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Evaluation of lowland rice (*Oryza spp.*) varieties for tolerance to flooding in freshwater and estuarine agro ecosystems in Delta State

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Abstract

The study was conducted to evaluate the best 21 identified rice varieties with the flood-tolerant trait in freshwater and estuarine environments. The experiment was a split-plot laid out in a Randomized Complete Block Design (RCBD) with three replications. The varieties by environmental interaction and stability estimate were investigated in four different environments; First Planting Estuarine (FPE)-E1, First Planting Freshwater (FPFW)-E2, Second Planting Estuarine (SPE) -E3 and Second Planting Freshwater (SPFW)-E4. Parameter accessed was Plant height (cm), Number of tillers, and Leaf diameter (cm), Days to 50% flowering, Days to 50% maturity, Number of panicle/plant, Number of grain/panicle, Harvest index, 1000 seed weight (g), Seed yields/plant(g), Seed yield (t/ha). Data collected were subjected to analysis of variance. The result showed that the partitioning of Genotype x Genotype x Environment through GGE biplot analysis showed that principal components I and II accounted for81.7% and 11.8% of GGE sum of squares, respectively, giving a total of 93.5% variation. The AMMI biplot showed a significant difference among varieties at ($P<0.05$) and Faro 44, Faro 4, Swana Sub 1, Faro 67, Faro 37, and Faro 66, giving the highest mean seed yield (t/ha) of 30.69t/ha, 30.36t/ha, 35.93t/ha, 34.73t/ha, 32.79t/ha and 32.64t/ha respectively in the winning environments E2 and E4. The study concluded Environments E2 and E4 as high yielding and stable and are therefore recommended to farmers for optimum yield.

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Introduction

Rice (Oryza *sp.*) is a member of the Poaceae family. Rice is an important crop that serves as a staple food for over 3.5 billion of the world's population and also serves as food security for many countries in Africa and Asia (Chukwu *et al.,* 2019). It is widely grown in varied environmental conditions, ranging from sea coasts to high altitudes. The major rice-growing areas are greatly affected by flooding caused by river discharge, excessive rainwater accumulation, and tidal movements. Globally, one-third of rice-cultivated areas are deep-water and rainfed lowland ecosystems, which account for about 50 million hectares (Bailey-Serre *et al.,* 2008).These areas are prone to frequent flooding, which could be attributed to poor drainage systems of excessive rainwater during the rainy season. Rice has anaerobic tolerance; however, extreme flooding, either complete or partial submergence, may result in various environmental stressors. Hence, rice cultivars respond differently to the variations in the floodwater regime (Wassmann *et al.*, 2004).

Rice has been found to thrive under four main ecologies. These are; rain-fed upland, shallow swamps and inland valley swamps (rain-fed lowland), irrigated lowland and mangrove or tidal swamp ecology (Imolehin and Wada, 2005). More than 16 million ha of rice lands in the world in lowland and deep-water rice areas are unfavorably affected by flooding due to complete submergence (Dey and Upadhyaya, 2018). Other most vulnerable deltas include Ayeyerwaddy delta in Myanmar, Red River and Mekong deltas in Vietnam. According to Wassmann *et al.* (2009), these deltas provide up to 70% of total rice cultivation areas in these countries, and continuous flooding will greatly threaten their food security. In fact, over 35% of rice-growing areas, mostly in Africa and Asia, where food insecurity is predominant, are prone to flooding (Bailey-Serres *et al.,* 2012). In Nigeria, approximately 70% of rainfed lowland rice farms are prone to seasonal flooding, which has led to serious yield losses ranging from 10% to total destruction (Akinwale *et al.,* 2012) and the most frequently affected states are Delta, Ebonyi, Kebbi, Niger, Kogi and Taraba states (Erenstein *et al.,* 2014). According to Anugwara and Emakpe (2013), the flood which occurred in 2012 damaged over 1.9 million hectares of land and reduced food production along the flood plains, and rice production in the submerged areas was reduced by 22.4% and was the most affected of all crops. Flood reduces rice production by about 22% and is one of the major constraints for rice production, particularly in rainfed lowland areas, because most varieties get severely damaged or killed within a week of severe flood effect (Dar, De Janvoy, Emerick, Raitzer and Sadoulet, 2013) and this is becoming a more serious issue concerning the global climate change, as the improved rice varieties are also susceptible to flooding (Afrin, Nafis, Hossain, Islam and Hossain, 2018). Considering the prevailing flood problem, which is almost becoming a recurrent global phenomenon and the subsequent impact of climate change on the environment, which has led to a reduction in rice production, especially in flood-prone areas. Therefore, this study seeks to bridge the gap by providing information on the flood tolerance of some lowland rice varieties. Hence the objective of the study is to identify the best rice varieties with flood-tolerant traits in freshwater and estuarine agro ecosystems of Delta State.

Materials and methods

Area of study

The experiment was carried out in Asaba and Warri, Delta State, Nigeria. The experiment was a 2-year experiment carried out during the 2019 and 2020 cropping seasons.

Asaba

The experiment was conducted at the Teaching and Research Farms of Delta State University Asaba Campus, Asaba (freshwater environment). Asaba is located between latitude 6°11'53.66" N and longitude 6°43'54.73" E, at the Equator, with a hot, humid climate, mixed vegetation of forest interspersed with shrubs and grasses. The rainfall pattern is bi-modal, with peaks in July-September and an annual rainfall amount of 2969mm; a mean temperature of 26.3-

33.5ºC and relative humidity varies from 61-89% (NIMET, 2021).

