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Performance of Korean Anther Culture Derived Rice (*O. sativa* L.) Across Agro-ecological System of Nigeria

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Abstract: Genotype by environment interactions is very important to plant breeders in the development of an improved varieties, as increase in world rice production will depends on the development of new cultivars with high yield and stable performance across diverse environments. The objective of this study is to identify high yielding genotypes that could be deployed to environmental specific and those across all environments. Multi-environmental trials (METs) were established at five locations (Akabba, Bakin Rijiya, Buba, Duduguru and Keffi) in Nassarawa state in the north central region of Nigeria. The genetic materials used for the MET comprised 10 anther culture varieties from Korea and two released varieties and one popular local variety in randomized complete block design in three replications. Plot size of 3m x 3m at a spacing of 20cm within and between rows. The analysis of variance for the combined trials showed that the genotypes, environments, and genotypes-by-environment interaction were highly significant and as well the grain yield and its components. Genotypes expressed better performance in some environments like Duduguru as compared to others and variability is one of the most important factors in plant breeding. The results showed that the most stable genotypes across locations were NERICA4, UPN268, UPN257 and UPN234 and the most unstable genotype was UPN347, but the local check (Mata Mallam) was stable but low yielding, its stability could be one of the major reasons the local farmers were still cultivating Mata Mallam. These results showed that genotypes of anther-culture derived rice from Korea were very promising and stable across the ecosystems tested in Nigeria.

Keywords: Rice, Genotypes, GGE Biplot, Stability, PCA, Anther-Culture Derived Progenies

1. Introduction

Rice belongs to the genus Oryzae which contains about 20 diverse species including *O. glaberrima*, *O. sativa*, *O. perennis*, *O. nivara*. Science technology has created a lot of genetic variations in rice to fast-track breeding processes and timely release for farmers' cultivation. The agricultural sector of the Nigeria economy offers more than 70% of the total workforce of which the rice sector takes the largest share of 38.5% through its production-consumption value chain. In Nigeria, women are the most vulnerable in terms of resource generation and they occupy more than 60% of the production-consumption value chain of the rice economy. Thus, developing robust and sustainable production-consumption value chain of the rice economy will allow the rural poor to emerge from poverty and hunger, not only in Nigeria but in Sub Saharan Africa [1]. Genotype by environment interactions is very important to plant breeders in the development of an improved varieties.

Korea anther culture derived (*O. sativa*) lines were evaluated across some rice growing locations. In breeding programme, wider adaptability and stability of genotypes are the major consideration for efficient breeding programme. Genotypes express different reaction over a series of environments, and they are ranked according to their performance in these environments. Therefore, GxE interaction is of major concern for breeders and stability performance of a genotype is a genetically controlled character. Genotype-by-environment interaction results when there is a change on the performance of genotypes across environments, thus showed the potential the genotypes in influencing the natural condition and magnitude of the selectin response achieved by breeding programme [2].

Expression of good agronomic characters by genotype are more acceptable by rice farmers and more of consideration in determine the most acceptable genotypes in the breeding programme. Germplasm characterization and evaluation is a basic requirement for a successful breeding programme and this may lead to the identification of phenotypic traits with high heritability and appreciable association with yield [3, 4].

Performance of genotypes varies across locations due to deferent environmental factors that affect the genotypes. Most breeders believed genotypes that had showed little variation s across environment could be regarded as the most stable genotype. Stability of genotype could be based on the character(s) under consideration. In Nigeria, high yielding genotypes are the most preferred by the rice farmers, which could translate to higher income and better livelihood.

The objective of this study is to identify high yielding genotypes that could be deployed to environmental specific and those across all environments.

2. Materials and Methods

Multi-environmental trials (METs) were established at five locations (Akabba, Bakin Rijiya, Buba, Duduguru and Keffi) in Nassarawa state in the north central region of Nigeria. Nassarawa state is in savanna geographic location with moderate rainfall. The genetic materials used for the MET comprised 10 anther culture varieties from Korea and two released varieties and one popular local variety of that location (Table 1) in randomized complete block design in three replications. Plot size of 3m x 3m at a spacing of 20cm within and between rows. Planting was done by dibbling four seeds per hole and thinned to two seedlings 15 days after sowing. Irrigation was applied regularly to maintain the soil capacity. Inorganic fertilizer (NPK 15:15:15) was applied in a basal application of 200 kg ha^{-1} (N_2, P_2O_5 and K_2O) and top-dressed with urea (46% N) 65 kg ha^{-1} at two splits of 35kg ha^{-1} each at tillering and booting stages of the crop development. All the essential agronomic traits were collected at the appropriate stage of the crop phenology.

