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Yield stability studies of soybean (*Glycine max* (L.) Merrill) under rhizobia inoculation in the savanna region of Nigeria

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Abstract

Soybean (*Glycine max* (L.) Merrill) production is expanding into temperate and tropical environments. Yield stability studies under rhizobia inoculation were investigated in 24 soybean genotypes over two successive growing seasons at three agro-ecological zone of Nigeria, during the 2015–2016 rainy seasons. Treatments were arranged in a split-plot design and replicated three times. Treatments were 24 soybean genotypes and three levels of rhizobia inoculation. Results indicated that the variation of genotypes and inoculation on percentage emergence, height, number of leaves, number of branches per plant, total biomass yield, above-ground biomass and seed yield was significant ($p = .05$). The effects of genotypes (G), environment (E) and G × E interactions on seed yield were also significant. Two soybean genotypes (TGx 1989-45F and TGx 1990-110FN) were identified as the most promising in relation to yield stability. Of the three locations, Abuja produced the least interaction effects followed by Igabi and may be most appropriate environments for large-scale soybean production. Appropriate inoculation of soybean with inoculants (LegumeFix and or NoduMax) should be encouraged in farmer's field.

KEYWORDS

genotype, inoculation, soybean, yield stability

1 | INTRODUCTION

Soybean has been recognized as one of the premier agricultural crops today; thus, it is the best source of plant protein and oil and has now been recognized as a potential supplementary source of nutritious food (Wilcox & Shibles, 2001). Therefore, it has become very suitable to other protein sources that are scarce or too expensive to afford (Asrat, Fistum, Fekadu, & Mulugeta, 2009). Soybean contains a good-quality protein of 42% and oil of 19.5% (Wilcox & Shibles, 2001). Soybean protein is considered complete, because it supplies sufficient amounts of the types of amino acids that are required by the body for building and repair of tissues (Jinze, 2010). Essential amino acids found in soybean are methionine, isoleucine, lysine, cystine, phenylalanine, tyrosine, theonine, tryptophan and valine (Bellaloui, Hanks, Fisher, & Mengistu, 2009). Amino acids are used in the formation of protoplasm, the site for cell division, and therefore facilitate plant growth and development. Soybean has been found to have different uses; for example in food industry, soybean is used for flour, oil, cookies, candy, milk, vegetable cheese, leathin and many other products (Coskan & Dogan, 2011).

In soybean production, inoculation with the appropriate Rhizobium strains has quite prominent effects on nodulation, growth and yield parameters (Shahid, Saleem, Khan, & Anjum, 2009). The factors which control the amount of nitrogen fixed include available soil nitrogen, genetic determinants of compatibility in both symbiotic partners and lack of other yield-limiting factors like edaphic factors associated with mineral elements nitrogen and other various microelements such as Cu, Mo, Co, B, which are necessary for nitrogen fixation (Harold & Keyser, 1992). The absence of the required rhizobia species limits legume production in different parts of the world. Inoculation with compatible and suitable rhizobia may be essential where a low population of native rhizobial strains prevail and is one of the key components of which grain legume farmers can use to optimize yields.

The impact of genotype by environment (G × E) on genotypes can be described by both their yield stability and adaptability. Yield stability is the ability of a genotype to perform consistently in various environments (Fekadu, Hussein, & Getinet, 2009). This applies to both high-yield and low-yield performance. Adaptability refers to the ability of a genotype to perform well in some environments and poorly in other environments (Akoura, Ozer, & Taner, 2004). A limited number of soybean cultivars have enormously contributed to the existing yield gap associated with seed yield in Nigeria savanna agro-ecologies. Low-yield production by farmers is partly due to biotic and abiotic stresses, including decline in soil fertility, low yield related to high instability in different environments and inadequate access to fertilizer by farmers to address the soil fertility challenges. Soybean yield has been associated with high instability at different environments in the savanna, and the use of stable genotypes, capable of high seed yield is an important objective for sustainable production (Alghamdi, 2009). There is need for the evaluation of promising breeding lines across savanna agro-ecological zones that provide stable and high yield for higher economic returns for farmers. This is attributable to a number of factors such as increased utilization of most commercially grown pulses as supplements in livestock feed (Blount, Wright, Sprenkel, Hewitt, & Myer, 2013), usefulness as a source of cheap-quality plant protein (Felton & Kerley, 2004) and the increasingly prohibitive cost of animal protein (Poore, 2003).

