GENOTYPE X ENVIRONMENT ANALYSIS OF TRAITS RELATED TO GRAIN YIELD OF UPLAND RICE

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ABSTRACT

Nine rice genotypes were cultivated over four environments generated from the early and late rains in two ecologies located forest and derived savannah ecologies in south western Nigeria to characterize genotype compatibility to cultivation environment. Grain weight per plant (GWPP) and other grain yield components were subjected to the additive main effect and multiplicative interaction (AMMI). Genotype and genotype by environment (GGE) analysis of GWPP was additionally done to identify genotypes with high but stable grain production and gain insight into the performance of grain yield components in order to assist in plant breeding efforts. The genotypic effect was significant for all traits except number of tillers(NT) and grain weight per panicle (GWPPN). The environment was significant for all traits while the interaction of genotype and environment (G x E) was equally significant for all traits except GWPPN. The AMMI PC1 was significant for all traits while the AMMI PC2 was significant only for TN, panicle secondary branching, spikelets number per panicle and spikelets fertility. Environment explained a significant 90.9% of the variation through the AMMI analysis for GWPP. Genotype and G x E captured equally significant 1.8% and 4.8% respectively. The PC1 for GWPP was responsible for 94.2% of the G x E. The GGE biplot for GWPP summarized 98.3% of the total variation and separated the four environments into three with similar genotypes. WAB 56-50 was best for GWPP but less stable compared to ITA 321, IRAT 170 and WAB 181-18 with above average but stable grain production.

Keywords: *Oryza sativa*, variation, classification, stability, grain yield components, grain yield

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Introduction

Rice grain yield has long been established to be influenced by different ecologies. Differential genotype response within and between specific ecologies exemplified by aerobic upland and lowland conditions, with differing soil moisture, soil mineral content, altitude, temperature etc. have been reported (Samonte *et al*., 2005, Ouk *et al*., 2007, Acuna *et al*., 2008, Nassir and Ariyo, 2011, Cairns *et al*., 2011, Jaruchai *et al*., 2018, Inabangan-Asilo, 2019). Grain yield remains the ultimate focus of most breeding efforts, although the response of other traits cannot be ignored. Grain yield is a function of the contributory vegetative and reproductive traits, and corresponding different cultivation ecologies. Several findings on different rice traits have attracted enough interest in the response of yield components to variable environments. Several researches had shown that many rice traits express variability due to the environmental factors, cultivation methods and inherent genetic components. These traits include tiller number, plant height and maturity (Laffitte *et al*., 2007), moderate plant size and thick roots for soils with variable moisture (Kamoshita *et al*., 2008), tiller number, percentage of filled spikelets, spikelet number per panicle (Moradpour*et al*., 2011; Shrestha *et al.,* 2012), and most panicle and grain characters (Liu *et al*., 2008, Nassir and Alawode, 2016).Tropical rice paddies are often defined by between and within location and season soil moisture differences, which itself is predicated upon rainfall, soil mineral nutrition factors among others (Pantuwan *et al*., 2002, Nassir and Ariyo, 2006; Kumar *et al*., 2008, Olaleye *et al*., 2010,). Indeed, many reports from genotype-environment analysis identified the environment as having the largest proportion of genotype-environment (GE) interaction (Yan *et al*., 2000; Samonte *et al.,* 2005; Egesi *et al*., 2007; Ouk et al., 2007, Acuna *et al*., 2008; Nassir and Ariyo, 2011, Inabangan-Asilo *et al*., 2019).Improved grain yield, being the ultimate goal of rice improvement has been established to benefit from direct and indirect selection through the components. Kumar *et al.* (2008) had observed that direct selection under moisture stress environment is advantageous in development of rice genotypes with superior grain yielders. Shrestha *et al* (2012) had however noted that stability of rice genotypes across environments reflected the target environments they were originally selected for and that contribution of yield components to grain yield is influenced by environmental conditions the rice experienced during the development stages.