Table 1. *Genetic materials used for the experiment.*

Variety	Source
FARO 59	Improved variety AfricaRice
NERICA 4	Improved variety AfricaRice
UPN 228	Anther culture, Korea
UPN 234	Anther culture, Korea
UPN 236	Anther culture, Korea
UPN 257	Anther culture, Korea
UPN 266	Anther culture, Korea
UPN 268	Anther culture, Korea
UPN 276	Anther culture, Korea
UPN 345	Anther culture, Korea
UPN 347	Anther culture, Korea
UPN 349	Anther culture, Korea
MATA MALLAM	Local variety

2.1. Data Collection

Data was collected at appropriate stage of the crop development. The agronomic characters were measured at weekly intervals. The 'Standard Evaluation System (SES) for Rice' reference manual was used for all trait measurements except where stated otherwise. [5].

2.2. Statistical Analysis

Analysis of variance (ANOVA) was performed separately on the individual experiments using the PROC GLM of SAS [6]. The means of the combined analysis were used for simple linear correlation and regression analysis. Biplot analysis was employed to investigate the cultivar-by-environment interaction (site regression model) [7]. Biplot construction was based on the first two principal components (PC1 and PC2). The PC1 and PC2 are referred to as primary and secondary effects, respectively, and were derived from singular-value decomposition (SVD) of the environment-centred data [7]. The environment-centred data were subjected to SVD for the construction of the biplots. This resulted in three component matrices: singular value (SV) matrix, the cultivar eigenvector matrix, and the environment eigenvector matrix. Thus, the biplot was constructed based on the following model [8]:

$$Yij - G - Ej = \sum \lambda n \, \varepsilon in \, \eta in + \varepsilon ij,$$

where Yij = the measured mean trait of cultivar i in environment j; G = the grand mean; Ej = the mean effect of environment j; (G + Ej) being the mean trait in environment j; λn = the SVD of nth principal component (PC), the square of which is the sum of square explained by PCn; εin = the eigenvector of cultivar i for PCn; ηjn = the eigenvector of environment j for PCn; and εij = the residual variation associated with genotype i in environment j.

3. Results

3.1. Agronomic Analysis

The analysis of variance for the combined trials showed that the genotypes, environments, and genotypes-by-environment interaction were highly significant. The genotypes contributed about 56.5% of the total variations and 20.7% by genotypes-by-environment interaction in the experiments (Table 2).

Table 2. *Analysis of variance for the combined experiments.*

Source	DF	SS	MS	F	Prob
TOTAL	129	137.71			
GENO	12	77.80	5.98	20	0.00001
ENV	4	12.38	3.09	10.3	0.00001
GE	47	28.50	0.56	1.9	0.01
BLK (ENV)	5	2.26	0.45	1.5	0.20
Error	52	16.77	0.30		
Grand Mean	3.58				
CV%	15.28				
LSD5%	1.12				

There is no observable significant difference among the traits measured except the grain yield at (P < 0.01) at Akabba location, and about 8 genotypes yielded above the average mean yield (3.5t/ha) Table 3. About 38% of the genotypes had higher grain yield above 4.0t/ha.

Table 3. *Agronomic evaluation at Akabba location.*

Variety	Plant height (cm)	No. Tiller /plant	No. effective tillers /plant	Panicle length (cm)	Days to 50% flowering	Grain Yield t//ha
NERICA 4	117.5	13	11	25.0	75	4.60
UPN 257	84.0	14	9	24.0	89	4.54
UPN 268	79.0	14	12	24.5	96	4.50
UPN 236	85.5	13	12	22.0	82	4.15
UPN 234	76.0	11	9	22.5	95	4.07
FARO 59	107.5	12	12	24.0	79	3.77
UPN 276	73.5	15	12	17.0	95	3.65
UPN 345	73.5	13	11	24.5	96	3.30
UPN 266	75.5	16	14	23.0	89	3.20
UPN 228	73.5	12	10	24.5	92	2.93
UPN 349	78.5	13	13	24.0	97	2.80
UPN 347	94.0	10	9	24.0	94	2.30
MATA MALLAM	103.5	16	13	26.5	82	1.30
Mean	85.2	13.0	11.1	23.5	89.3	3.5
STD	14.15	1.113	0.873	2.115	7.083	0.827
Probability	NS	NS	NS	NS	NS	**