To satisfy the demand by producers and consumers, a number of soybean varieties with excellent seed quality and agronomic characteristics have been released for cultivation in the tropical Africa (FAO, 2011). Farmers have shown increasing interest in soybean production, which has extended to the high rainfall belts of sub-Saharan Africa. Although there is considerable potential for soybean production in these belts, yield varied considerably in farmers' fields (Akparobi, 2009). Therefore, the objective of this study was to identify stable soybean genotype(s) for yield, evaluate the performance of soybean genotypes in individual environment and across environments and assess the extent of genotype-by-environment interaction for yield in soybean.

2 | MATERIALS AND METHODS

The study was conducted during the 2015–2016 rainy seasons at three experimental sites across three different agro-ecologies of Nigeria. Abuja (9°16′N and 7°20′E) in the Southern Guinea Savannah, Igabi (112°12′N and 7°20′E) in the Northern Guinea Savanna and Gwarzo (11°19′N and 8°51′E) in the Sudan Savanna of Nigeria.

2.1 | Source of inoculants

Two peat-based rhizobia inoculants (LegumeFix and NoduMax) used in this study were obtained from International Institute of Tropical Agriculture (IITA). LegumeFix contains 10^9 cells/g of peat of *Bradyrhizobium japonicum* strain 532c, manufactured by Legume Technology, United Kingdom. NoduMax contains approximately 10^9 cells/g of peat of *B. japonicum* strain USDA 110, manufactured by the Technology Incubation Centre, IITA, Ibadan, Nigeria.

2.2 | Treatments and experimental design

The experimental treatment was a factorial combination of 24 soybean genotypes (TGx 1989-11F, TGx 1990-110FN, TGx 1989-42F, TGx 1990-95F, TGx 1989-45F, TGx 1990-114FN, TGx 1989-53FN, TGx 1993-4FN, TGx 1989-75FN, TGx 1990-78F, TGx 1987-62F-Check, TGx 1448-2E-Check, TGx 1989-40F, TGx 1990 -52F, TGx 1989-48FN, TGx 1990-40F, TGx 1989-49FN, TGx 1990-57F, TGx 1989-68FN, TGx 1990-46F, TGx 1990-55F, TGx 1987-10F-Check, TGx 1835-10E-Check, TGx 1485-1D-Check), and three inoculation types (Without Inoculation, LegumeFix and NoduMax) were fitted into a split-plot design with three replications. The main plots consisted of the soybean genotypes, and the subplots were the inoculation types. Gross plot size was 3×4 m (12 m^2) containing five ridges of 3 m length each. Net plot size was 3 × 2.5 m (7.5 m^2). An alley of 1 m was used to separate the blocks and 0.5 m for the treatment plots.

2.3 | Agronomic practices

2.3.1 | Land preparation

The experimental field in each location was ploughed, harrowed and ridged with tractor. Then, followed by field layout 216 subplots were marked out as per treatments.

2.3.2 | Seed inoculation with *Rhizobium*

The seeds were inoculated at sowing with rhizobial inoculants (LegumeFix and NoduMax) at the rate of 50 g/5 kg seed as recommended by Woomer (2010) by mixing the seeds with each inoculant, ensuring that the seeds were completely covered by the inoculant.

2.3.3 | Sowing of seeds

Seeds of each genotype inoculated and without inoculation were sown at the rate of three seeds per stand at an intrarow spacing of 30 cm and inter-row spacing of 75 cm. The seedlings were later thinned to one plant per stand. Seeds were sown on 5th July, 15th July and 18th July in 2015 for Gwarzo, Igabi and Abuja, respectively. Also sowing was done on 22nd June, 1st July and 16th July in 2016 for Gwarzo, Igabi and Abuja, respectively.

2.3.4 | Weed control

Weed control was done manually with hoes at 2, 4 and 6 weeks after sowing as recommended by Dugje et al. (2009).

2.3.5 | Fertilizer application

Single super phosphate (SSP) was applied by hand at the rate of 40 kg P_2O_5 ha^{-1} at 2 weeks after sowing, using side placement method of fertilizer application.

2.3.6 | Insect control

Cypermethrin (Best) at the rate of 0.14 kg a.i ha^{-1} (Afolayan and Braimoh, 1991) was applied once on the seedlings with knapsack sprayer to control insect pests' infestation.

2.3.7 | Harvesting

At physiological maturity (when the leaves turn brown and 95% of the pods turn straw colour to brown), soybean plants were harvested from each net plot leaving the border rows on either ends of the central rows. The number of plants per net plot was recorded at harvesting from the three central rows, and the means were computed and used for the analysis of final plant stands. The harvested net plots were threshed after taking the necessary parameters. The seeds were separated from the husk and kept in labelled bags representing respective plots for further observations.

