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Full Length Research

Screening for yield and pod shattering resistance stabilities in soybean [*Glycine max* (L.) Merril] genotypes in Nigeria

Ngwu, C. H.*, Gana, A. S., Tolorunse, K. D., and Mamudu, A. Y.

Department of Crop Production, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria.

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ABSTRACT: Yield and pod shattering resistance stabilities for twenty-six (26) soybean genotypes were evaluated across three locations in Nigeria. In each location, the experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. At harvest, pod shattering evaluation was done using the sun-dry method. Data were collected on seed yield and pod shattering percentage and analyzed using Analysis of Variance (ANOVA), Additive Main Effect and Multiplicative Interaction (AMMI) and Genotype plus Genotype × Environment Interaction (GGE) bi-plot analyses. Out of the 26 soybean genotypes screened, seven (NCRI SOYAC20, NCRI SOYAC22, NCRI SOYAC7, NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC69, and NCRI SOYAC28) were identified to produce high and stable yield across environments; five genotypes (NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC7, NCRI SOYAC17, and NCRI SOYAC69) produced stable pod shattering resistance across environments. Therefore, only four (NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC69 and NCRI SOYAC7) were stable in both high yield and resistance to pod shattering. These four genotypes are recommended as donor parents in breeding of soybean varieties with both stabilities in high yield and pod shattering resistance across environments. Also, the four genotypes are recommended for large scale soybean production in order to ensure adequate production and food security.

Keywords: Screening, shattering, soybean, stability, yield.

INTRODUCTION

Soybean (*Glycine max* (L) Merril) has become a valuable crop in Nigerian agricultural system as a result of its high quality protein supply (Akande *et al*., 2009), and rich domestic oil (Ikeogu and Nwofia, 2013). The production of this crop in Nigeria is due to its high adaptability and predominant utilization as a food crop for human, source of protein for animal nutrition; as medicinal and industrial crop. However, the cultivation of this crop in Nigeria has been faced with some challenges including pod shattering and yield instability across production areas of the country.

*Corresponding author: Email: hilarychukwudi@gmail.com; Tel: +2348035337753.

Soybean is largely produced in the middle belt of Nigeria. However, its production in recent years has extended beyond these traditional areas to cover other Northern and Southern regions of Nigeria, which were otherwise considered to be unsuitable or marginal for production (Ikeogu and Nwofia, 2013).

Pod shattering is the opening of matured pods along the dorsal or ventral sutures of the soybean pod and subsequent seed dispersal as the crop reaches maturity, as well as during harvest, resulting in seed loss (Bhor *et al*., 2014). In susceptible varieties, wind disturbances could result in pod shattering even before harvest or during harvest as the harvesting implement move through the crop in dry weather conditions. Pod shattering in soybean may result to a yield loss that ranges from 34 to 100% (Tefera *et al*., 2009). It could be caused by some factors like; the time of harvesting after maturity, environmental conditions, chemical composition of the pod wall; anatomical structure of the pod, and genetic factor of the variety (Krisnawati and Adie, 2017). In the major soybean production areas of Nigeria, the crop reaches maturity at the end of October or early November. Coincidentally, this is the period of rainfall cessation and the beginning of dry harmattan wind, with low relative humidity and rising temperatures, creating a suitable condition for pod shattering.

Another major constraint to effective soybean production in Nigeria is yield instability associated with the crop across environments (Ikeogu and Nwofia, 2013). Also, the inability of some soybean genotypes to maintain resistance to pod shattering across environments is a thing of concern to both soybean farmers and breeders. Stability has been defined as the tendency of a crop to maintain its performance across environments (Cucolotto *et al*., 2007). Good performance of stable genotypes is less dependent upon favourable environments, which makes their yield more predictable (Baiyeri and Nwokocha, 2001).

Thus, the aim of this study is to identify high yielding stable soybean genotypes that are resistant to pod shattering for production and breeding purposes.

MATERIALS AND METHODS

Twenty-six (26) soybean genotypes were selected and they include; NCRI SOY AC3, NCRI SOY AC7, NCRI SOY AC9, NCRI SOY AC10, NCRI SOY AC17, NCRI SOY AC18, NCRI SOY AC20, NCRI SOY AC22, NCRI SOY AC24, NCRI SOY AC25, NCRI SOY AC26, NCRI SOY AC28, NCRI SOY AC29, NCRI SOY AC61, NCRI SOY AC62, NCRI SOY AC63, NCRI SOY AC64, NCRI SOY AC65, NCRI SOY AC67, NCRI SOY AC68, NCRI SOY AC69, NCRI SOY AC73, NCRI SOY AC75, NCRI SOY AC76, NCRI SOY AC77, and NCRI SOY AC78. The study was conducted in three locations across Nigeria in 2019 cropping season.