**= significant at 0.01 probability level, NS = non-significant.

At Bakin Rijiya location, only panicle length and grain yield had significant difference (P < 0.01) and 46% of the genotypes had grain yield above 4.0t/ha Table 4. The panicle length had a mean of 22.82 cm and the longest panicle was observed in UPN 234.

Table 4. *Agronomic evaluation at Bakin Rijiya location.*

Variety	Plant height (cm)	No. Tiller /plant	No. effective tillers /plant	Panicle length (cm)	Days to 50% flowering	Grain Yield t//ha
UPN 257	82.3	12	11	24.0	76	4.30
UPN 236	85.0	13	12	24.0	82	4.25
UPN 268	80.0	14	13	23.0	96	4.25
NERICA 4	130.0	12	12	24.5	75	4.20
UPN 234	78.0	11	14	25.5	96	4.10
FARO 59	112.5	12	12	22.5	79	4.00
UPN 228	74.0	14	12	24.0	90	3.65
UPN 276	71.5	14	12	20.5	95	3.55
UPN 345	73.5	14	13	19.0	96	3.05
UPN 266	74.5	16	13	21.0	89	2.90
UPN 349	75.5	13	12	22.0	96	2.75
UPN 347	95.0	10	10	20.0	93	2.40
MATA MALLAM	107.5	17	16	24.5	82	0.70
MEAN	87.63	12.94	12.13	22.66	88.04	3.39
STD	17.346	1.275	2.794	1.800	8.509	0.887
PROBABILITY	NS	NS	NS	**	NS	**

** = significant at 0.001 probability level NS = non-significant.

At Buba location, three agronomic traits showed significant variations among the genotypes tested, UPN 347 had grain yield above 5.00t/ha (Table 5). The mean grain yield was 3.25t/ha and only five genotypes had grain yield above the mean yield. The earliest maturing genotype was NERICA 4 and the earliest anther culture materials were UPN 234 and UPN 257 (Table 5).

Table 5. *Agronomic evaluation at Buba location.*

Variety	Plant height (cm)	No. Tiller /plant	No. effective tillers /plant	Panicle length (cm)	Days to 50% flowering	Grain Yield t//ha
UPN 347	68.0	13	10	19.0	89	5.2
NERICA 4	60.6	13	11	25.5	78	4.4
UPN 234	52.5	11	9	25.0	92	3.8
UPN 268	60.5	14	11	23.0	93	3.5
UPN 257	70.0	11	8	24.5	84	3.4
FARO 59	100.0	9	8	24.0	80	3.2

Variety	Plant height (cm)	No. Tiller /plant	No. effective tillers /plant	Panicle length (cm)	Days to 50% flowering	Grain Yield t//ha
UPN 345	79.5	17	15	19.0	89	3.2
UPN 349	52.0	15	13	23.5	86	3.0
UPN 276	64.5	10	9	20.0	86	2.8
UPN 266	57.0	12	9	20.0	93	2.7
UPN 236	54.5	13	11	23.5	82	2.6
UPN 228	66.0	14	12	23.0	88	2.6
MATA MALLAM	94.0	17	14	24.0	81	1.9
MEAN	67.62	12.73	10.50	22.62	85.96	3.25
STD	7.356	1.924	1.696	2.172	4.494	0.676
PROBABLITY	NS	NS	NS	***	**	*

*, **, and *** significant at 0.05, 0.01 and 0.001 probability level respectively, NS = non-significant.

Only number of tillers per plant and effective tillers, which are the number of harvestable tillers at the time of harvest showed significant difference among the genotypes (Table 6). It was observed that the genotypes performance based on grain yield were better at Duduguru with mean grain yield of 4.12t/ha as compared to other locations.