2.4 | Data collection

In each of the location and year of research, the following environmental parameters were taken: (i) mean monthly rainfall (mm), (ii) mean monthly temperature (°C) and (iii) mean monthly relative humidity (%) (Tables 1 and 2). Also, above-ground biomass yield was taken after removing the root part from the plant using cutlass, the remaining above-ground biomass was measured and converted to kilogram per hectare. Seed yield was taken in which seeds were separated from the husk and kept in labelled bags representing respective plots and then converted to kilogram per hectare.

2.5 | Statistical analysis

Analysis of variance procedure was adopted to test the effect of inoculation, significance of location, genotype and interactions assuming the location effects as random and genotype effect as fixed. The Additive Main Effects and Multiplicative Interaction (AMMI) model (BMS, 2015) was used to evaluate soybean genotypes × environment interaction using the following relationship:

$$\text{Yij} = \mu + \text{gi} + \text{ej} + \Lambda\text{k}\Upsilon\text{ik}\delta\text{jk} + \mathcal{E}\text{ij}\ \Sigma\text{N1},$$

where Yij is the grain yield of the ith genotype in the jth environment, μ is the grand mean, gi and ej are the genotype and environment deviation from the grand mean, respectively, Λk is the eigenvalue of the principal component analysis (PCA) axis k, ϒik and δjk are the genotype and environment principal component scores for axis k, N is the number of principal components retained in the model, and Ɛij is the residual term.

2.5.1 | Best genotypes in mega-environments

Genotype plus genotype × environment interaction (GGE) biplot was used to identify the best-performing genotype across environments. The polygon view of the GGE biplot was used to show "which-won-where" that is the best genotype in each environment and it summarized the GEI pattern of a multi-environment yield trial data. The GGE biplot used is based on the sites regression (SREG) linear–bilinear (multiplicative) model (BMS, 2015), which is given below:

$$\bar{y}_{ij} - \mu_j = \sum_{k=1}^{t} \lambda_k\, \alpha_{ik}\, \gamma_{jk}\ + \bar{\varepsilon_{ij}},$$

where $\bar{y}_{ij}$ is the cell mean of genotype i in environment j; μj is the mean value in environment j; $i = 1, \cdots g$; $j = 1, \cdots e$, g and e being the numbers of cultivars and environments, respectively; and t is the number of principal components (PC) used or retained in the model, with $t \le \min\ (e,\ g\ -\ 1)$. The model is subject to the constraint $\lambda_1 \ge \lambda_2 \ge \cdots \lambda_t \ge 0$ and to orthonormality constraints on the α_{ik} scores, with similar constraints on the γ_{jk} scores (defined by replacing symbols [i, g, α] with [j, e, γ]). The ε_{ij} are assumed normally and independently distributed (0, σ^2/r), where r is the number of replications within an environment.

Genotype plus genotype × environment interaction biplot methodology (Yan, Hunt, Sheng, & Szlavnics, 2000) was used to analyse multi-environment trial data. The statistical analysis was conducted using the Integrated Breeding Platform (BMS, 2015).

3 | RESULTS

The boxplot for seed yield during the 2015 cropping season across the three environments is revealed in Figure 1. Igabi environment recorded the highest mean performance than Abuja and Gwarzo environments. However, the soybean genotypes showed wider variability in Igabi and Abuja environments. The boxplot encloses observations between the 25th (lower) and 75th quartiles (upper) with the lines extending to the minimum and maximum of observed values. Figure 2 reveals the boxplots for seed yield from soybean genotype inoculation in 2015 cropping season across the environments.

Additive main effect multiplicative interaction (AMMI) biplot for seed yield across the environments during the 2015 cropping season (Figure 3) shows the presence of genotype-by-environment interaction was demonstrated by the AMMI model. The interaction principal component analysis (IPCA1) explained 69.95% genotype-by-environment interaction. This implied that the interaction of the genotypes with three environments was predicted by the first principal components of genotype and environment. The differences among genotypes in terms of direction and magnitude along the X-axis (yield) and Y-axis (IPCA1 scores) were provided by AMMI biplot using the main effect and the first principal component scores

TABLE 1 Monthly meteorological data for the experimental locations during the 2015 cropping season