The first location was at Upper Niger River Basin Development Authority (UNRBDA) farm in Minna, Niger State (latitude 9.6737ºN, longitude 6.5109ºE); the second was at UNRBDA farm in Chinka, Kaduna State (latitude 9.0535ºN, longitude 7.3026ºE); while the third location was at the Teaching and Research Farm of the Department of Crop Science and Horticulture, Nnnamdi Azikiwe University, Awka, Anambra State (latitude 6.3437ºN, longitude 7.0938ºE).

Randomized Complete Block Design (RCBD) with three (3) replications was used in each location. The gross plot size was 3 x 2 m = 6 m^2; giving 4 ridges of 2 m long each. The net plot size was 1.5 x 2 m = 3 m^2; to give 2 ridges of 2 m long each. Along each replication, gross plots were separated by a distance of 0.5 m, while 1 m distance separated one replication from the other. The total experimental area was 65 x 11 m = 715 m^2.

Three (3) soybean seeds were sown per hill and later thinned down to one plant per stand. The planting distance used was 75 × 20 cm between and within rows, respectively. This gave a plant population of 66,667 plants ha^{-1}. Single super phosphate (SSP) was applied at the rate of 40 kg/ha at 2 weeks after planting. Weeds were controlled manually using hoe, at 2 and 6 weeks after planting. Insects were properly controlled with a single spray of Cypermethrin plus Dimethoate 10 EC at the rate of 100 ml in 15 l of water, as recommended by Dugje *et al.* (2009).

Seed yield was taken during harvest after threshing the pods from the net plot and weighed in kg and converted to ton/ha.

Pod shattering identification was done using sun-dry method as described by Krisnawati and Adie (2016). Five plants were sampled per plot and four pods harvested from each plant; giving a total of 20 pods. The harvest was done when about 95% of the pods turned brown. These pods were placed inside brown envelops and sun-dried for seven days. On the 7th day, the number of shattered pods were counted and calculated in percentage. Pod shattering resistance or susceptibility of the genotypes was determined using the Table 1.

To determine the effect of genotype by environment interaction (GEI) and stability on yield and pod shattering, the data collected were subjected to Additive Main Effect and Multiplicative Interaction (AMMI) using the Breeding View of Breeding Management System (BMS); version 3.0.9 (Murray *et al*., 2015).

The ANOVA model is $Y_{ij.} = \mu + g_i + e_j + ge_{ij} + \varepsilon_{ij.}$

The AMMI model is $Y_{ij.} = \mu + g_i + e_j + \sum \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij.}$

Where Y_{ij} is the mean of the *i*th line in the *j*th environment, μ is the grand mean, g_i is the genotype effect, e_j is the location effect, λ_k is the singular value for principal components k, α_{ik} is the eigenvector score for genotype i and component k, γ_{jk} is the eigenvector score for environment j and component k, and $\varepsilon_{ij.}$ is the error for genotype i and environment j.

The result of the AMMI model analysis was interpreted by a biplot between Principal Component (PC) Axis 1 versus PC Axis 2.

Genotype plus Genotype × Environment Interaction (GGE) bi-plot analysis was used to show “which-won-where”; that is the best genotype in each environment and it summarizes the GEI pattern of a multi environment yield trial data. GGE biplot is a graphical tool that displays, interprets and explores two important sources of variation, namely genotype main effect and GE interaction of MET data (Fan *et al*., 2007).

Table 1. Pod shattering scoring rate.

Score	Description	Category
1	No pod shattering	Very resistant
2	< 25% pod shattering	Resistant
3	25 - 50% pod shattering	Moderately Resistant
4	51 - 75% pod shattering	Highly susceptible
5	> 75% pod shattering	Very highly susceptible

Source: Krisnawati and Adie (2017).

Table 2. Mean seed yield of soybean genotypes across the three locations (ton/ha).