The use of some statistical tools has assisted in classifying genotypes and environments and identifying genotype adaptation to specific environments. Such tools as the AMMI, GGE biplots and other stability indices have proved to be efficient in identifying genotypes that are compatible with environmental groupings. (Gauch and Zobel, 1997, Yan *et al*., 2000, 2007, Gauch, 2006, Ouk *et al*., 2007, Acuna *et al*., 2008).The practicality of the tools become even more valuable when the traits that confer the adaptation to environment clusters can be isolated. This information will assist the breeder in set breeding objectives for increase grain yield and genotypic adaptation. The objectives of this study is therefore to examine the performance of rice genotypes in four environments located in two rice cultivation ecologies in south west Nigeria and to identify traits related to grain yield as a selection criteria for rice genotypes adapted to the ecologies.

Materials and methods

Study locations: Research plots were established at Ayetoro and Ago-Iwoye campuses of the Olabisi Onabanjo University. Ayetoro occupies part of the derived savannah ecology with total rainfall of of 336.3mm and mean temperature of 27.2^{0}C for early season, year 1 (AY1) and rainfall of 760.6mm and temperature of 26.9^{0}C for the late season, year 2 (AY2) over the cultivation period(Table 1). The Ayetoro experimental site has a loamy soil with the coordinates 7.23091^{0}N and 3.04630^0 E and an elevation of 272ft above sea level (a.s.l.). Ago-Iwoye is located in the rain forest region with total rainfall of 964.5mm and mean temperature of 26.2^{0}C for early season year 1 (AG1) and rainfall of 827.4mm with mean temperature of 25.9^{0}C for late season, year 2 (AG2) over the cultivation months (Table 1). The experimental site coordinates are 6.95471^{0}N and 3.90413^{0}E and an elevation of 118ft a.s.l. The soil of the experimental site was a sandy loam.

Plant establishment: Seed were sown with the early and late rains in both locations. Nine upland rice genotypes including established varieties and breeding lines were used. These are ITA 150(G1), WAB 56-50 (G2), WAB 224-8-HB (G3), ITA 321 (G4), OS6 (G5), ITA 257 (G6), WAB 337-B-B-20-1-129 (G7), IRAT 170 (G8), and WAB 181-18 (G9). Three weeks old seedlings were transplanted into ploughed and harrowed plots as rainfall became regular. An inter-plant and inter-row spacing of 30cm was used. Each genotype occupied 3m single row plots at 10 plants per row. The rows were arranged in a randomized complete block design and replicated three times. Adequate agronomic practices, including weeding at 3 and 6 weeks after planting (WAP), insect pest control with foliar sprays of Cypermethrine 10% EC at maximum tillering and panicle filling stages and soil fertilization with 100kg of NPK 20:10:10 and 60Kg Urea at 2 and 6 WAP respectively (Oikeh *et al*., 2008, IRRI, 2015).

Data collection and analysis: For each of the established plots in each season and location, six plants in the middle of the rows were used to collect vegetative and yield data as described by IRTP (2013).

The additive main effect and multiplicative interaction (AMMI) was carried out for all the traits while the genotype plus genotype by environment interaction (GGE) analyses was done for the grain weight per plant (GWPP), being a trait that cumulatively translate to grain yield. Correlations of trait means with AMMI PC 1 and 2 were also obtained. Genotypes with striking features as detected by the GGE analysis were classified along with their trait means. The GENSTAT software package, 12^{th} Edition (Payne *et al*., 2009) was used for all the statistical analyses.

Results

The mean squares from AMMI GxE analysis for rice traits are as shown in Table 2. The genotype effect was significant for traits, with the exception of tiller number and grain weight per panicle. The environment was significant ($p<0.01$) for all traits. Variation within plot indeed accounted for sizable and significant component of the variation for the traits except panicle number, panicle length and grain weight per panicle. The G x E was significant for all the traits and was substantially accounted for by the first Interaction principal Component Axis (IPCA 1) for all traits. The IPCA 2 was also significant ($p<0.05$) for tiller number and panicle secondary branching; and also significant ($p<0.01$) for spikelet number per panicle and spikelet fertility.