Table 6. *Agronomic evaluation at Duduguru location.*

Variety	Plant height (cm)	No. Tiller /plant	No. effective tillers /plant	Panicle length (cm)	Days to 50% flowering	Grain Yield t//ha
UPN 268	89.5	14	13	24.0	96	5.5
UPN 257	103.1	15	13	21.7	88	4.7
UPN 276	82.5	9	8	24.0	96	4.7
NERICA 4	125.0	12	11	24.0	76	4.7
UPN 234	91.5	14	11	24.5	94	4.6
UPN 228	86.0	15	13	25.0	92	4.5
UPN 236	77.5	12	10	26.0	83	4.4
UPN 345	78.5	13	11	21.0	93	4.3
FARO 59	200.0	14	13	24.0	80	4.1
UPN 347	80.5	10	8	23.5	94	4.0
UPN 349	97.5	13	11	22.0	96	3.3
UPN 266	74.5	9	7	22.5	89	3.1
MATA MALLAM	172.5	15	12	24.5	83	2.1
MEAN	104.51	12.38	10.71	23.59	89.23	4.12
STD	37.043	1.786	1.866	0.944	4.672	0.828
PROBABILITY	NS	**	**	NS	NS	NS

** = significant at 0.01 probability level, NS = non-significant.

At Keffi location, number of tillers per plant and effective tiller numbers showed significant difference among the genotypes tested (Table 7). The mean grain yield was 3.72t/ha and about 54% of the genotypes had grain yield above 4.0t/ha (Table 7).

Table 7. *Agronomic evaluation at Keffi location.*

Variety	Plant height (cm)	No. Tiller /plant	No. effective tillers /plant	Panicle length (cm)	Days to 50% flowering	Grain Yield t//ha
NERICA 4	117.5	14	13	25.5	75	4.8
UPN 268	74.5	14	13	23.5	96	4.7
UPN 276	80.0	13	11	24.0	96	4.5
UPN 236	92.5	14	13	24.0	84	4.4
UPN 257	89.9	14	12	23.0	89	4.4
FARO 59	99.0	13	12	24.0	80	4.3
UPN 349	80.0	10	10	20.0	96	4.0
UPN 234	81.0	10	8	23.5	95	3.6
UPN 228	77.5	12	9	24.5	92	3.5
UPN 345	75.0	13	12	20.5	95	3.3
UPN 266	74.5	14	12	20.5	91	3.0
UPN 347	90.0	11	10	22.0	94	2.9
MATA MALLAM	117.5	16	14	25.0	84	1.1
MEAN	88.38	12.88	11.31	23.08	89.77	3.72
STD	14.536	1.627	1.547	1.704	4.806	0.979
PROBABILITY	NS	***	**	NS	NS	NS

, and * significant at 0.01 and 0.001 probability level respectively, NS = non-significant.

Combined analysis across the five locations showed significant difference based on agronomic characters observed (Table 8). NERICA 4 had the highest yield and the earliest genotypes of 76 d to 50% flowering followed by MATA MALLAM (local check) 82 d and 85 d for antler culture derived materials respectively. The anther culture materials occupied from second to forth position based on yield performance of the genotypes evaluated. There are five genotypes of the anther culture materials above the mean yield (3.58t/ha) of the experiment (Table 8).

Table 8. *Agronomic performance of genotypes across locations.*

Variety	Plant height (cm)	Number of tillers/plant	Number of effective tillers /plant	Panicle length (cm)	Day to 50% flowering	Grain yield/ha
NERICA 4	110.12	13	11	24.90	76	4.52
UPN 268	76.70	14	12	23.60	95	4.48
UPN 257	81.00	13	11	23.90	85	4.13
UPN 234	75.80	11	10	24.20	94	4.01
UPN 236	79.00	13	11	23.90	83	3.95
FARO 59	123.80	12	11	23.70	80	3.88
UPN 276	74.40	12	10	21.10	94	3.83
UPN 345	76.00	14	12	20.80	94	3.43
UPN 228	75.40	13	11	24.20	91	3.42
UPN 347	85.50	10	9	21.70	93	3.35
UPN 349	76.70	13	11	22.30	94	3.16
UPN 266	71.20	13	11	21.40	90	2.98
MATA MALLAM	119.00	16	14	24.90	82	1.42
MEAN	86.51	12.77	11.15	23.12	88.45	3.58
LSD	18.23***	1.73***	1.90**	1.44***	2.56***	0.63***
CV%	23.80	15.29	19.14	7.03	3.27	19.88

, and * significant at 0.01 and 0.001 probability level respectively.