Locations			Months											
			January	February	March	April	May	June	July	August	September	October	November	December
Abuja	RF		2.0	8.0	29.0	80.0	155	177	233	280	284	130	10.0	1.0
	Temp	Max	32.5	34.2	35.1	34.4	31.8	29.6	28.2	27.7	28.9	30.7	32.5	32.6
		Min	17.6	19.5	21.7	22.7	22.0	20.6	20.4	20.2	19.9	19.9	18.8	16.9
		Mean	25.1	26.9	28.4	28.6	26.9	25.1	24.3	23.9	24.4	25.3	25.6	24.7
	Humi	Max	24.0	24.0	35.0	50.0	62.0	83.0	88.0	83.0	74.0	65.0	42.0	29.0
		Min	8.0	9.0	17.0	10.0	62.0	58.0	58.0	52.0	55.0	17.0	10.0	20.0
		Mean	14.0	14.0	23.0	25.0	62.0	68.0	73.0	67.0	65.0	38.0	22.0	24.0
Igabi	RF		0.0	0.0	90.0	0.0	90.1	66.4	300.	387.1	281	11.3	0.0	0.0
	Temp	Max	28.9	31.5	36.2	36.3	37.4	32.6	30.6	29.7	31.8	31.3	34.2	28.5
		Min	13.2	15.7	21.1	21.5	24.2	22.1	20.1	19.8	24.9	17.5	12.8	13.4
		Mean	21.1	23.6	28.7	28.9	30.8	27.35	25.4	24.8	28.4	24.4	23.5	20.9
	Humi	Max	22.2	21.0	34.0	34.0	63.2	73.4	85.5	84.8	84.2	62.8	27.5	31.4
		Min	16.3	15.1	34.0	18.0	37.7	57.8	69.6	67.8	73.2	54.8	24.6	25.8
		Mean	19.8	17.5	34.0	26.0	48.9	65.7	77.4	74.4	78.9	58.2	26.0	28.5
Gwarzo	RF		0.0	0.0	0.0	19.4	58.1	145.8	236	329	107	41.9	0.0	0.0
	Temp	Max	32.5	36.9	37.8	40.7	39.9	35.2	31.4	31.2	33.2	34.8	35.5	30.9
		Min	14.8	19.1	22.2	26.1	26.5	24.3	23.1	22.3	23.1	22.5	18.2	14.4
		Mean	23.7	28.0	30.0	33.4	33.2	29.8	27.3	26.8	28.2	28.7	26.9	22.7
	Humi	Max	46.2	37.5	30.8	27.3	52	75.2	77	82.8	84.3	75.2	29.8	37.8
		Min	13.2	8.5	8.2	6.4	15.7	34.2	49.9	67.7	84.3	57.1	26.5	31.1
		Mean	26.7	21.0	17.8	15	32.5	52.7	62.6	76.6	84.3	65.6	28.2	33.9

Source: Institute for Agricultural Research, Samaru, Zaria, Kaduna State, Nigeria (Igabi and Gwarzo locations), and International Institute of Tropical Agriculture (IITA) Kubwa Station, Abuja, Nigeria (Abuja location); RF, rainfall (mm); Temp, temperature (°C); Humi, humidity (%); Max, maximum; Min, minimum.

TABLE 2 Monthly meteorological data for the experimental locations during the 2016 cropping season

Locations			Months January	February	March	April	May	June	July	August	September	October	November	December
Abuja	RF		1.0	8.0	36.0	90.0	165	197	253	288	294	150	13.0	2.0
	Temp	Max	26.0	31.4	31.5	32.7	27.4	26.5	23.5	25.0	28.5	29.8	27.5	30.9
		Min	22.0	23.1	28.4	28.6	24.7	25.7	17.5	16.0	26.7	25.3	24.0	22.3
		Mean	24.0	27.7	30.1	30.7	26.1	26.1	20.5	20.5	27.6	27.6	25.7	26.6
	Humi	Max	43.5	34.2	47.7	58.1	73.7	78.5	84.1	64.2	52.7	48.1	36.5	30.7
		Min	30.7	27.4	35.2	37.6	58.4	64.2	50.3	52.6	45.3	37.3	22.4	19.5
		Mean	31.1	30.8	41.5	47.9	66.05	71.4	67.2	58.4	49.0	42.7	29.5	25.1
Igabi	RF		0.0	0.0	0.0	0.0	70.0	80.0	316	373	272	68	0.0	0.0
	Temp	Max	31.1	32.2	33.5	32.8	29.0	26.5	25.5	29.0	28.5	29.3	29.5	30.4
		Min	23.3	22.0	32.6	30.0	26.4	25.3	25.5	26.0	26.7	29.3	27.0	25.3
		Mean	24.2	27.4	33.0	30.6	27.4	25.3	25.5	27.0	27.5	29.3	28.0	27.9
	Humi	Max	24.9	21.0	42.9	57.3	74.2	79.3	75.0	58.0	56.2	37.3	53.6	30.6
		Min	14.3	19.6	38.1	49.6	64.4	73.5	75.0	56.0	54.8	36.5	17.5	16.2
		Mean	19.4	20.4	40.4	53.1	69.0	76.3	75.0	57.0	55.5	37.0	34.7	23.4
Gwarzo	RF		0.0	0.0	0.0	0.0	18	66	162	381	263	84	0.0	0.0
	Temp	Max	25.8	31.0	38.0	40.5	38.2	32.3	30.1	30.0	31.8	35.1	28.9	25.1
		Min	16.8	15.3	24.9	26.3	26.0	22.8	22.1	22.3	22.4	20.5	17.0	17.1
		Mean	20.9	22.9	31.2	33.0	31.8	26.8	26.2	26.3	27.0	27.6	19.8	19.2
	Humi	Max	32.0	42.6	41.1	53.1	69.9	79.1	88.8	95.0	91.6	79.7	53.6	36.2
		Min	13.7	9.4	11.6	14.0	25.9	41.5	52.4	57.2	48.7	20.8	17.5	15.1
		Mean	22.1	23.9	25.8	31.5	48.1	60.3	72.5	78.4	73.6	50.7	35.7	24.4