Table 3 presents the AMMI analysis of grain weight per plant over the four environments. The genotype and environments were significant ($p<0.01$). The environment accounted for about 91% of the total variation within 3 degrees of freedom (df). Genotype accounted for only 1.8% of the total variance within a larger 8df. The block effect was also significant ($p<0.05$). The interaction component was significant ($p<0.01$) and accounted close to three times (4.8%) the magnitude of variation due to genotypic effect. The interaction component was described largely by IPCA 1 with a significant 94.2% leaving a non-significant 5.8% in the residual.

The environment centered GGE biplot for grain weight per plant (Fig.1) separated the environments into three. The Ago-Iwoye environments (AG1 and AG2) clustered together and were identified with WAB 337-B-B-20-1-129 (G7) as the best in the environments. ITA 321 (G4), IRAT 170 (G8), and WAB 181-18 (G9) were also grouped along with the Ago-Iwoye environments. The Ayetoro environments were separated into two with WAB 56-50 (G2) being the best for the AY 2 (late season) while ITA 150 (G1) had the best adaptation to the early season.

The ranking and stability indicators for grain weight per plant of the upland rice genotypes are shown in Fig 2. WAB 56-50 (G2) had the overall best grain weight per plant across the environments, followed by WAB 337-B-B-20-1-129 (G7); while OS6 (G5) was the least. ITA 321 (G4), IRAT 170 (G8), and WAB 181-18 (G9) had the best stability rating compared to the others. ITA 150 (G1) was the most unstable followed by WAB 224-8-HB (G3) and WAB 56-50 (G2) respectively.

The means of specific groups identified by the GGE analysis is presented in Table 4. ITA 150 (G1) had the least spikelet number per panicle and grain weight per panicle but recorded the highest 100-grain weight. However,, the highest mean spikelet number per panicle was recorded by WAB 56-50 (G2), along with the largest mean panicle number, panicle length, primary and secondary branching, all culminating into the highest mean grain weight per plant (61.03g). ITA 321 (G4), IRAT 170 (G8), and WAB 181-18 (G9) group had the highest mean grain weight per panicle but also had the least mean trait value for final height and panicle length even though the genotypes shared the same sector with WAB 337-B-B-20-1-129 (G7) which had the tallest plants, the least mean panicle number 100-grain weight. WAB 224-8-HB (G3), OS6 (G5) and ITA 257 (G6) had generally low means for the traits and are not classified with any of the environments.

Discussion

The significant mean squares for most traits affirmed the presence of variability among the genotypes thereby showing that it is adequate to influence specific relationship with the environments. The environment, by its significance also presented enough variability to help in the understanding peculiar genotype performance. The interaction of genotype and environment expresses the typical instability of rice across upland ecologies. The first IPCA which describes the non-cross over (linear) feature of the interaction (Yan *et al*, 2000, Nassir *et al*., 2018) appeared to be the major contributor to G x E across the study environments. This may be advantageous as the effect of unpredictable interactions is minimized. This is even more definite with panicle number, panicle length and spikelets fertility which had significant correlation alluding to significant non crossover prediction of genotypic performance based on IPCA 1 (Yan and Hunt, 1998, Yan *et al*., 2000). The significant IPCA 2 obtained for number of tillers, panicle secondary branching, spikelet number per panicle and spikelet fertility is indicative of the disproportionate response to environment and the presence of cross-over effect (Yan *et al*., 2000 and Gauch, 2006). The traits are therefore likely to confer instability on the genotypes with higher means for the traits.

The high proportion of the %SS accounted for by the environment for grain weight per plant is indicative of the large contrast between the environment but more importantly, the disadvantage of specific location-based development of cultivars and blanket recommendation of same across large upland ecologies. Tropical upland ecology is quite unpredictable even within season in a location (Acuna *et al*., 2008, Olagunju *et al*., 2018) hence the need to develop genotypes for specific location in order to minimize grain yield instability.