Warri

The experiment will also be carried out in National Cereal Research Institute, Warri sub-station (estuarine environment). Warri is located between latitude 5°31'. 30" N and longitude 5°46'.9"E at the Equator. The region experiences moderate rainfall and moderate humidity for the most part of the year. The climate is monsoonal and is marked by two distinct seasons: the dry season and the rainy season. The dry season lasts from about November to April and is significantly marked by the cool "harmattan" dusty haze from the northeast winds. The rainy season spans May to October, with a brief dry spell in August, but it frequently rains even in the dry season. The area is characterized by a tropical monsoon climate with a mean annual temperature of 32.8 °C and an annual rainfall amount of 2768.8 mm (NIMET, 2021).

Experimental design and plot layout

The experimental design was a split-plot laid out in a Randomized Complete Block Design (RCBD) with three replications. Location was the main plot treatment, while the rice lines (varieties) were the subplot treatment. The best 21 varieties that had the best survival and growth performance in Experiment 1 were selected and sown in the field under 0 -50cm flood water level. Germinated seedlings were sown in each plot with a spacing of 20cm by 20cm. Each plot dimension will measure 2m by 2m with 50cm in-between, giving a total of 100 plants per plot. Each variety was labeled appropriately using board markers.

Data collection

Plant height (cm): This was measured from soil level to the tip of the flag leaf with the aid of a meter rule at 2, 4, 6, 8, 10, 12 Weeks after Transplanting.

Tiller number: numbers of tillers per variety were counted at 2, 4, 6, 8, 10, 12 Weeks after Transplanting.

Number of leaves per plant: numbers of leaves on each variety were counted at 2, 4, 6, 8, 10, 12 Weeks after Transplanting.

Number of tillers/plant: The tiller number of the selected five plants was counted and their mean was computed at 2, 4, 6, 8, 10, 12 Weeks after Transplanting.

Number of grains/ panicles: Number of filled grains of five was randomly selected panicle from each of the selected plants was taken and their mean was calculated.

Panicle number was obtained by counting all developed panicles from randomly selected 10 panicles from the center of each plot. The average number of panicle was computed.

Panicle length (cm) was measured from the middle panicle using a meter rule.

Grain yield weight was obtained by harvesting rice from a one-meter square area in the middle of each plot and threshed accordingly. The paddy will then be adjusted at 14% moisture content using the formula that follows, and then the grain weights for each plot were recorded and converted into kg/ha as described by Gomez (1972).

Harvest index computed as described by (Fageria, 2001) as follows below:

$$\text{Harvest index} = \frac{\text{Grain yield (g)}}{\text{Total biomass (g/m2)}}$$

1000 seed weight(g): 100 seeds were counted for each variety in each replication and then their weight was taken in gram which was multiplied by 10 and their mean was calculated.

Seed yield (t/ha): Seed yield/plant was taken from the five selected plants for each replication and their mean was computed.

Environmental data

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)
iii. Mean monthly relative humidity (%)

Statistical analysis

The data collected were subjected to analysis of variance (ANOVA) using the Genstat package version 8.1 and means separation using LSD at a 5% level of significance. The Varieties by Environment Interaction was analysed using the Genotype and Genotype by Environment (GGE) biplot model according to Yan *et al.* (2001) and Yan *et al.* (2007). Yield data were also subjected to the Additive Main Effect and Multiplicative Interaction (AMMI) analysis using the MATMODEL version 2.0 (Gauch, 1986). The AMMI biplots were obtained from the graphical ordination of mean grain yield and the interaction principal component axes (Kempton, 1984). Coefficients of linear correlation were obtained between PC scores and some environmental indices to identify the special feature of the environment influencing the Genotype by Environment interaction (Gauch, 2006). Similarly, genotype PC scores were correlated with the means of agronomic and yield characters (Yan, 2001).

Results

Response of 21 varieties for yield-related character traits of rice

Table 1 shows the mean performance of 21 varieties for yield-related character traits in the four environments. Significant replicate effects were observed for flowering days, maturity days, plant height (cm), 1000 seed weight (g), and seed yield t/ha. The result indicates that the rice varieties varied significantly with respect to all traits.

Table 1. Weather data from 2016-2021 for Asaba.

