 soybean genotypes from two locations.

Genotype	DF (50%)	PH (cm)	NP	PW (g)	SY (g)	100 seed weight (g)
	(NSK/JAL)					
Agbon kagoro	43.17±45.67	25.42±29.84	35.66±37.29	12.33±12.33	8.10±7.08	12.50±14.00
Akwanga	42.14±44.64	29.10±33.21	54.69±63.55	20.09±25.02	12.44±16.58	14.00±13.50
Andaha	44.90±46.90	29.79±32.12	44.67±53.87	14.84±21.34	8.57±13.65	12.00±12.00
Ashuku	43.97±44.81	32.65±39.25	63.99±79.92	22.09±27.89	14.21±18.88	13.00±13.50
Dadinkowa	45.28±46.28	29.63±31.87	38.43±40.36	12.13±16.03	8.07±10.32	14.00±13.00
Garkawa	42.00±45.00	33.32±37.06	48.29±59.06	15.93±19.70	10.78±13.50	14.00±13.00
Gwantu	43.97±44.47	30.10±34.56	46.09±56.22	16.22±20.72	10.98±13.61	12.00±13.00
Kafanchan	42.48*±48.32*	30.18±31.76	43.62±54.18	14.24±21.54	9.37±14.56	13.50±12.00
Kagoro	43.44±44.61	31.67±37.63	52.70±57.76	15.56±19.46	11.43±13.59	9.50±14.50
Langtang	46.44*±50.28*	29.13±32.30	50.43±55.96	21.90±24.46	14.50±16.48	11.50±12.50
Lau	50.51±52.01	30.56±37.03	57.20±74.84	20.57±25.37	12.54±16.89	10.50±13.00
Mangu	42.47±44.64	34.18±38.35	60.45±67.42	22.62±25.46	14.20±16.85	14.50±14.00
Mararaba	45.44±46.61	30.27*±38.00*	49.16±59.96	14.56±18.86	9.70±13.45	13.50±13.00
TGX1485-ID	38.73±40.37	31.82±30.32	53.07±51.43	19.68±20.54	12.21±12.95	14.00±14.00
TGX1448-2E	40.37*±44.37*	34.94±38.67	47.28±72.08	12.81*±22.35*	8.13*±14.59*	14.50±13.50
TGX1987-10F	41.57±43.71	31.52±34.35	38.83±54.20	17.98±23.11	10.51±15.41	15.50±15.00
TGX1835-10E	39.21*±43.71*	31.44±33.01	41.68±47.28	14.88±17.41	10.80±11.59	13.00±14.50
TGX1987-62F	47.87±48.64	35.94±41.83	42.44±65.65	13.45±21.74	8.50±14.97	12.00±13.00
Tiv local	41.23±42.73	33.29±36.22	50.77±68.30	18.18±24.78	11.44±16.65	15.00±13.00
Vom	56.07±54.73	49.85±53.35	76.20±86.77	21.98±23.18	12.47±14.68	9.50±11.00
LSD(0.05)	3.83	6.69	24.90	9.27	6.35	5.70

DF = Days to 50% flowering, PH = plant height, NP = number of pods, PW = pod weight/plant, SY = seed yield, NSK = Nsukka, JAL= Jalingo, LSD= least significant difference.

components such as number of pods and pod weight were higher in Jalingo than Nsukka. The low yield in Nsukka location may be as a result of the soil nature which is sandy clay loam with pH of 4.9 whereas Jalingo soil is sandy loam with pH 6.0. However, genotypes had more leaves in Nsukka location even though the difference is of no statistical significance. In Jalingo location, elite varieties such as TGX1448-2E, TGX1987-10F and TGX1987-62F had a fairly impressive yield performance that compared favorably with *Ashuku* and that had the highest yield in both locations. In Nsukka location, despite the poor performance of all the genotypes, TGX1987-10F still compared with *Ashuku* statistically. Non-significance of genotype × environment and genotype × year for traits such as plant height, number of pods, pod weight and seed yield indicated the relative consistency in performance of the genotypes across the two locations and years. This implies that in any of the two locations, the same genotype will have the same plant height, number of pods, pod weight and seed yield. The findings are in agreement with the report of Ojo et al. (2010) who recorded non-significance of genotype × year interaction in plant height, as well as number of pods and seed yield in soybean. Highly significant variations were observed for most of the parameters studied among the genotypes across the environments indicating the existence of variability among the soybean genotypes.