Genotype	Minna	Chinka	Awka	Mean
NCRI SOYAC78	1.7	1.37	1.27	1.45
NCRI SOYAC18	1.7	1.23	1.5	1.48
NCRI SOYAC17	1.53	1.1	0.97	1.2
NCRI SOYAC69	1.5	1.5	0.97	1.32
NCRI SOYAC77	2.37	1.73	0.23	1.44
NCRI SOYAC73	1.87	1.37	0.83	1.36
NCRI SOYAC26	1.67	1.63	1.4	1.57
NCRI SOYAC29	1.63	1.33	1.07	1.34
NCRI SOYAC25	1.7	1	1.1	1.27
NCRI SOYAC28	1.83	1.4	1.17	1.47
NCRI SOYAC64	1.27	1.4	1.5	1.39
NCRI SOYAC65	1	0.9	0.67	0.86
NCRI SOYAC24	1.17	1.13	0.93	1.08
NCRI SOYAC3	1.6	1.1	0.97	1.22
NCRI SOYAC9	1.5	1.3	1.46	1.42
NCRI SOYAC7	1.57	1.27	1.1	1.31
NCRI SOYAC68	1.47	1.2	0.83	1.17
NCRI SOYAC20	1.5	1.43	1.1	1.34
NCRI SOYAC62	1.47	1.3	0.8	1.19
NCRI SOYAC63	1.2	1.43	1.1	1.24
NCRI SOYAC75	1.33	1.27	0.7	1.1
NCRI SOYAC10	1.27	1.23	1.23	1.24
NCRI SOYAC67	1.33	1.1	1.07	1.17
NCRI SOYAC76	1.7	1.37	1	1.36
NCRI SOYAC61	1.6	1.6	0.97	1.39
NCRI SOYAC22	1.67	1.2	1.13	1.33
Mean	1.54	1.3	1.04	1.3

RESULTS AND DISCUSSION

Seed yield

The seed yield of the 26 soybean genotypes across the three locations ranged from 0.86 to 1.57 tons/ha (Table 2). Sixteen genotypes gave higher seed yield than the grand mean (1.30 tons/ha). The environments' seed yield ranged from 1.04 tons/ha in Awka to 1.54 tons/ha in Minna (Table 2).

The regression coefficient (b) and the mean values for seed yield, for the 26 soybean genotypes over three

Table 3. Sensitivity and stability coefficients for seed yield from soybean genotypes across three environments.

Genotype	Sensitivity (b value)	Mean	Static Stability	Mean square Deviation
NCRI SOYAC78	0.819	1.45	0.0506	0.01586
NCRI SOYAC18	0.303	1.48	0.0556	0.09955
NCRI SOYAC17	1.067	1.2	0.0859	0.02696
NCRI SOYAC69	1.109	1.32	0.0936	0.03062
NCRI SOYAC77	4.322	1.44	1.2065	0.03497
NCRI SOYAC73	2.054	1.36	0.2705	0.00391
NCRI SOYAC26	0.555	1.57	0.0212	0.00321
NCRI SOYAC29	1.098	1.34	0.0785	0.00344
NCRI SOYAC25	1.084	1.27	0.1433	0.13702
NCRI SOYAC28	1.276	1.47	0.1122	0.0172
NCRI SOYAC64	-0.45	1.39	0.0133	0.00088
NCRI SOYAC65	0.666	0.86	0.0286	0.00077
NCRI SOYAC24	0.492	1.08	0.0165	0.00219
NCRI SOYAC3	1.196	1.22	0.1106	0.03916
NCRI SOYAC9	0.035	1.42	0.0112	0.02225
NCRI SOYAC7	0.91	1.31	0.0566	0.00781
NCRI SOYAC68	1.273	1.17	0.1032	0.00006
NCRI SOYAC20	0.82	1.34	0.0456	0.00566
NCRI SOYAC62	1.361	1.19	0.1213	0.00692
NCRI SOYAC63	0.266	1.24	0.0286	0.04828
NCRI SOYAC75	1.304	1.1	0.1209	0.02538
NCRI SOYAC10	0.074	1.24	0.0005	0.00037
NCRI SOYAC67	0.488	1.17	0.0202	0.01017
NCRI SOYAC76	1.384	1.36	0.1226	0.00135
NCRI SOYAC61	1.319	1.39	0.1323	0.04327
NCRI SOYAC22	1.015	1.33	0.0862	0.04131

environments are presented in Table 3. The b value is the genotypic sensitivity to changes in the environmental conditions. Values of b>1 means genotypes with a higher than average sensitivity and less stable, while b<1 means genotypes that are less sensitive and more stable.

Table 3 shows that the genotype with the least sensitivity to changes in environment was NCRI SOYAC64, as it had the lowest b value (-0.450). This genotype also had mean seed yield (1.39 ton/ha) greater than grand mean (1.30 ton/ha). Therefore, among the genotypes, NCRI SOYAC64 is considered the most stable with high yield. However, six other genotypes (NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC26, NCRI SOYAC9, NCRI SOYAC7, and NCRI SOYAC20), had low sensitivity to changes in the environments (b<1) with above average seed yield.

Although NCRI SOYAC18 and NCRI SOYAC26 performed better than NCRI SOYAC78 in the mean performance, NCRI SOYAC78 is superior to both NCRI SOYAC18 and NCRI SOYAC26 in the high quality environments. This is due to the fact that NCRI SOYAC78 has a better capacity to exploit improved environmental conditions, which is reflected in its higher genotypic sensitivity. Similar result was obtained by Ishaq *et al*. (2015). All the high yielding and low sensitive genotypes also produced high static stability, which is the ability to give same performance across environments (Table 3).