	2016 WEATHER DATA			2017 WEATHER DATA			2018 WEATHER DATA			2019 WEATHER DATA			2020 WEATHER DATA			2021 WEATHER DATA		
	R	T	RH	R	T	RH	R	T	RH	R	T	RH	R	T	RH	R	T	RH
JAN	0	36.6	48	3.9	36.4	47	0	35.3	56	0	35.6	58	0	35.7	58	0	35.7	57
FEB	18.2	38.4	35	0	37.9	37	32	35.8	62	32	36	43	0	36.2	54	0	35.2	54
MAR	184.6	35.4	52	78.1	37.3	35	6.9	34.9	68	6.9	35.4	49	151.8	35.3	65	151.8	35.3	65
APRIL	91.6	35.5	55	268.9	34.9	52	32.5	33.7	74	32.5	34.9	58	136.5	34.6	72	126.5	34.6	72
MAY	186.2	34.4	69	354.7	34.4	62	389.8	32.6	76	389.8	34	65	222.6	33.2	78	212.6	33.2	78
JUNE	622.5	32.3	76	373.5	33.3	78	334.9	31.9	79	334.9	31.6	72	291.6	34.8	76	281.6	34.6	74
JULY	482.4	31.8	85	681.5	31.3	84	616.4	30.3	85	616.4	30	78	277.7	30.3	84	287.7	30.3	82
AUGUST	325.8	30.9	87	499.4	29.8	89	782.1	30.8	86	782.1	30.2	84	123.9	30.7	87	133.9	30.6	85
SEPT	353.1	32	83	263.3	30.3	83	811.1	31	81	811.1	31.3	86	443	29.9	89	443	29.9	87
OCT	164.4	33.5	76	404.3	32.4	76	311.7	30.2	79	311.7	31.1	84	348.2	31.4	78	338.2	31.4	74
NOV	15	35.7	65	14.2	34.4	64	102.2	33.1	72	102.2	33.1	78	10.2	34.4	72	10.2	34.4	72
DEC	68.8	35.5	58	70.5	34.6	62	69.0	34.8	64	60.5	35.2	73	83.9	35.2	68	83.9	35.2	66
TOTAL	2443.8	412	789	2941.8	407	769	3418.2	394.4	882	3418.2	398.4	823	2089.4	401.7	881	2969.4	400.4	866
MEAN		34.3	66		33.9	64		32.8	74		33.2	69		33.5	73		33.4	72.2

Source: Nigerian Meteorological Agency (NIMET)
R-Rainfall
T-Temperature
RH- Relative Humidity.

The means were highly significant for all the measured parameters. The two years differed significantly with respect to all traits observed during the study. Faro 37 was the earliest to flower at (46.17) and early to mature (79.90), followed by Faro 67 (47.00) to flower and the least to flower was Faro 17 (61.67) and also mature at 103.67 days. Faro 4 (103.89) and Faro 57 (103.41) were the tallest varieties, while faro16 (84.25), Faro 26 (89.50) and Faro 4 (92.01) were the shortest varieties. The highest number of grain/panicle was recorded by Faro 37 (172), while the varieties with the least number of grain/ panicle were Faro 26 (75.33). The highest mean seed yield was in m²/g was recorded by Faro 37

(626), followed by Faro 67 (604), while the least was recorded by Nicro 49 (301).

Additive main effect and multiplicative interaction (AMMI) analysis of variance for seed yield per plot for 21 lowland rice varieties tested across 4 environments

Table 2 presents the Additive Main effect and Multiplicative Interaction (AMMI) analysis of variance for seed yield per plot for 21 lowland rice varieties tested across 4 environments (2-locations by 2-seasons) and is presented in (Table 4). There was significant variation at (P<0.05) among varieties, environments and seed yield. The result showed that differences between the environments accounted for about half (84%) of the treatment sum of squares. The genotypes and the GxE interaction also accounted significantly for 52% and 38%, respectively, of the treatment SS. The first interaction PCA was highly significant, capturing 81.7% of the total variation in the GxE interaction SS and 63% of the interaction degrees of freedom. The second interaction PCA was also significant (P < 0.05). The first two IPCA axes jointly accounted for 93.5% of the GxE interaction SS, leaving 11.8% of the variation in the GxE interaction (within 21% of the interaction df) in the residual. The residual, in fact, accounts for only 15.7% of total SS.

Table 2. Weather data from 2016-2021 for Warri.

	2016 WEATHER DATA			2017 WEATHER DATA			2018 WEATHER DATA			2019 WEATHER DATA			2020 WEATHER DATA			2021 WEATHER DATA		
	R	T	RH	R	T	RH	R	T	RH	R	T	RH	R	T	RH	R	T	RH
JAN	0	33.6	45	3.9	36.2	45	0	32.1	52	0	32.6	59	0	34.7	56	0	34.7	55
FEB	18.2	39.1	34	0	34.5	32	35	33.5	60	32	38	43	0	34.2	55	0	32.2	54
MAR	174.6	33.4	47	78.1	35.5	33	6.8	32.7	64	6.5	35.1	55	151.8	36.3	59	143.8	36.3	59
APRIL	91.6	33.5	56	258.8	32.1	49	35.5	31.4	73	32.5	34.5	58	130.5	33.2	79	130.5	32.2	75
MAY	186.2	35.4	65	364.7	34.2	63	379.6	36.6	71	359.8	32	65	212.6	35.2	75	210.6	35.2	75
JUNE	612.5	31.3	65	373.5	34.5	76	328.9	31.9	75	334.9	31.3	72	271.6	36.8	78	271.6	35.8	78
JULY	482.4	31.8	83	681.5	30.6	80	603.4	30.3	85	612.4	30	79	270.7	34.3	82	260.7	34.3	80
AUGUST	325.8	30.9	82	489.4	27.7	87	780.1	30.5	85	772.1	27.2	81	133.9	30.7	87	132.9	30.7	89
SEPT	343.1	31	85	223.3	30.3	85	801.1	30	71	820.1	31.3	84	443	29.9	85	443	27.9	85
OCT	164.4	32.5	78	410.3	32.4	75	312.7	29.9	77	299.7	30.1	84	338.2	34.4	73	328.2	34.4	72
NOV	15	34.5	60	12.1	33.1	65	99.2	29.1	74	102.2	32.1	76	10.2	32.4	70	10.2	32.4	70
DEC	22.7	34.5	60	34.6	34.3	59	42.8	32.9	54	53.4	35.2	73	83.9	35.2	67	82.9	34.2	65
TOTAL	2413.8	401.5	760	2895.6	395.4	749	3382.3	380.9	841	3372.2	389.4	829	2046.4	407.3	866	2768.8	400.3	857
MEAN		33.8	63.3		30.8	59.2		38.6	129.4		59.9	73.5		32.7	77.2		33.4	71.4

Source: Nigerian Meteorological Agency (NIMET)

R-Rainfall

T-Temperature

RH- Relative Humidity.