3.2. Principal Component Analysis

Principal component analysis for locations shown in Table 8. The principal component 1 (Prin 1) contributed more than 75.5% of the total variations observed in the locations and all the locations contributed highly except Buba to Prin 1 of the variations observed in the experiments. However, Buba location contributed highly to Prin 2 and Keffi to Prin 3 (Table 9).

Table 9. *Principal component analysis for locations.*

Eigenvectors			
Location	**Prin 1**	**Prin 2**	**Prin 3**
Akabba	0.49045	-0.173959	0.232013
Bakin Rijiya	0.49703	-0.179239	0.01455
Buba	0.226676	0.954579	0.175543
Duduguru	0.478087	0.063152	-0.824911
Keffi	0.482153	-0.149677	0.484421
Eigenvalue	0.755	0.176	0.037
Cumulative value	0.755	0.931	0.968

3.3. Stability Analysis Using GGE Biplot

The GGE biplot analysis showed that PC 1 and PC 2 contributed about 76.6% and 16.5% of the observed variations in the experiments, respectively (Figure 1). The varieties were ranked based on the direction indicated by the single-headed arrow (average tester coordinate) in ascending order of the mean grain yield of the experiments. Therefore, stability of varieties was equally ranked based on their projection from the average tester coordinate (axis) of the average environment main effect. The greater the length of the projection of a variety, the more unstable that variety. The highest yielding genotypes based on the direction indicated by the single-headed arrow were the most stable genotypes across locations NERICA4, UPN268, UPN257 and UPN234. The most unstable genotype was UPN347, the local check Mata Mallam was stable but low yielding (Figure 1). The varieties at the vertices of the pentagon had highest grain yield at that location [7]. The varieties at the apex of the vertices were best performed at that location (Figure 2). At location Buba, UPN347 performed best based on yield was located at apex of the vertices closed to Buba, while NERICA4 at Duduguru and UPN236 and UPN268 performed best at Akabba, Bakin Rijiya and Keffi, however, Duduguru location is the most idea because is closed to the zero mark of average tester coordinate (axis) (Figure 2). Thus, from the visual Biplot, two mega environments were identified, environment 1 has Buba and environment 2 comprised (Akabba, Bakin Rijiya, Duduguru and Keffi) Figure 2.

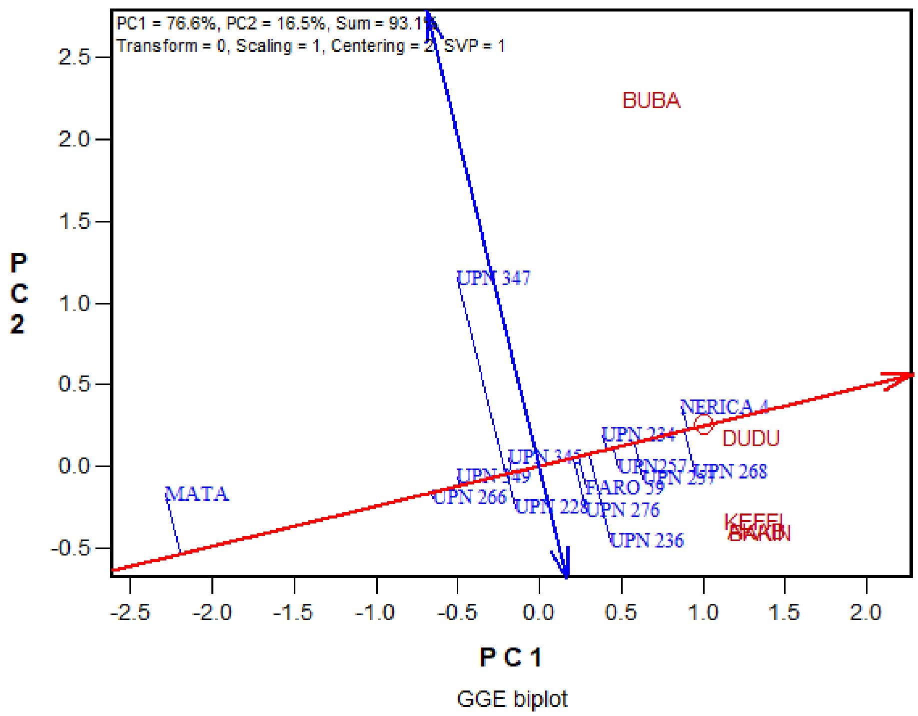

Figure 1. *Stability analyses across four locations in Lafia Nassarawa state in 2020 planting season.*