Source: Institute for Agricultural Research, Samaru, Zaria, Kaduna State, Nigeria (Igabi and Gwarzo locations), and International Institute of Tropical Agriculture (IITA) Kubwa Station, Abuja, Nigeria (Abuja location); RF, rainfall (mm); Temp, temperature (°C); Humi, humidity (%); Max, maximum; Min, minimum.

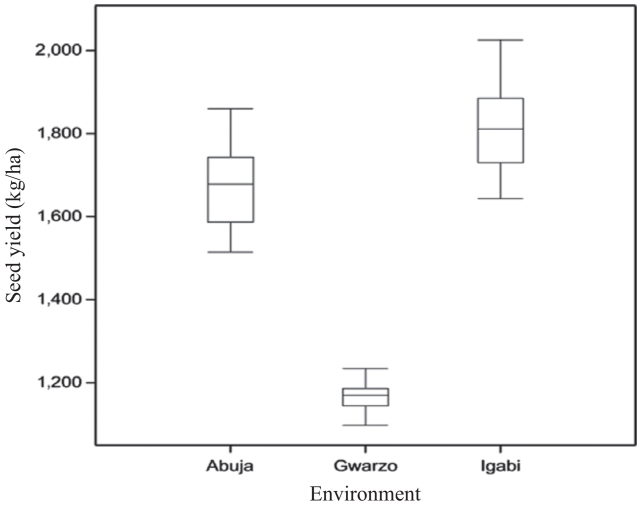

FIGURE 1 Combined analysis of boxplot for seed yield (kg/ha) during the 2015 and 2016 cropping seasons across environments

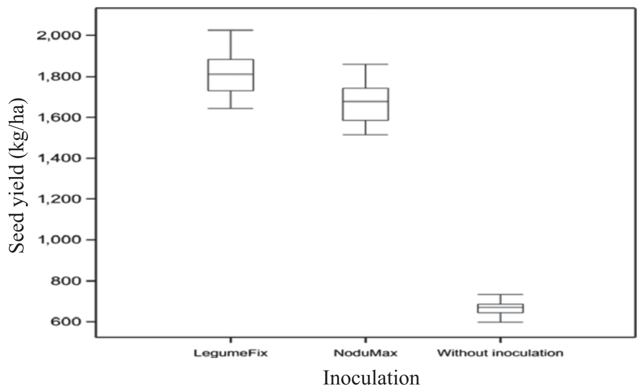

FIGURE 2 Combined data boxplot for seed yield (kg/ha) from soybean genotypes inoculation during the 2015 and 2016 cropping seasons across environments