Response of 1000 seed weight (g) of 21 varieties across four environments

Table 5 represents the mean for 1000 seed weight per plot of (28.73 g) was recorded by Faro 44, while the least value of (14.27 g) was recorded by Faro 20 in environment 1. In Environment 2, the 1000 seed weight per plot was highest for Swana sub 1 (27.75 g) and lowest was 17.07g for Faro 18. In environment 3, the highest 1000 seed yield weight per plot was recorded by Faro 67 (36.97 g), while the lowest was observed in Faro 24 (17.20g). In environment 4, the highest 1000 seed yield weight per plot was recorded by Swana sub 1 (39.64g), while the lowest yield weight of (17.45 g) was observed in Faro 18.

Table 3. Response of 21 varieties for yield-related character traits of rice.

Variety Codes	Varieties (names)	Days to flowering	Days to maturity	Plant height (cm)	No of Grain/Panicle	Seed yield m²/(g)
G1	FARO 66	52.0	86.3	124.6	155.0	603
G2	FARO 15	58.6	96.6	98.00	99.00	360
G3	FARO 16	57.0	95.6	106.6	77.33	305
G4	FARO 17	61.6	103.6	140.6	129.3	447
G5	FARO 18	58.6	91.0	120.3	115.0	458
G6	FARO 29	48.0	89.3	94.00	86.67	332
G7	FARO 20	52.0	96.0	84.00	103.3	410
G8	FARO 22	55.3	97.0	91.00	97.67	372
G9	FARO 24	51.3	81.3	114.6	92.33	363
G10	FARO 26	56.6	98.3	88.67	75.33	353
G11	FARO 33	52.6	99.6	83.33	84.33	316
G12	FARO 37	46.1	79.9	77.33	158.0	508
G13	FARO 4	48.6	85.1	102.3	104.0	412
G14	FARO 50	56.3	90.3	129.3	95.33	399
G15	FARO 52	50.0	96.0	128.3	102.0	416
G16	FARO 57	54.3	91.0	105.6	126.3	445
G17	FARO 44	48.6	95.3	98.33	168.6	469
G18	FARO 67	47.0	87.4	125.6	141.6	604
G19	NICRO 49	56.0	91.6	93.00	76.33	301
G20	RASA	59.3	95.3	117.6	90.30	370
G21	SWANA	56.5	88.1	142.7	172.7	626
	Mean	46.6	93.0	115.2	126.0	305
	CV%	4.5	4.3	7.3	13.5	7.8
	LSD 0.05	0.05	0.72	0.05	0.65	0.55

The different varieties reacted differently in the four environments with regard to seed yield per plot.

Seed yield of rice across four environments

The mean seed yield t/ha of the individual environments for the 2 year seasons were highly significant at (p<0.05) and individual means of environments are presented in (Table 6). The mean seed yield of varieties across environment 1 ranged between 22.12t/ha to 33.53t/ha, while the mean seed yield of varieties across environment 2 ranged between 21.63t/ha to 33.90t/ha. The mean seed yield of varieties across environment 3 ranged between 17.90t/ha to 35.97t/ha, while the mean seed yield of varieties across environment 4 ranged between 21.56t/hq to 35.93t/ha.

Table 4. Additive Main effect and Multiplicative Interaction (AMMI) analysis of variance for seed yield per plot for 21 lowland rice varieties tested across 4 environments.

Source	df	Sum of squares	Mean squares
Treatment	83	423.211	5.435 **
Varieties (V)	21	169.338	5.569**
Environment (E)	3	288.521	47.584 **
GxE	63	146.260	6.903 **
IPCA 1	22	331.590	15.072 **
IPCA 2	20	47.824	2.391 **
Residual	21	15.702	0.883 NS
Error	150	185.599	0.275NS
Total	383	1.608.045	

Therefore, the high-yielding varieties like; Faro 66, Swana sub 1 and Faro 67 showed 78.85%, 97.30% and 71.34% yield advantage over the low-yielding varieties of Faro 15, Faro 20 and Faro 22, which recorded 34.25%, 22.75% and 16.75%, respectively.

Additive main effect and multiplicative interaction (AMMI) bi-plot showing mean seed yield for environment

Environments suitable for rice production are classified according to their position found in the quadrant is presented in (Figs 1, 2 and 3).

Environments in 1st and 2nd quadrants, E2 and E4 were favorable, while E1 and E3 in 3rd and 4th quadrants of the graph were considered unfavorable environments. Therefore E2 and E4 were favorable environments, while E1 and E3 were unfavorable environments for mean for rice growth due to environmental factors, the rice yield varied among varieties. Hence, varieties like Faro 16, Faro 17, Faro 57, Faro 20, Faro 26, Nicro 49, and Faro 44 had low mean seed yield in unfavorable environments and Faro 15, Faro 4, Faro 37, Faro 67, Faro 37, Faro 18, Faro 19, Faro 66, Faro 33, Faro 52, Rasa 20 and Faro 24 had high mean seed yield in the favorable environments while Swana sub 1, Faro 67, Faro 66, Faro 44 and Faro 37 were the best yielding varieties amongst all and also the most stable varieties in the four environments.