The separation of four environments into three sectors underscores the immense variation that cultivation conditions can cause across ecologies. This would also require the development of many genotypes that would be required to take advantage of each environment cluster. Identification of specific genotypes for specific environment is part of the strength of the AMMI analyses and GGE biplot (Zobel *et al*., 1988, Gauch and Zobel,1997, Yan *et al*., 2000, Samonte *et al*., 2005, Gauch, 2006). Although the Ago-Iwoye environment was similar over the two seasons, the Ayetoro environments differ markedly due to difference rainfall intensity over the cultivation months for the two seasons and the observed uneven distribution of rainfall over the cultivation months. The Ago-Iwoye forest ecology status was high in rainfall but the temperature was lower than the Ayetoro ecology. A combination of high soil moisture and air temperature encourages high evapotranspiration and increases vegetativeness, from which grain filling would conscientiously draw. This perhaps explains higher expression of the potential of WAB 56-60 (G2) in the ecology. The genotype (WAB 56-60) recorded the highest mean panicle number, panicle length, primary and secondary branching and spikelets number per panicle which culminated in the highest grain weight per plant (61.03g). Jaruchai *et al* (2018) had also observed high yield of some rice genotypes was due to the combination of some yield components of which panicle number and grain weight were prominent. WAB 56-60 is a high yielding Asian *Oryza sativa* rice crossed with *O. glaberrima* specie to develop the New Rice for Africa (NERICA) selections reputed to combine the high grain yield of the former with the drought tolerance typical of the latter (Africa Rice Center (WARDA)/ FAO/SAA. 2008). WAB 56-60, even though unstable, should find some use in carefully planned hybridization exercise to develop varieties which combine high grain yield with the stability features of ITA 321 (G4), IRAT 170 (G8)as well as WAB 181-18 (G9) which is another parental genotype in the development of the NERICA series. ITA 150 (G1) was more compatible to the limited soil moisture due to the very poor rainfall over the latter part of the cultivation period. Its strength may be due to its larger grain weight which was better than other genotypes and also above the overall average across environments. The involvement of genes for heavier grains (a function of length and size) in development of genotypes for cultivation across ecologies, particularly where variable rainfall may be the underlying factor, deserves some consideration.

Conclusion

This study evaluated the performance of nine upland rice genotypes in four environments obtained from early and late rain season plantings in Ago Iwoye, located in forest region and Ayetoro which is in the derived savannah ecologies of Ogun State. The AMMI analyses showed significant genotype x environment interaction for grain weight per plant and most of the other traits considered. This was accounted for majorly by the proportionate genotypic response to cultivation environment. The GGE analysis captured over 98% of the variation in grain weight per plant over environments and identified WAB 56-50 (G2) as compatible to the second season of Ayetoro which is characterized by high rainfall. The genotype ranked the overall best for GWPP but was also less stable and this could be due to its relatively higher mean value for most panicle traits. ITA 150 (G1) was the most unstable but was best for the season 1 in Ayetoro which had relatively low rain fall as its feature. The high yield of ITA 150 under low rainfall condition was possibly due to its higher mean 100-grain weight. The need for plant breeding to develop genotypes that would combine grain yield traits in a way that would ensure stable and high grain yield for cultivation across seasons and environment is again emphasized.

Table 1. Mean monthly temperature (MMT) and monthly total rainfall (MTR) for Ayetoro and Ago Iwoye over the four environments

Ayetoro Early Season Year 1 (AY1)			Ayetoro Late Season Year 2 (AY2)		
Month	MMT	MTR	Month	MMT	MTR
April	26.4	51.3	July	28.15	281.8
May	25.55	50.1	August	27.6	136.5
June	26.85	102.7	September	26.4	121.5
July	27.7	121	October	25.55	85
August	29.4	11.2	November	26.85	135.8
Total	135.9	336.3	Total	134.55	760.6
Mean	27.18	67.26	Mean	26.9	152.1
Ago-Iwoye Early Season Year 1 (AG1)			Ago-Iwoye Late Season Year 2 (AG2)		
Month	MMT	MTR			
March	27.5	222.1	March	26.9	96.9
April	26.8	211.4	April	25.6	198.5
May	26.2	266.6	May	25.2	40.8
June	25.3	180.9	June	26	245.6
July	25.4	83.5	July	26	245.6
Total	131.2	964.5	Total	129.7	827.4
Mean	26.2	192.9	Mean	25.9	165.5