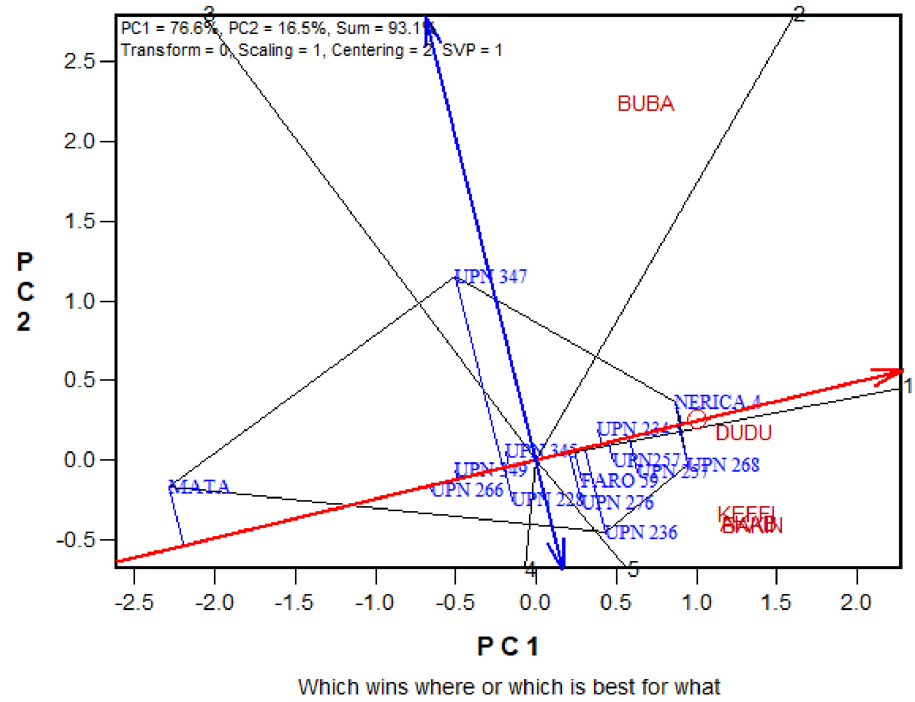

Figure 2. *Which variety wins where and which best variety.*

4. Discussion

4.1. Agronomic Performance of the Genotypes

The analysis of variance for grain yield showed significant differences among the genotypes and environments tested. Genotypes expressed better performance in some environments like Duduguru as compared to others and as variability is one of the most important factors in plant breeding [9]. The increase in world rice production will depends on the development of new cultivars with high yield and stable performance across diverse environments [10]. Currently, there is needs to develop and release varieties for eco-specific based on their performance and farmers' preference of the area. This will therefore facilitate the breeders in releasing new crop varieties. The following genotypes performed well across all the locations NERICA4, UPN257 and UPN268 that could be deployed to his locations the results also corroborate, they stated that eco-specific breeding could accelerate the release of new varieties [11]. Other agronomic traits that showed significant variation were plant heigh, tiller number and effective tillers. The effective tiller numbers are the number of tillers that produced harvestable economic yield at harvest time. The local check (MATA MALLAM) had the highest numbers of harvestable tillers but with poor yield, which could be due to genetic effects as compared to other genotypes. These results showed that the anther culture derived progenies from Korea performed effectively well and some of the genotypes could be recommended for Nigeria agricultural systems. It has also been reported that effective tillers had significant correlation with total grain yield and plant height under copper stressed condition [12].