Table 5. Mean of 1000 seed weight (g) of 21 varieties across 4 environments.

		Environments				
Code	Varieties	FPE	FPFW	SPE	SPFW	Mean
G1	FARO 66	23.8	15.9	30.9	22.9	20.6
G2	FARO 15	21.2	20.7	22.3	24.0	21.3
G3	FARO 16	24.2	22.3	30.2	33.2	25.4
G4	FARO 17	17.3	19.8	28.1	30.2	27.2
G5	FARO 18	14.9	17.0	22.9	24.1	17.4
G6	FARO 19	19.1	17.4	22.2	23.4	22.1
G7	FARO 20	14.2	19.8	24.6	23.6	20.9
G8	FARO 22	24.4	24.2	23.2	22.9	23.4
G9	FARO 24	22.4	20.0	17.2	22.6	21.5
G10	FARO 26	18.8	18.7	23.1	22.9	19.6
G11	FARO 33	16.6	18.6	23.5	23.6	23.5
G12	FARO 37	21.3	25.5	28.4	30.2	26.0
G13	FARO 4	18.8	18.7	24.5	23.5	19.6
G14	FARO 50	19.7	21.4	24.5	23.5	24.6
G15	FARO 52	21.0	23.0	23.9	24.7	23.4
G16	FARO 57	27.0	20.1	29.7	31.2	28.4
G17	FARO 44	22.2	22.6	31.5	31.8	30.6
G18	FARO 67	28.7	22.0	36.9	30.3	28.6
G19	NICRO 49	19.4	22.9	27.1	26.1	25.3
G20	RASA	17.1	19.9	33.6	34.5	20.8
G21	SWANA	23.3	27.7	35.3	39.6	35.6
	Mean	19.6	20.5	25.3	26.1	26.8
	LSD	0.52	0.55	2.33	6.28	0.56

Legend:

FPE: First planting estuarine

FPFW: First planting in freshwater

SPE: Second planting in estuarine

SPFW**:** Second planting in freshwater.

The small circle is the mean yield of varieties. However, the AEC is the double arrowed line that passes through the biplot origin and perpendicular to the abscissa representing the GE interaction or stability/instability of the varieties.

The single arrowed line points towards the direction of increasing mean yield and the two arrows on the AEC-ordinate point to greater GE interaction or lower stability. Thus, the two environments (E1 and E3) were very unstable and had lesser mean yields, while the other two environments (E2 and E4) were more stable and had higher mean yields. Swana Sub 1, Faro 66, Faro 67, Faro 44 and Faro 37 were the best (most ideal) varieties. Faro 24, Faro 19, Faro 16 and Faro 52 were the most stable varieties.

Table 6. Yield (t/ha) of 21 varieties across 4 , mean and PCA from AMMI analysis.

		Environments					
Code	Varieties	FPE	FPFW	SPE	SPFW	Mean	First PCA Score
1	FARO 66	22.1	23.6	29.5	30.2	32.6	0.03
2	FARO 15	22.7	23.9	20.7	20.4	21.5	0.36
3	FARO 16	24.9	25.1	29.6	28.5	27.4	-1.35
4	FARO 17	27.2	26.1	27.1	27.9	27.1	-0.06
5	FARO 18	24.9	23.3	23.6	24.8	23.2	0.58
6	FARO 19	23.5	25.5	20.9	19.5	21.7	0.52
7	FARO 20	22.2	22.2	18.8	20.1	22.3	0.58
8	FARO 22	24.5	24.8	23.6	24.2	23.5	0.01
9	FARO 24	23.9	22.7	23.0	21.7	22.6	0.09
10	FARO 26	24.0	24.5	20.6	21.7	24.5	-0.55
11	FARO 33	23.9	24.1	17.9	18.8	22.8	0.05
12	FARO 37	28.1	28.9	29.8	32.8	32.7	0.31
13	FARO 4	22.7	22.5	28.1	33.2	30.3	-0.35
14	FARO 50	24.9	25.3	25.4	26.9	25.8	0.52
15	FARO 52	23.1	23.4	24.2	23.2	23.8	-0.49
16	FARO 57	21.0	27.8	28.2	27.6	27.4	-0.45
17	FARO 44	28.0	27.6	28.1	30.1	30.6	1.25
18	FARO 67	29.2	23.5	24.7	34.7	34.7	0.53
19	NICRO49	22.5	22.9	28.5	28.0	28.7	0.53
20	RASA	23.5	21.6	25.7	23.3	23.7	-0.02.
21	SWANA	33.5	33.9	35.9	35.7	35.9	0.59
	Mean	25.1	25.9	24.4	24.5	29.9	0.56
	First PCA score	1.43	-1.48	0.55	0.45	28.2	

Legend:

FPE: First planting estuarine

FPFW: First planting in freshwater

SPE: Second planting in estuarine

SPFW: Second planting in freshwater.

The results of Fig. 5 represent the ranking of the varieties in the different environments, eight varieties namely; Faro 66, Faro 37, Faro 67, Faro 44, Swana sub 1, Faro 18, Faro 4 and Faro 24 were found in the favorable environments, while eight varieties namely; Faro 16, Faro 57, Faro 26, Faro 20, Faro 33, Nicro 49 and Rasa had low seed yield and were found in the unfavorable environments. The stable varieties were adaptive to wider areas and gave consistency with higher mean yields across the locations. In contrast, Faro 66, Swana sub 1, Faro 67, Faro 44 and Faro 37 were the most stable in favorable environments, while Faro 26, Faro 50 and Faro 52 were also unstable varieties with very low yields.