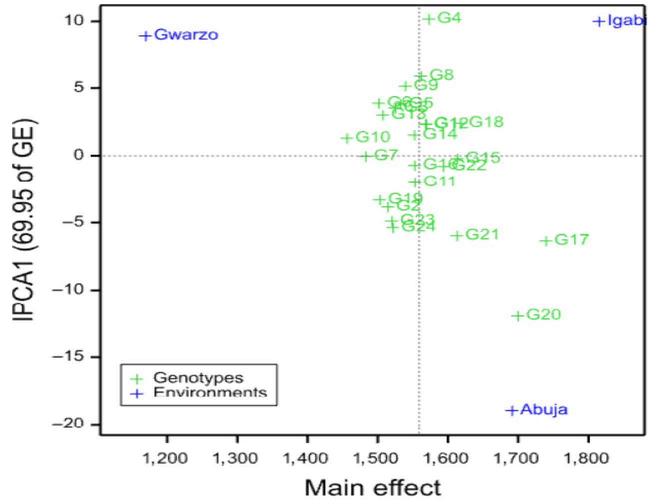

FIGURE 3 Additive main effect multiplicative interaction (AMMI) biplot for seed yield across environments in 2015 and 2016 cropping seasons combined analysis. 1, TGx 1989-11F; 2, TGx 1990-110FN; 3, TGx 1989-42FN; 4, TGx 1990-95F; 5, TGx 1989-45F; 6, TGx 1990-114FN; 7, TGx 1989-53FN; 8, TGx 1993-4FN; 9, TGx 1989-75FN; 10, TGx 1990-78F; 11, TGx 1967-62F-Check; 12, TGx 1448-2E-Check; 13, TGx 1989 -40F; 14, TGx 1990-52F; 15, TGx 1989-48FN; 16, TGx 1990-40F; 17, TGx 1989-49FN; 18, TGx 1990-57F; 19, TGx 1989-68FN; 20, TGx 1990-46F; 21, TGx 1990-55F; 22, TGx 1987-10F-Check; 23, TGx 1835-10E-Check; 24, TGx 1485-1D-Check [Colour figure can be viewed at wileyonlinelibrary.com]

of interaction (IPCA1) of both genotypes and environment (Figure 3). In the biplot, genotypes or environments that appear almost on a perpendicular line of the graph have similar mean seed yields and those that fall almost on a horizontal line have similar interaction. Hence, the variability due to environment was greater than that due to genotype differences. Genotypes or environments on the right side of the mid-point of the perpendicular line have higher yields than those on the left side.

The genotypes TGx 1989-49FN (17), TGx 1990-46F (20), TGx 1990-55F (21), TGx 1989-48FN (15) and TGx 1990-57F (18) were high-yielding. In contrast, TGx 1990-78F (10), TGx 1989-53FN (7), TGx 1989-68FN (19) and TGx 1990-110F (2) were low-yielding. Genotypes or environments with large negative or positive IPCA1 scores have high interactions, while those with IPCA1 scores near zero (close to the horizontal line) have little interaction across environment and are considered more stable than those further away from the horizontal line. In the biplot, TGx 1989-53FN (7) and TGx 1989-48FN (15) fell almost on the horizontal line near the zero point on IPCA1. This implies that these genotypes showed high and stable yield. Genotypes TGx 1987-10F (22), TGx 1448-2E (12) and TGx 1990-57F (18) were a little far away from the horizontal line and imply that the genotypes are high-yielding but relatively unstable. The genotypes TGx 1990-78F (10), TGx 1990-52F (14) and TGx 1989-68FN (19) were close to the horizontal line but at the left side of the perpendicular line, meaning that the genotypes are relatively stable but produce below-average yield. The poorest of the genotypes due to instability and lowest yield were TGx 1990-114FN (6) and TGx 1989-40F (13). In terms of the environments, Igabi is the most yielding while Gwarzo recorded the least yielding but most stable.

The polygon view (Figure 4) of the genotype plus genotype-by-environment interaction (GGE) biplot displays the best genotypes in each environment, and it is a summary of the genotype-by-environment pattern of a multi-environment yield trial. To each side of the polygon, a perpendicular line starting from the origin is drawn and extended beyond the polygon so that the biplot is divided into several sectors and the different environments were separated into different sectors. The genotypes at the vertices of each sector are the best performers at the environment included in that sector. Although there were six sectors in all, the three mega-environments were identified. Abuja was one mega-environment with TGx 1990-40F, TGx 1990-46F (20) and TGx 1990-55F (21) as the best genotypes in this environment. The best genotypes for the second mega-environment Igabi were TGx 1989-49FN (17), TGx 1989-48FN (15) and TGx 1987-10F (22), while the last mega-environment Gwarzo had TGx 1993-4FN (8), TGx 1989-75FN (9), TGx 1448-2E (12), TGx

1989-40F (17) and TGx 1990-52F (14) as the best. The remaining sectors without environment within them contained the following genotypes: TGx 1989-45F (5), TGx 1990-114FN (6), TGx 1989-53FN (7), TGx 1990-78F (10), TGx 1990-110FN (2), TGx 1989-68FN (19), TGx 1835-10E (23) and TGx 1485-1D (24). These genotypes were not the highest yielding genotype at any environment. Additive main effect multiplicative interaction (AMMI) biplot for inoculation across the environments is revealed in Figure 5.