In the AMMI bi-plot (Figure 1), the difference among genotypes in terms of direction and magnitude along the X-axis (yield) and Y-axis (IPCA 1 scores) are provided. It makes use of the main effect and the First Principal Component Scores of Interactions (IPCA1) of both genotypes and environments. In the bi-plot, genotypes or environments that are located almost on the perpendicular line of the graph have similar seed yields and those that appear almost on the horizontal line have similar

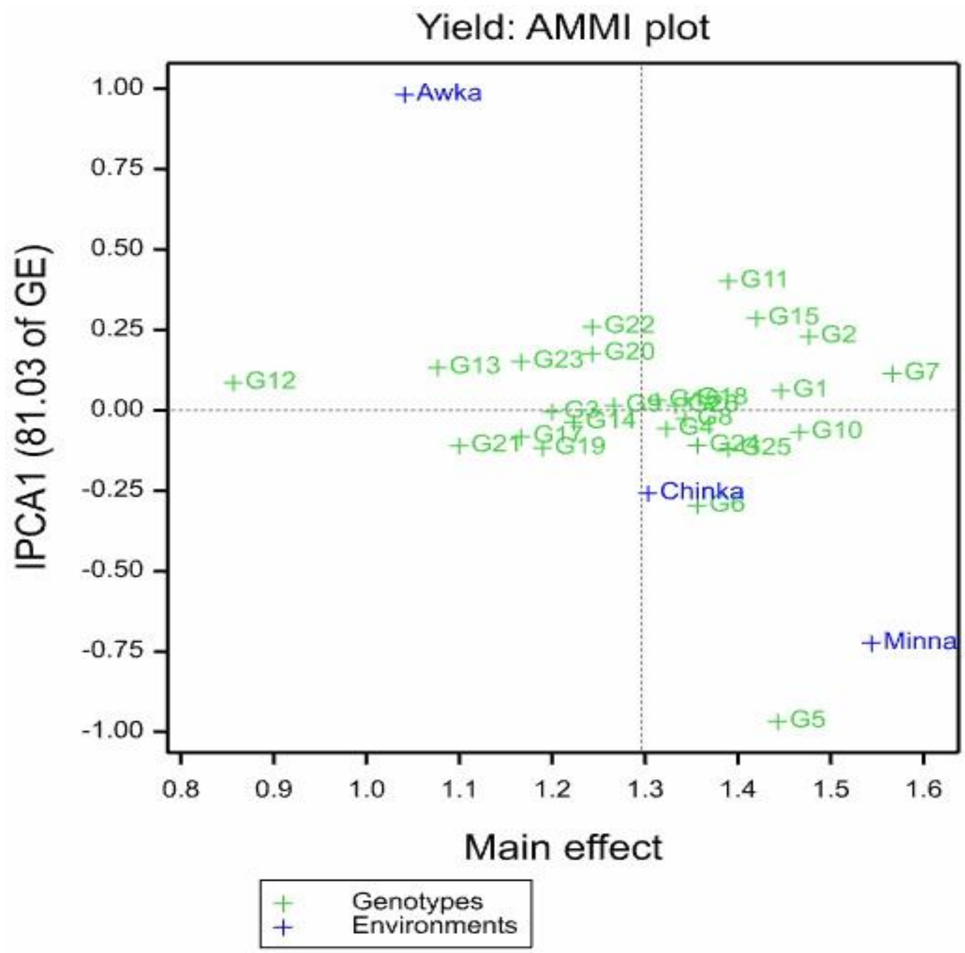

Figure 1. Yield AMMI bi-plot for the soybean genotypes across three locations (1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22).

interaction (Ishaq *et al*., 2015). Therefore, environments provided greater variability than genotype differences. Genotypes or environments that are located at the right side of the midpoint of the perpendicular line have higher yields than those on the left side. The genotypes NCRI SOYAC78 (coded 1), NCRI SOYAC18 (coded 2), NCRI SOYAC69 (coded 4), NCRI SOYAC77 (coded 5), NCRI SOYAC73 (coded 6), NCRI SOYAC26 (coded 7), NCRI SOYAC29 (coded 8), NCRI SOYAC28 (coded 10), NCRI SOYAC64 (coded 11), NCRI SOYAC9 (coded 15), NCRI SOYAC7 (coded 16), NCRI SOYAC20 (coded 18), NCRI SOYAC76 (coded 24), NCRI SOYAC61 (coded 25), NCRI SOYAC22 (coded 26) recorded high yields. In contrast, NCRI SOYAC65 (coded 12), NCRI SOYAC24 (coded 13), NCRI SOYAC67 (coded 23), NCRI SOYAC63 (coded 20), NCRI SOYAC10 (coded 22), NCRI SOYAC17 (coded 3), NCRI SOYAC25 (coded 9), NCRI SOYAC3 (coded 14), NCRI SOYAC75 (coded 21), NCRI SOYAC68 (coded 17), and NCRI SOYAC62 (coded 19) were low yielding.