However, any genotype that demonstrates consistency of performance or little variation across the environments is said to be generally adapted. In this study, most genotypes revealed little variation in performance across the two locations (Table 3). Significant ($p<0.05$) variation was observed in pod weight per plant and seed yield per plant in TGX1448-2E. The study also revealed that most of the genotypes showed little variation in performance across the two locations. With particular interest to note is TGX1485-1D that recorded the same value for 100 seed weight (14.00 g) across the two locations. This consistent or little variation in performance of a genotype across the environments showed general adaptation as observed by Adeseye et al. (2018). It was also observed that there were variations between the two locations with respect to days to flowering especially in Kafanchan, Langtang, TGX1448-2E and TGX1835-10E. Similar findings were obtained by Yan and Tinker (2006), and Jese et al. (2017) who reported variation between two locations in respect to days to flowering in cowpea. Likewise, there was variation between the two locations with respect to plant height particularly in Mararaba. In the same vein, there were variations between the locations with respect to pod weight and seed yield in TGX1448-2E. The purpose of stability analysis is to identify soybean

Table 4. Mean of soybean seed yield evaluated in the 4 environments.

Genotype	Environment				Mean
	ENV 1	ENV 2	ENV 3	ENV 4	
ANDAHA	5.5	11.5	2.4	5.0	6.1
AGBON KAGORO	**11.9**	13.4	3.4	**19.6**	12.1
AKWANGA	5.1	10.5	3.9	14.5	8.5
ASHUKU	9.8	19.0	4.4	18.6	13.0
DADINKOWA	6.9	10.9	4.2	12.3	8.6
GARKAWA	4.9	17.4	3.5	10.9	9.2
GWANTU	6.5	14.9	3.7	12.1	9.3
KAFACHAN	7.3	11.9	3.2	17.7	10.0
KAGORO	10.5	14.0	4.6	15.7	11.2
LANGTANG	7.3	**23.3**	4.3	12.2	11.8
LAU	10.7	13.6	4.1	18.0	11.6
MANGU	**11.9**	16.9	4.4	16.7	12.5
MARARABA	7.3	13.7	4.1	15.7	10.2
TGX1485-1D	3.4	12.5	5.1	17.0	9.5
TGX1835-10E	10.9	11.9	4.0	11.7	9.6
TGX1987 -10F	7.2	14.0	3.9	9.5	8.7
TGX1448-2E	6.8	12.6	4.9	15.9	10.1
TGX1987-62F	5.8	10.8	4.7	17.4	9.7
TIV LOCAL	7.1	14.1	**6.1**	16.8	11.0
VOM	10.8	12.5	3.5	12.9	10.0
Mean	7.9	14.0	4.1	14.5	10.1