The panicle parameters are one of the major grain yield determiners in rice crop, as grain yield is a function of the panicle parameters, therefore they could be used as secondary trait in the selection for grain yield and genotype performance [13]. Genotypes UPN 268 and UPN 345 expressed good panicle parameters across locations. Panicle length is one of the yield determinants and the longer the panicle length the more rice spikelet that could be accommodated thus corroborate the earlier report [14, 15].

Plant height is a good agronomic traits and preference for height varies from localities and it is also culture dependent [16]. Plant height is one of the predominant factors determining the nitrogen response of rice plant and determines the rate of lodging in genotypes, and lodging genotypes had reduced yield and poor grain quality. On the other hand, tall plant facilitates light penetration which may enhance high photosynthetic activities of plant [17, 18]. All the anther culture derived genotypes are of medium height that could be resistant to lodging.

Tillering ability in rice is an important agronomy trait for grain production and a report showed that high tiller numbers were most reliable character in selecting genotypes of rice for higher yield [19]. Higher tillers result in higher sink: source ratio, spikelet number, proportion of filled grain, leaf area per panicle and sink capacity [20]. Therefore, varieties such as UPN268 (14) and UPN345 (14) with high tillering ability could exhibit some of these above characters.

4.2. Principal Component Analysis

Technically, a principal component is usually defined as a linear combination of optimally weighted observed variables. The proportion of variation in principal component one (Prin 1) was about 75.5% of the total variation. Location Akabba, Bakin Rijia, Duduguru and Keffi had contributed significantly to the variation in Prin 1 because of their high weigh and factor loading values (Table 9). This showed that these locations were highly correlated, and they could serve as one location to reduce the cost of multilocational trials in the breeding programme. While in Principal component two (Prin 2), the location Buba significantly contributed 95.5% of the total variation. Location Buba was also negatively correlated with some other location like Akabba (Table 9). The location Buba could be regarded as distinct environment good for multilocational comparisons.

4.3. Stability Analysis Using GGE Biplot

Wide adaptation and stability of genotypes are considered as some of the most important traits in breeding programs. Stability of genotypes across environments is an important index of genotype performance. Breeders are very much concern about yield, which has grate economic value to farmers. Yield is quantitatively control by multi-genes and environmentally dependent. A better understanding of genotype × environment interaction plays a vital role in the identification of stable genotypes for commercialization of the cultivars [21]. It has been observed that combination of analysis of variance over locations and stability parameters could be precise concept in identification of high yielding and stable genotypes in multi-environmental trails [22]. The GGE refers to the genotype main effect (G) and the genotype x environment interaction (GE), which are the two most important sources of variation for cultivar evaluation in a multi environment trials [23]. Biplot analysis revealed differential response of genotypes to locational changes by visual pattern. The results showed that the most stable genotypes across locations were NERICA4, UPN268, UPN257 and UPN234 and the most unstable genotype was UPN347, but the local check (Mata Mallam) was stable but low yielding, its stability could be one of the major reasons the local farmers were still cultivating Mata Mallam. As indicated above, this experiment has identified high yielding and stable genotypes that could replace the local variety (Mata Mallam). Stability of genotypes are considered as one of the most important traits in developing new varieties that will be acceptable by farmers across ecologies [24]. The experiment has identified two mega environments that could lead to cost reduction in multilocational tries. The genotype UPN347 performed best in environment 1 while in environment 2 NERICA4, UPN268, UPN257 and UPN234 were the best performed genotypes, these genotypes could be deployed into these environments for farmers used. These results showed that genotypes of anther-culture derived rice from Korea were very promising and stable across the ecosystems tested in Nigeria.

5. Conclusion

The increase in world rice production will depends on the development of new cultivars with high yield and stable performance across diverse environments. Currently, there is needs to develop and release varieties for eco-specific based on their performance and farmers' preferences of that location. Genotypes expressed better performance in some environments like Buba were UPN234 performed better as compared to others and variability is one of the most important factors in plant breeding. Biplot analysis revealed differential response of genotypes across the locations. The results showed that the most stable genotypes across locations were NERICA4, UPN268, UPN257 and UPN234 and the most unstable genotype was UPN347. The local check (Mata Mallam) was stable but low yielding, its stability could be one of the major reasons the local farmers were still cultivating Mata Mallam. The experiment has identified two mega environments that could lead to cost reduction in multilocational tries.

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