According to Egesi and Asiedu (2002), genotypes or environments that have large negative or positive IPCA1 scores have high interactions, while the ones with scores close to zero (near the horizontal line) have little interaction across environments and are considered to be more stable than those that are further away from the line. In the bi-plot, NCRI SOYAC20 (coded 18), NCRI SOYAC22 (coded

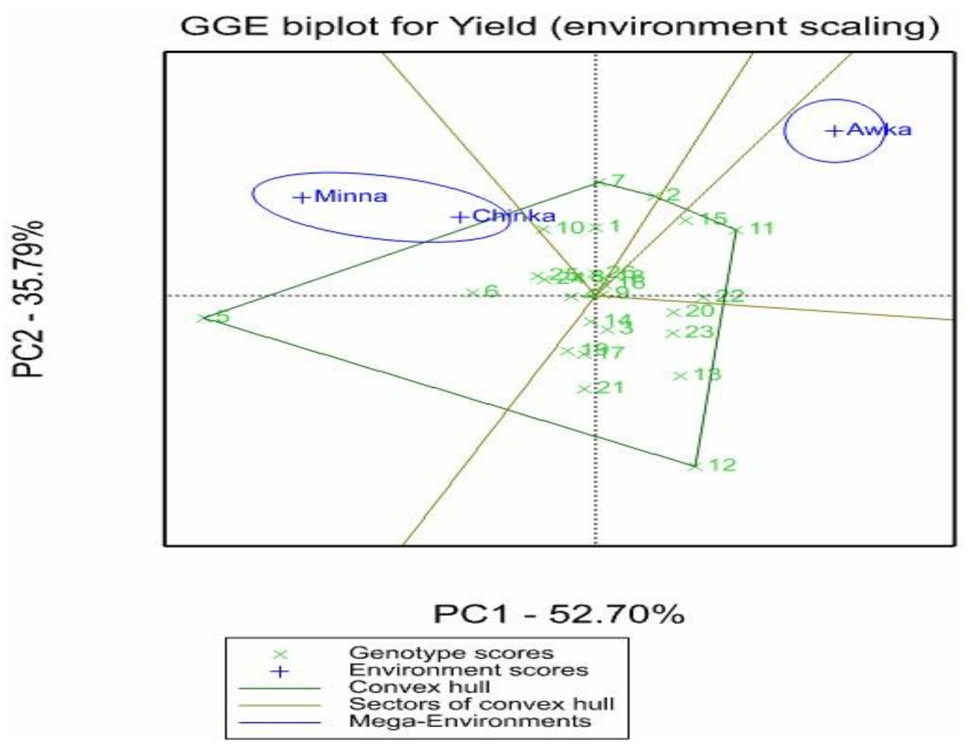

Figure 2. GGE biplot for best genotypes in different environments for seed yield (1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22).

26), NCRI SOYAC7 (coded 16), NCRI SOYAC78 (coded 1), NCRI SOYAC29 (coded 8), NCRI SOYAC69 (coded 4), and NCRI SOYAC28 (coded 10) are very close to the horizontal line near the zero point on IPCA1. Since these genotypes are located on the right side of the midpoint of the perpendicular line, they produced high and stable yield. Genotypes NCRI SOYAC26 (coded 7), NCRI SOYAC18 (coded 2), NCRI SOYAC9 (coded 15), NCRI SOYAC64 (coded 11), NCRI SOYAC76 (coded 24), NCRI SOYAC61 (coded 25), and NCRI SOYAC73 (coded 6) were a little far away from the horizontal line, meaning that the genotypes were high yielding but relatively unstable. Genotypes like NCRI SOYAC17 (coded 3), NCRI SOYAC3 (coded 14) and NCRI SOYAC25 (coded 9) were also stable but low yielding (located at the left side). The most unstable genotype was NCRI SOYAC77 (coded 5), while the poorest in yield was NCRI SOYAC65 (coded 12). In terms of environment, Chinka was the most stable, as it produced the least interaction score, while Minna and Akwa in that order were relatively unstable, producing highest interaction scores. Effective selection will be obtained in a stable environment like Chinka as the performance of the genotypes will be relatively uniform.