4 | DISCUSSION

The yield variations expressed by the environments showed that environments were diverse. Although temperature distribution was relatively uniform and favourable across the three environments during the production period, rainfall pattern varied, and this could be the major cause of yield variations across the environments. Similarly, the high mean performance of genotypes in Igabi and Abuja environments could be traced to the similar favourable rainfall pattern exhibited by the two environments. The genotype and environment interaction clearly plays a significant role in breeding adaptable genotypes to the wide environment. This interaction was validated by the highly significant difference for seed yield. These results relate the findings of Gebeyehu and Assefa (2003) who reported that selections based on the highest yielding genotypes appeared less stable than

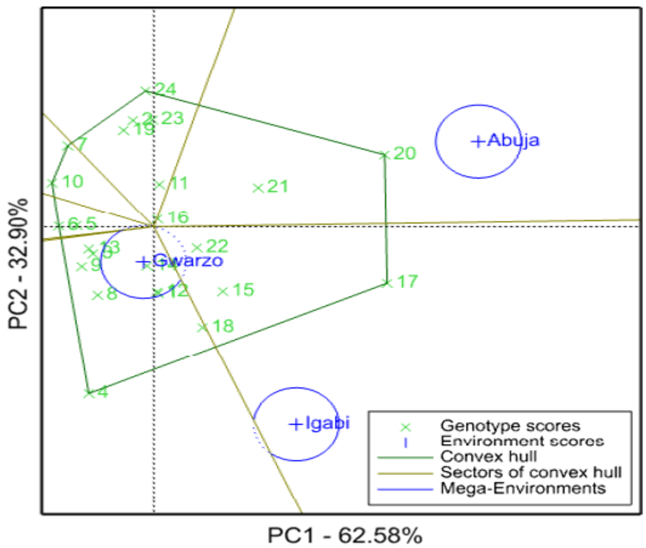

FIGURE 4 Genotype plus genotype-by-environment interaction (GGE) biplot sectors for seed yield (environment scaling) in 2015 and 2016 cropping seasons combined analysis. 1, TGx 1989-11F; 2, TGx 1990-110FN; 3, TGx 1989-42FN; 4, TGx 1990-95F; 5, TGx 1989-45F; 6, TGx 1990-114FN; 7, TGx 1989-53FN; 8, TGx 1993-4FN; 9, TGx 1989-75FN; 10, TGx 1990-78F; 11, TGx 1967-62F-Check; 12, TGx 1448-2E-Check; 13, TGx 1989 -40F; 14, TGx 1990-52F; 15, TGx 1989-48FN; 16, TGx 1990-40F; 17, TGx 1989-49FN; 18, TGx 1990-57F; 19, TGx 1989-68FN; 20, TGx 1990-46F; 21, TGx 1990-55F; 22, TGx 1987-10F-Check; 23, TGx 1835-10E-Check; 24, TGx 1485-1D-Check [Colour figure can be viewed at wileyonlinelibrary.com]

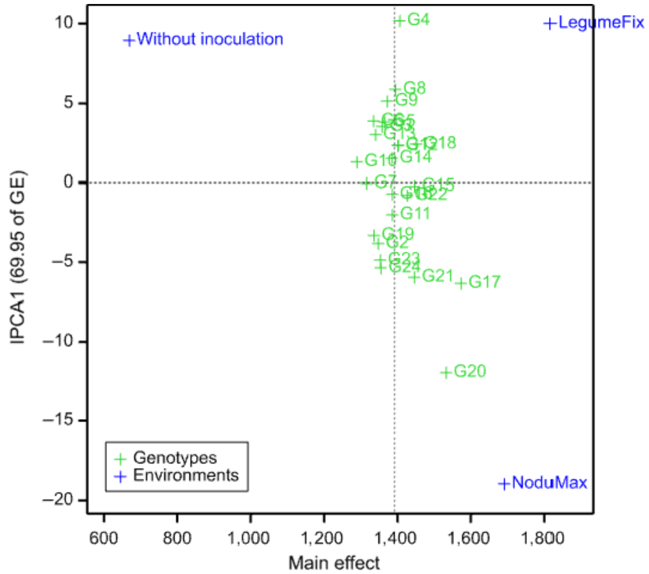

FIGURE 5 Additive main effect multiplicative interaction (AMMI) biplot for inoculation across environments in 2015 and 2016 cropping seasons combined analysis. 1, TGx 1989-11F; 2, TGx 1990-110FN; 3, TGx 1989-42FN; 4, TGx 1990-95F; 5, TGx 1989-45F; 6, TGx 1990-114FN; 7, TGx 1989-53FN; 8, TGx 1993-4FN; 9, TGx 1989-75FN; 10, TGx 1990-78F; 11, TGx 1967-62F-Check; 12, TGx 1448-2E-Check; 13, TGx 1989 -40F; 14, TGx 1990-52F; 15, TGx 1989-48FN; 16, TGx 1990-40F; 17, TGx 1989-49FN; 18, TGx 1990-57F; 19, TGx 1989-68FN; 20, TGx 1990-46F; 21, TGx 1990-55F; 22, TGx 1987-10F-Check; 23, TGx 1835-10E-Check; 24, TGx 1485-1D-Check [Colour figure can be viewed at wileyonlinelibrary.com]