ENV1 = Jalingo 2015, ENV2 = Jalingo 2016, ENV3 = Nsukka 2015, ENV4 = Nsukka 2016

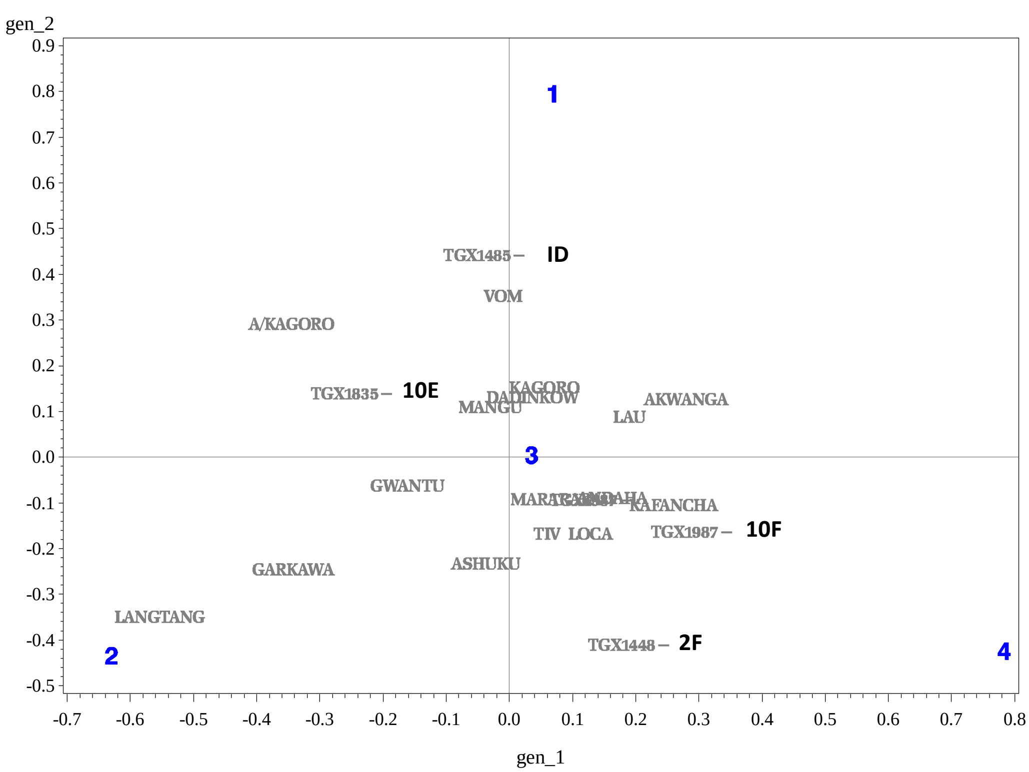

Figure 1. Biplot of G*E interaction: for seed yield.

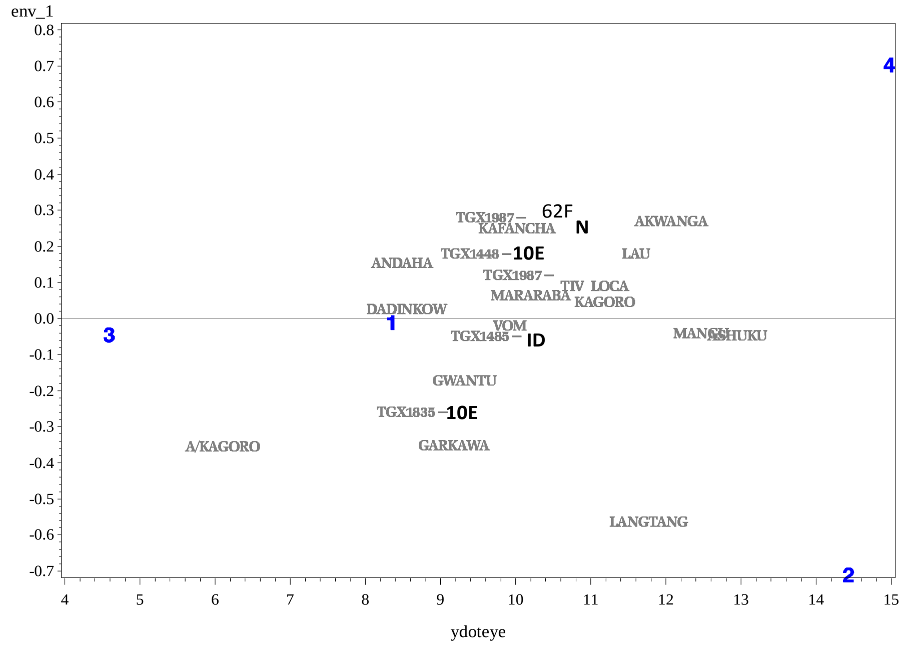

Figure 2. Biplot of first E*Vector vs Means.

genotypes with wide geographic adaptation, high agronomic performance and high seed yield (preferably above the overall mean of 10.1 g) as observed in this study in heterogeneous environments. The identification of genotypes with specific adaptations can be extremely useful for more regionalized genotypic recommendations.

Based on mean performance of the genotypes, the environments were classified into three mega environments. The first include ENV1 and ENV4 with genotype *Akwanga* having the highest seed yield and was joined by *Mangu* only in ENV1. The second mega environment is ENV2 in which *Langtang* performed the best. The third mega environment is ENV3 with *Tiv local* as the outstanding genotype. The superiority of mega environments formed from the mean seed yield can be attributed to the portion of noise incorporated into estimates of raw data as reported by Silveira et al. (2013).

The results of biplot showed that *Akwanga* performed very well in the overall performance and was closely followed by *Lau*. However, *Dadinkowa* and *Vom* were the most stable genotypes across the two locations. Also, the biplot result identified ENV1 and ENV3 as the ideal environments across the two locations. Therefore, the use of GGE in this study has not only identified the most stable genotypes across locations but is also able to identify the locations that optimize the genotypes performance as confirmed by Agyeman et al. (2015).

CONCLUSIONS AND RECOMMENDATION

Crop yield is a complex trait that is influenced by a number of component characters along with the environment either directly or indirectly. The G × Y and G × L effects were not significant for most of the traits indicating general adaptation of the genotypes across the locations. However, the study is able to identify the most stable genotypes and the ideal environments across the locations that optimize the genotypes performance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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