The polygon view of the GGE bi-plot (Figure 2) shows “which-won-where”; that is the best genotype in each environment and it summarizes the GEI pattern of a multi environment yield trial data. The polygon is formed by connecting the genotypes located further away from the origin of the bi-plot such that all other genotypes are contained within the polygon. A perpendicular line starting from the origin is drawn to each side of the polygon and extended beyond the polygon so that the bi-plot is divided into several sectors, and the different environments were separated into different sectors. The genotype at the vertices of each sector is the best performer at environment(s) included in that sector, provided that GGE is sufficiently approximated by PC1 and PC2. Hence, though there were five sectors in all, two environments were identified; with Minna and Chinka grouped as one environment, having NCRI SOYAC77 (coded 5), NCRI

Table 4. Mean pod shattering percentage of soybean genotypes across the three locations.

Genotype	Minna	Chinka	Awka	Mean
NCRI SOYAC78	23.33	15	16.67	18.33
NCRI SOYAC18	36.67	23.33	28.33	29.44
NCRI SOYAC17	17	11.67	18.33	15.67
NCRI SOYAC69	27.67	16.67	16.67	20.34
NCRI SOYAC77	0	15	11.67	8.89
NCRI SOYAC73	16.67	3.33	15	11.67
NCRI SOYAC26	16.67	21.67	21.67	20
NCRI SOYAC29	11.67	3.33	10	8.33
NCRI SOYAC25	20.33	16.67	23.33	20.11
NCRI SOYAC28	32	18.33	30	26.78
NCRI SOYAC64	30	10	26.67	22.22
NCRI SOYAC65	39	21.67	31.67	30.78
NCRI SOYAC24	26.67	8.33	23.33	19.44
NCRI SOYAC3	13.33	15	18.33	15.55
NCRI SOYAC9	23.33	21.67	23.33	22.78
NCRI SOYAC7	8.33	1.67	10	6.67
NCRI SOYAC68	26.67	3.33	25	18.33
NCRI SOYAC20	21.67	10	21.67	17.78
NCRI SOYAC62	28.33	11.67	28.33	22.78
NCRI SOYAC63	90	90	88.33	89.44
NCRI SOYAC75	28.33	5	21.67	18.33
NCRI SOYAC10	25.67	5	21.67	17.45
NCRI SOYAC67	25	25	21.67	23.89
NCRI SOYAC76	0	5	5	3.33
NCRI SOYAC61	28.33	21.67	28.33	26.11
NCRI SOYAC22	3.33	21.67	16.67	13.89
Mean	23.85	16.22	23.21	21.09

SOYAC73 (coded 6), NCRI SOYAC61 (coded 25), NCRI SOYAC76 (coded 24) and NCRI SOYAC69 (coded 4) as the best genotypes (winning genotypes) in this environment. The best genotypes for the second environment (Awka) were NCRI SOYAC9 (coded 15), NCRI SOYAC64 (coded 11), NCRI SOYAC10 (coded 22), and NCRI SOYAC25 (coded 9). The remaining sectors have no environment within them, thus the genotypes they contain were not the highest yielding at any environment. This suggests that Minna and Chinka had similar environmental conditions; while Awka was distinct. Similar result was reported by Ishaq *et al*. (2015); where out of five (5) environments studied, three were group into one, while the other two were distinct.

Pod shattering

The pod shattering rates of the 26 soybean genotypes across the three locations ranged from 3.33 to 89.44% (Table 4). Based on their shattering rates (%), the genotypes are grouped into different categories (Table 5). From Table 5, none of the genotypes was very resistant to pod shattering (0% pod shattering); 21 genotypes were resistant (<25% pod shattering); 4 genotypes were moderately resistant (25-50% pod shattering); none was highly susceptible (51-75% pod shattering); while only 1 was very highly susceptible (>75% pod shattering). Therefore, only one genotype (NCRI SOYAC63) falls within the range of 34 to 100% pod shattering reported by Tefera *et al*. (2009); and 21 genotypes can resist pod shattering even with delay in harvest, according to the rating of Krisnawati and Adie (2017).

The AMMI bi-plot for pod shattering (Figure 3) shows the stable genotypes in terms of pod shattering across the three environments. In the bi-plot, the environments are located almost on the perpendicular line of the graph and thus have similar influence on pod shattering behaviour of

Table 5. Genotype grouping based on mean pod shattering percentage across three environments.