the average of all genotypes. Furthermore, Gebeyehu and Assefa (2003) stated that selection solely for seed yield could result in rejection of several stable genotypes. TGx 1989-45F and TGx 1990-110FN out-yielded others because of its yield components such as plant height, number of leaves, number of pods per plant and some other growth traits that have contributed to the high yield. In contrast, Arslanoglu and Aytac (2010) reported contrary finding on the effect of genotype, environment and genotype-by-environment interaction on soybean pod number per plant, whereby plant height, seed yield and one hundred-seed weight were found to be significant at $p = .01$. From the findings of this study, it was evident that total biomass yield and seed yield declined in the same trend. The mean performance analysis revealed that high-yielding genotypes across the environments over the 2 years were TGx 1989-45F, TGX 1990-110FN and TGx 1989-53FN. Thus, the outstanding performance by TGx 1989-45F in terms of yield and yield-related traits made it the best performer across the three environments over 2 years. These conform to Egli (1998) explanation for soybean performance that yield variation across environments and years was associated with changes in number of seeds per unit area. A contrary explanation is that an ideal soybean cultivar is one that achieves the greatest yield across many environments (Fasoula & Fasoula, 2002). The exhibited non-significance by these traits, number of branches per plant, number of pods per plant and one hundred-seed weight was confirmed by Baker (1988) who defined the non-significant difference as failure of genotypes to achieve the same relative performance in different environments. Thus, the genotype-by-environment interaction might have made it difficult for breeders to identify the best genotypes, during selection and recommendation. The positive and significant correlation estimated between seed yield and other traits agreed with the findings of Malik, Qureshi, Ashraf, and Ghafoor (2006). This implies that selections aimed at increasing seed yield would invariably select for higher plant height, higher leaf number and earliness to flower and as against one hundred-seed weight, number of branches per plant and number of pod per plant. This finding was in agreement with Karasu, Goksoy, and Turan (2002) who revealed that crop yield variations are strongly influenced by growth and yield parameters. The yield variations explained by environments indicates that the environments were diverse, with large differences between environmental means contributing most of the variations in yield. According to Eberhart and Russel (1996), an ideal cultivar would have both a high-average performance over a wide range of environments plus stability. Although genotypic main effect was highly significant, this shows difference in genotypic performance across environments resulting in genotype-by-environment interaction. The existence of genotype-by-environment interaction raised the need to identify stable and high-yielding genotypes. The additive main effect multiplicative interaction analysis of variance revealed that the environmental variance was significant and higher than both the genotype and genotype-by-environment interaction variance. The result revealed that the environment main effect was the most important source of variation, due to its large contribution to the total sum of squares for yield. Variations due to genotype were larger than those due to genotype-by-environment interaction, meaning that differences among genotype vary across environments. Similar observations were obtained by Kaya, Palta, and Taner (2002) and Admassu, Lind, Friedt, and Ordon (2008) in their studies. The observed differential genotypic responses can be traceable also to differences in inherent genetic composition. Such responses had been reported by Sanginga, Thottappily, and Dashiell (2000) and Osodeke (2001). This observation is also consistent with the findings of Aduloju, Mahamood, and Abayomi (2009) for the savanna region of Nigeria.

5 | CONCLUSION

The performance of inoculated seeds was higher than that without inoculation. Therefore, symbiotic N_2 requirement and optimum yield potential of soybean genotypes grown in the savanna region of Nigeria may be met by rhizobia population. Of the 24 genotypes evaluated for genotype-by-environment interaction and yield stability, two (TGx 1989-45F and TGx 1990-110FN) were identified by the analytical tools used as the overall best in relation to seed yield and stability as compared to the checks and grand mean performance of the genotypes. In terms of the environment, Gwarzo produced the least interaction scores, while Abuja and Igabi produced the highest interaction scores. Therefore, Gwarzo was most stable than Abuja and Igabi. However, the average yield performance of Gwarzo was poor when compared with the yield performance of the other two environments.

AUTHORS CONTRIBUTION

Tolorunse, K. D., Gana, A. S., Bala, A. and Sangodele, E. A. conceived the study. Tolorunse, K. D., Gana, A. S. and Sangodele, E. A. collected the data. Tolorunse, K. D., Gana, A. S. and Bala, A. analysed the data. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

Authors declare that no conflict of interests exist.

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