The varieties which had the longest vector with small IPCA fell into the center of the concentric circle and are considered the ideal varieties in terms of being the most representative of the overall varieties and the best yielding varieties. The AEC is the double arrowed line that passes through the biplot origin and perpendicular to the abscissa representing the GE interaction or stability/instability of the varieties.

Hence, the two environments (E3 and E4) were very unstable and had lesser mean yields, while the other two environments (E1 and E2) were more stable and had higher mean yields. Swana Sub 1, Faro 66, Faro 67, Faro 44 and Faro 37 were the best (most ideal) varieties, while Faro 24, Faro 20, Faro 16, Faro 4 and Faro 52 were also stable and closer to the ideal varieties, followed by Faro 57, Rasa and Nicro 49 that had above-average mean yield but were relatively unstable.

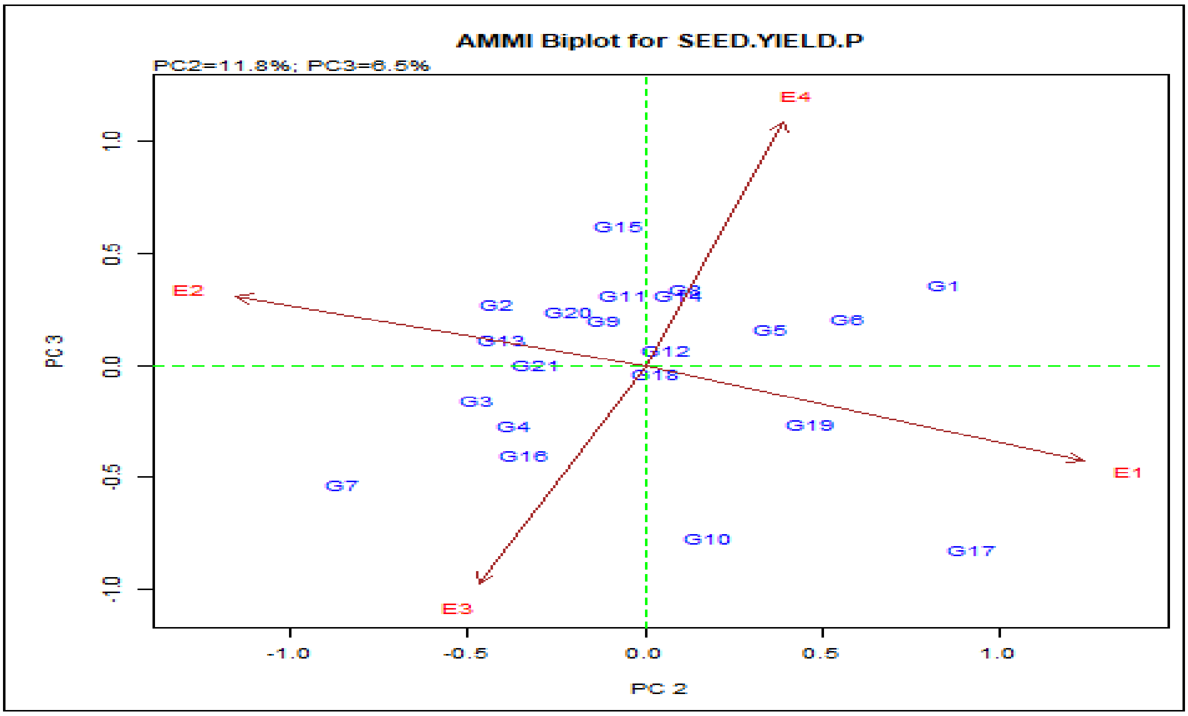

Fig. 1. AMMI Biplot for SEED.YIELD.P.

AMMI-1 model for grain yield (t/ha) showing the means of genotypes (G) and environments (E) against their respective IPCA-1 score.

The GGE Biplot environment view of seed yield is presented in Fig. 4. The first environment is termed the highest yielding environment and is found in freshwater habitat (E4), which contains outstanding varieties (Faro 66, Faro 37, Faro 44, Faro 67 and Swana sub 1) performing excellently well in them. The second environment is also termed the second-highest yielding environment and is also found in freshwater habitat (E2), also containing outstanding varieties performing excellently well in them. The third and the fourth environments are E1 and E3 with the low yielding response and they are found in estuarine habitats, containing the least performing varieties such as Faro 16, Faro 15, Faro 20, Faro 26, Rasa, Faro 22 and Nicro 49. The polygon for which varieties won where and where is presented in Fig. 6. The four environments fell into four sectors with some varieties displaying outstanding performance and the bi-plot showed that five varieties from among the other varieties were high yielding in favorable environments, hence were termed the best varieties among the rest varieties. Significant differences at ($p<$ 0.05) for seed yields were observed across the different locations due to environmental factors. Therefore Faro 66, Faro 37, Faro 44, Faro 67 and Swana sub 1 are termed ideal varieties for high seed yields and are regarded as winning varieties, while varieties such as Faro 16, Faro 15, Faro 20, Faro 26, Rasa, Faro 22 and Nicro 49 had low seed yields and are regarded as unstable and unfavourable varieties.