Score	Description	Category	Genotypes
1	No pod shattering	Very resistant	Nil
2	< 25% pod shattering	Resistant	NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, NCRI SOYAC76, NCRI SOYAC22
3	25 - 50% pod shattering	Moderately resistant	NCRI SOYAC18, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC61
4	51 - 75% pod shattering	Highly susceptible	Nil
5	> 75% pod shattering	Very highly susceptible	NCRI SOYAC63

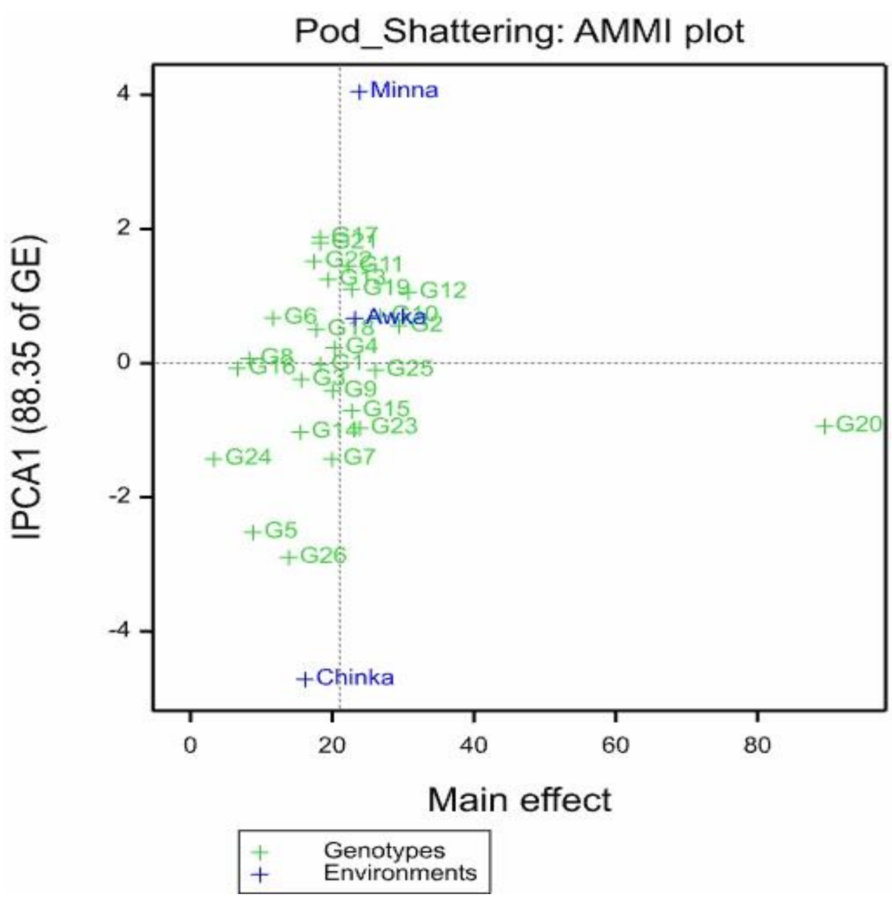

Figure 3. AMMI Bi-plot for pod shattering percentage of the soybean genotypes across three locations (1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22).