Table 2. Mean squares from AMMI analysis of upland rice traits planted in the forest and derived savannah ecologies

Source/Trait	df	Number of tillers	Final height (cm)	Panicle number	Panicle length (cm)	Panicle primary branches	Panicle secondary branching (s)	Grain weight per panicle (g)	Grain weight per plant (g)	Spikelet number per panicle	Spikelet fertility (s)
Genotypes	8	10.9	369**	31.7*	71.8**	10.4**	0.761**	20.16	844**	8746**	5.31**
Environments	3	1649.4**	34073**	2158.2**	3155.2**	942.1**	24.813**	250.77**	113884**	243214**	86.59**
Block	8	18.9**	207**	16.3	6.3	8.7**	0.75**	16.32	245*	3082**	2.24**
Interactions	24	10.6*	158**	19.6*	60.5**	12.4**	0.469**	18.92	754**	2627**	10.75*
IPCA 1	10	13.1*	253**	34.9**	134.2**	25.8**	0.788**	34.91*	1706**	3395**	22.53**
IPCA 2	8	12.3*	104	12.6	10.9	3.5	0.315*	11.81	103	2665**	2.87**
Residuals	6	4.2	73	3.3	3.9	1.8	0.142	1.76	36	1295	1.6
Error	64	5.5	69	11.5	10.3	2.8	0.113	16.76	119	862	0.82

*,** = significant at p<0.05 and 0.01 respectively

Table 3: AMMI analysis of nine upland rice genotypes (G) planted over four environments (E)

Source	df	Sum of Squares	Mean Squares	% of SS	% of G x E
Total	107	376063	3515		
Genotypes	8	6751	844**	1.8	
Environments	3	341653	113884**	90.9	
Block	**8**	**1963**	**245***	**0.5**	
Interactions	24	18102	754**	4.8	
IPCA 1	10	17061	1706**	4.5	94.2
Residuals	14	1041	74	0.3	5.8
Error	64	7593	119	2.0	