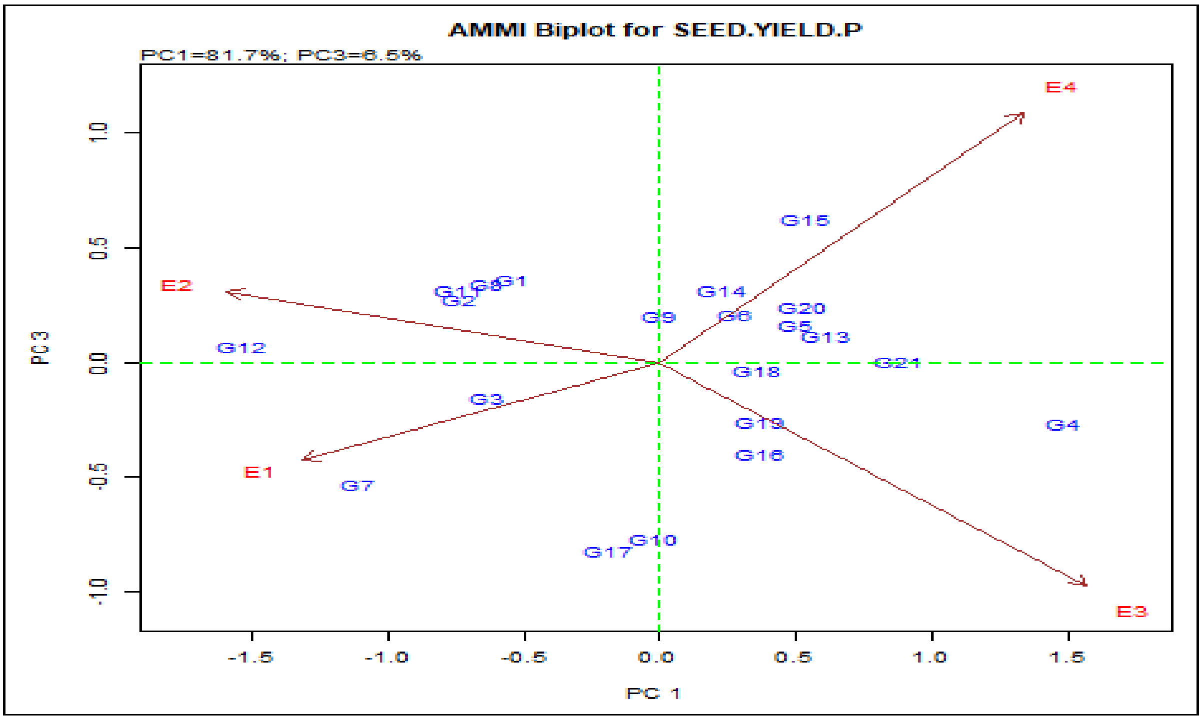

Fig. 2. AMMI Biplot for SEED.YIELD.P.

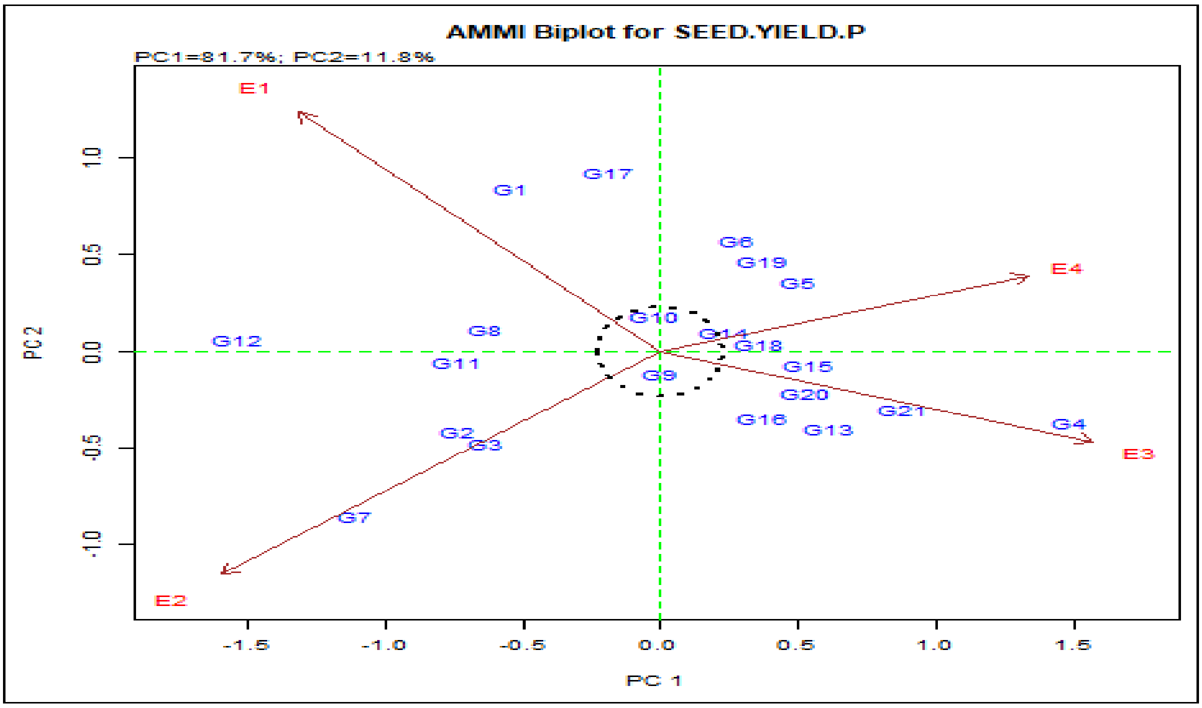

Fig. 3. AMMI Biplot for SEED.YIELD.P.