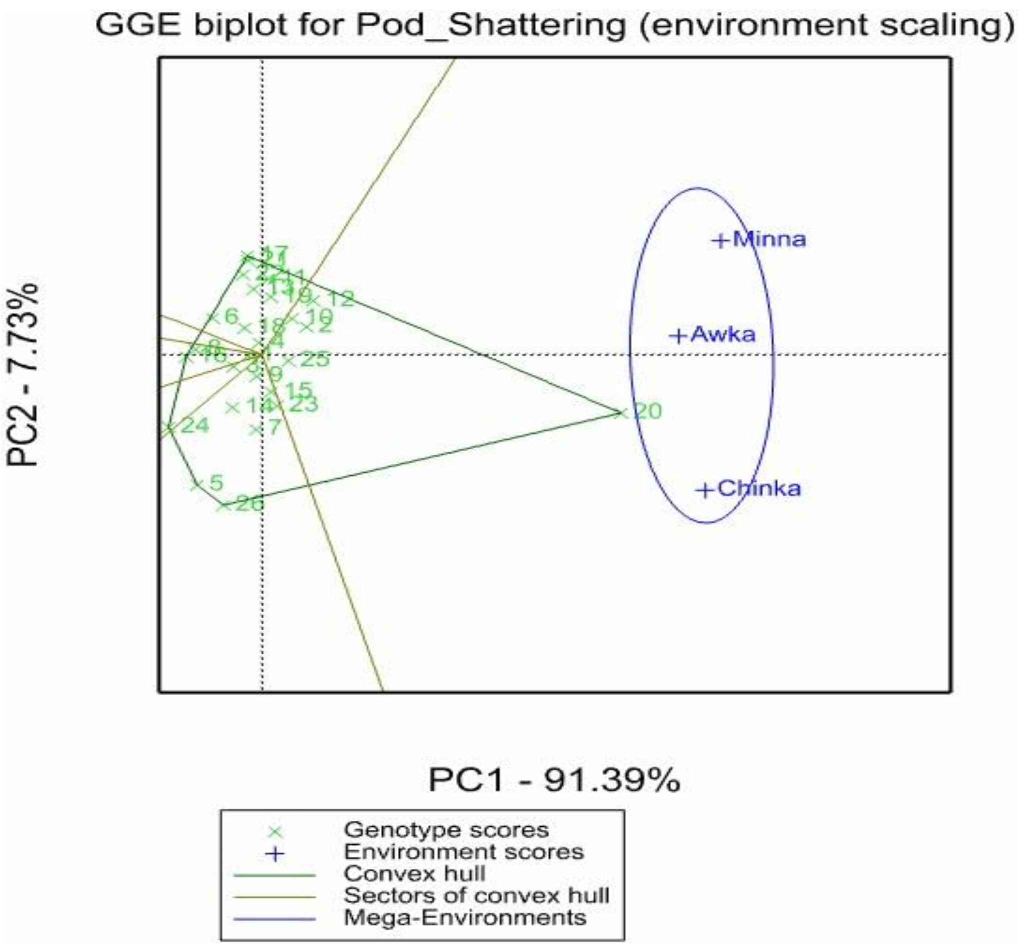

Figure 4. GGE bi-plot for pod shattering in different environments (1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22).

the genotypes. Therefore, genotypes provided greater variability than environmental differences. That is, irrespective of the environment, some soybean genotypes can still exhibit the same level of resistance or susceptibility to pod shattering. This is in agreement with the findings of Bhor *et al*. (2014), which state that among the climatic factors, the genotypic characteristics of any genotype play a key role in the overall expression of pod shattering of that genotype.

Genotypes NCRI SOYAC78 (coded 1), NCRI SOYAC29 (coded 8), NCRI SOYAC7 (coded 16), NCRI SOYAC61 (coded 25), NCRI SOYAC17 (coded 3), and NCRI SOYAC69 (coded 4) were located very close to the horizontal line of the bi-plot and are termed stable. Five of these stable genotypes (NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC7, NCRI SOYAC17, and NCRI SOYAC69) were resistant to pod shattering while one (NCRI SOYAC61) was moderately resistant. Genotype NCRI SOYAC63 was both unstable and very highly susceptible to pod shattering.

The GGE bi-plot (Figure 4) grouped the three environments into one environment, with NCRI SOYAC63 (coded 20), NCRI SOYAC18 (coded 2), NCRI SOYAC61 (coded 25), NCRI SOYAC28 (coded 10) and NCRI SOYAC65 (coded 12) as the genotypes with the highest pod shattering percentage; therefore, the environments were similar according to Ishaq *et al*. (2015). This further confirms the earlier observation in AMMI bi-plot that genotypes provided greater variability than environmental differences in pod shattering behaviour of the 26 soybean genotypes.

Conclusion

Environments provided greater variability in yield than genotype differences, while differences observed in the rate of pod shattering was a function of genotype differences, as environments had little influence on the way the genotypes shattered. Out of the 26 soybean genotypes screened for yield stability and pod shattering resistance, seven (NCRI SOYAC20, NCRI SOYAC22, NCRI SOYAC7, NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC69, and NCRI SOYAC28) were identified to produce high and stable yield across environments; NCRI SOYAC65 was the poorest in yield, while NCRI SOYAC77 was the most unstable. In terms of pod shattering resistance, five genotypes (NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC7, NCRI SOYAC17, and NCRI SOYAC69) produced stable pod shattering resistance across environments. NCRI SOYAC 63 was both unstable and very highly susceptible to pod shattering. Therefore, out of the 26 genotypes, only four (NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC69 and NCRI SOYAC7) were stable in both high yield and resistance to pod shattering.

Recommendations

With the results obtained from genotypes' performances across the three environments, it is recommended that NCRI SOYAC20, NCRI SOYAC22, NCRI SOYAC7, NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC69, and NCRI SOYAC28 could be selected for breeding as well as production of high yielding stable soybean varieties. When breeding for stable pod shattering resistance, genotypes NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC7, NCRI SOYAC17, and NCRI SOYAC69 could be included in germplasm collection, as donor parents for pod shattering resistance. Also, when soybean production is considering pod shattering resistance, these genotypes could be included. For soybean breeding programme that involves both stability in high yield and pod shattering resistance across environments, NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC69 and NCRI SOYAC7 are recommended. They are also recommended for large scale soybean production in order to ensure effective production and food security.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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