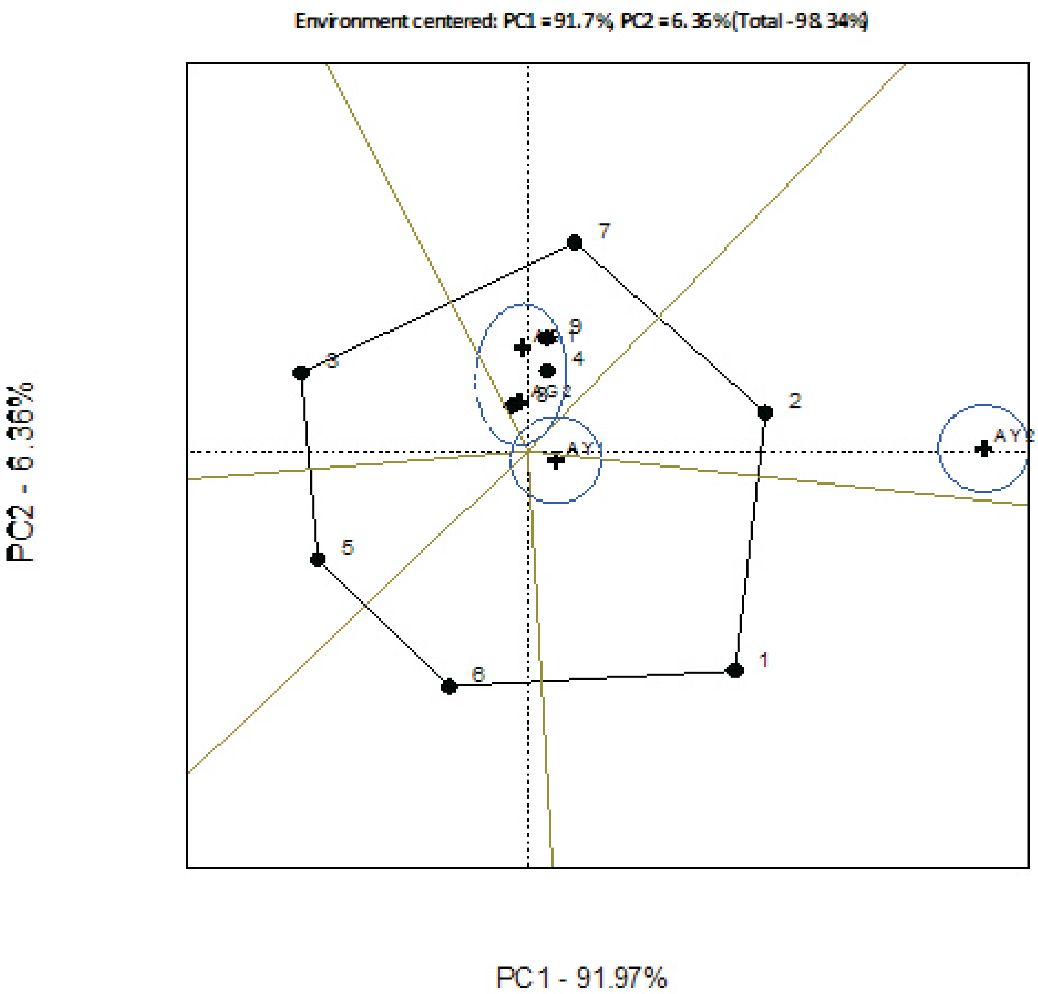

Figure 1. GGE biplot for grain weight per pant(GWPP) of upland rice genotypes (●) planted over four environments(+)
ITA 150 = G1, WAB 56-50 (G2), WAB 224-8-HB (G3), ITA 321 (G4), OS6 (G5), ITA 257 (G6), WAB 337-B-B-20-1-129 (G7), IRAT 170 (G8), and WAB 181-18 (G9).

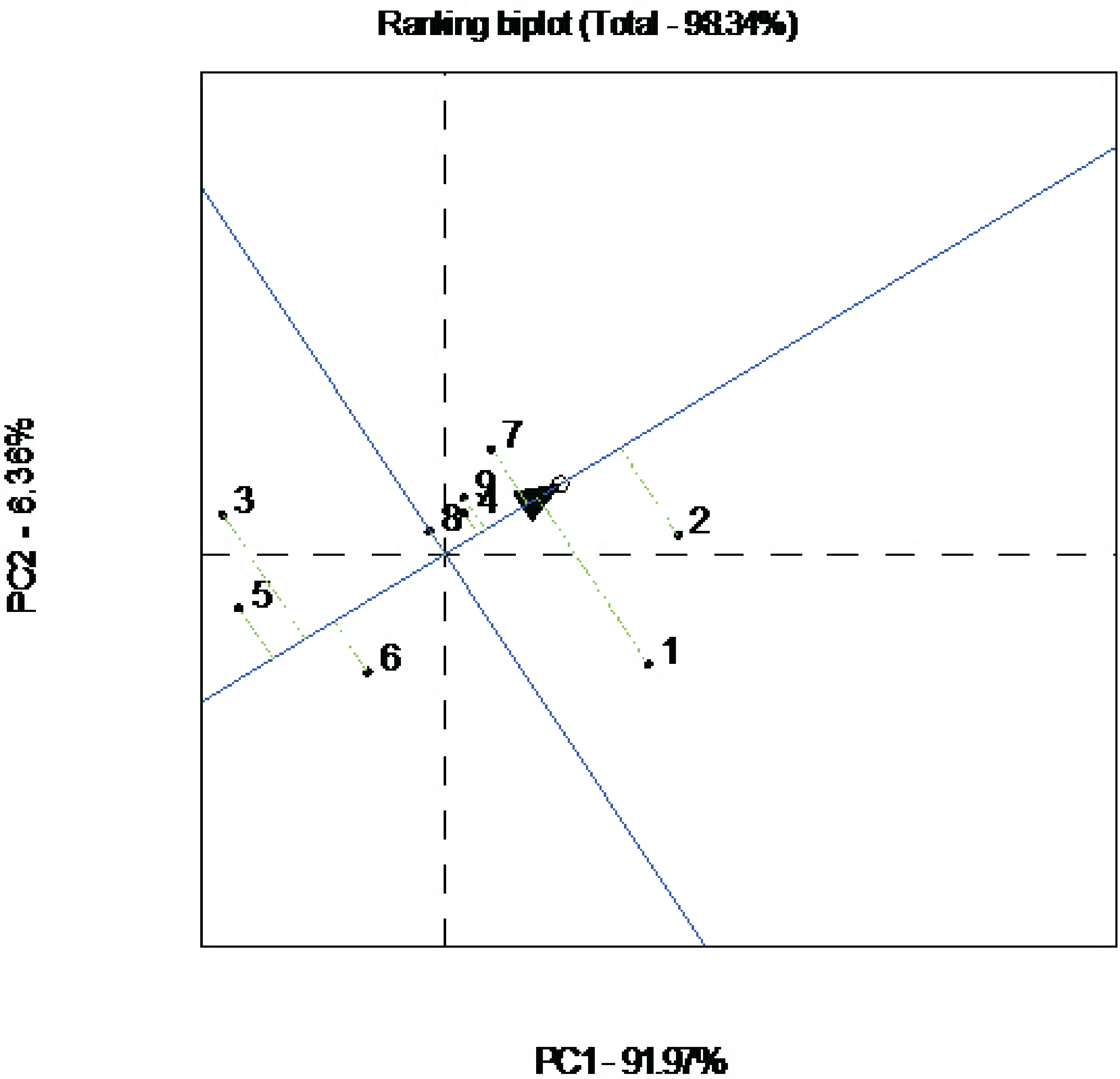

Figure 2. Stability and ranking of the upland rice genotypes(●) over the forest and derived savannah ecologies.
ITA 150 = G1, WAB 56-50 (G2), WAB 224-8-HB (G3), ITA 321 (G4), OS6 (G5), ITA 257 (G6), WAB 337-B-B-20-1-129 (G7), IRAT 170 (G8), and WAB 181-18 (G9).

Table 4. Mean values of genotype traits from environment-centered GGE biplot groups

Genotype traits	Trait means for GGE Environment-Genotype groups$^{\Psi}$					
	1	2	4,8,9	3,5,6	7	Grand mean
Tiller number	11.15	10.83	11.73	9.97	11.45	10.95
Final height (cm)	110.68	114.02	**106.78**	107.29	**119.97**	109.66
Panicle number	9.80	**12.46**	8.77	**7.78**	8.75	8.96
Panicle length (cm)	25.41	**25.90**	**20.23**	21.84	20.64	22.02
Panicle primary branches	10.90	**12.68**	10.51	**10.36**	10.61	10.75
Panicle secondary branching (s)	1.74	**2.13**	1.69	**1.65**	1.70	1.73
Grain weight per panicle (g)	4.29	5.23	**5.99**	**3.99**	4.67	4.90
Grain weight per plant (g)	53.99	**61.03**	48.77	**37.78**	52.80	47.50
100-Grain weight (g)	**3.82**	3.24	2.58	2.35	2.35	2.69
Spikelet number per panicle	**143.21**	**197.02**	150.62	150.83	168.22	156.98
Spikelet fertility (s)	3.59	3.45	4.48	3.86	4.57	4.07

ITA 150 = G1, WAB 56 -50 (G2), WAB 224 -8-HB (G3), ITA 321 (G4), OS6 (G5), ITA 257 (G6), WAB 337 -B-B-**20-1-129 (G7), IRAT 170 (G8), and WAB 181 -18 (G9); Ψ: extreme means for traits with notable range are in bold** letters.

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