The Average Environment Coordinate points of GGE biplot view for environment for seed yield across four locations.

Discussion

Yield related character across four environments

The response of the 21 varieties for yield-related character traits in the four environments showed significant replicate effects for flowering days, maturity days, plant height, number of panicle/panicle and 1000 seed yield weight/m² (g). The result indicates that there was variation in the yield-related character trait. This finding is in line with (Oladosu, Rafii, Abdullah, Magaji, Miah, Hussin

, Ramli , 2017) in rice who stated that early maturing varieties are important for less flood stress areas while late-maturing varieties are for flooded areas. Hence varieties with a high number of tillers, number of seeds and one thousand seed yield weight are important for increasing the yield of rice.

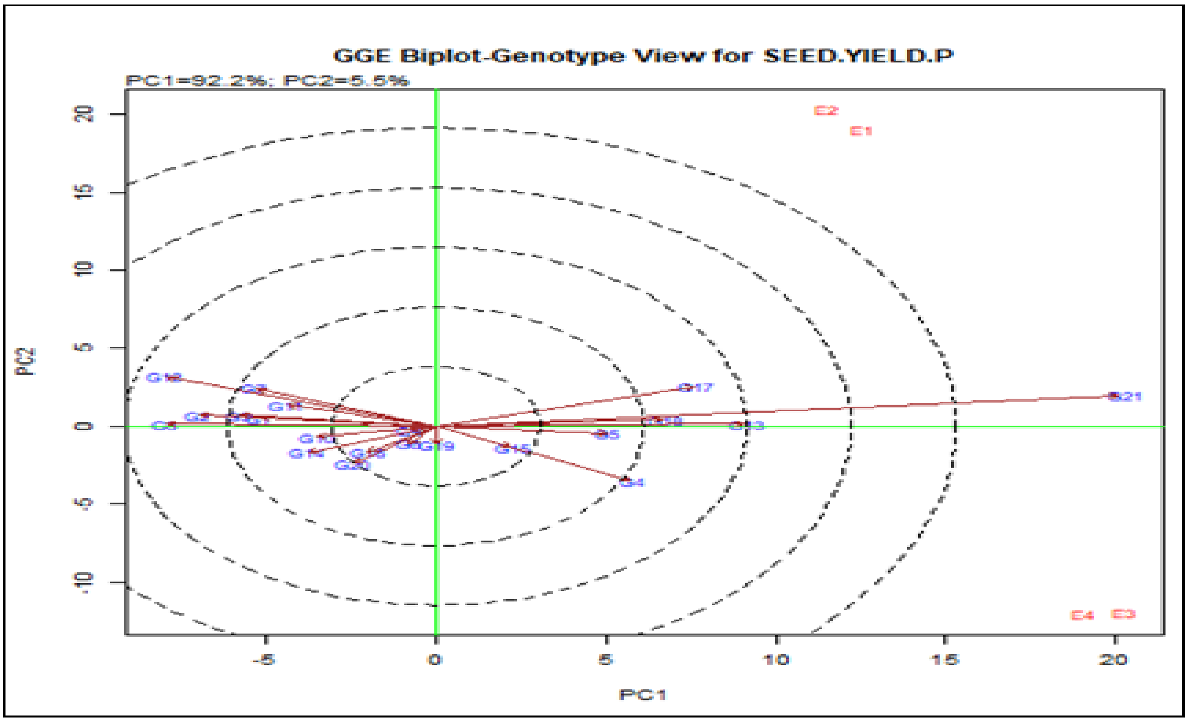

Fig. 4. GGE Biplot View for SEED.YIELD.P.

GGE biplot view for environment for seed yield across four locations.

Additive Main effect and Multiplicative Interaction (AMMI) analysis of variance for seed yield

Additive Main effect and Multiplicative Interaction (AMMI) analysis of variance for seed yield per plot for 21 lowland rice varieties tested across 4 environments (2-locations by 2-seasons) showed there was significant variation at (p<0.05) among varieties, environments and seed yield. High environmental variations and differential responses of varieties to the variable environments leading to a consistent ranking of varieties were observed. The result is in agreement with the previous findings of Ogunbayo *et al.* (2007) in rice, who reported the significant influence of environments of rice varieties in different locations in Ogun State. The first two IPCA were also highly significant leading to a cumulative 93.5% variation over the rest of 6.5%. Hence the AMMI with only the two interaction principal component axes was the best predictive model for seed yield. This is in harmony with Zobel *et al.* (1988) and Annicciarico (2002) who stated that further interaction principal component axes captured mostly noise and it did not help to predict validation observations.

Hence, the interaction of the 21 varieties with four environments was best predicted by the two interaction principal components.

GGE Bi-plot for evaluation of environments and varieties

The GGE biplot analysis of yield in twenty-one rice varieties evaluated in four environments showed that Swana sub 1, Faro 66, Faro 44. Faro 67 and Faro 37 were the ideal varieties and they had the highest mean seed yield. They are also considered the most stable across the environments. Some other varieties like Faro 4 and Faro 17, were also closer to the ideal varieties in seed yields, while varieties that were far away from the ideal varieties were considered unstable varieties and they include; 50, Faro 33, Faro 15, Faro 19, Faro 20, Faro 26 and Nicro 49.

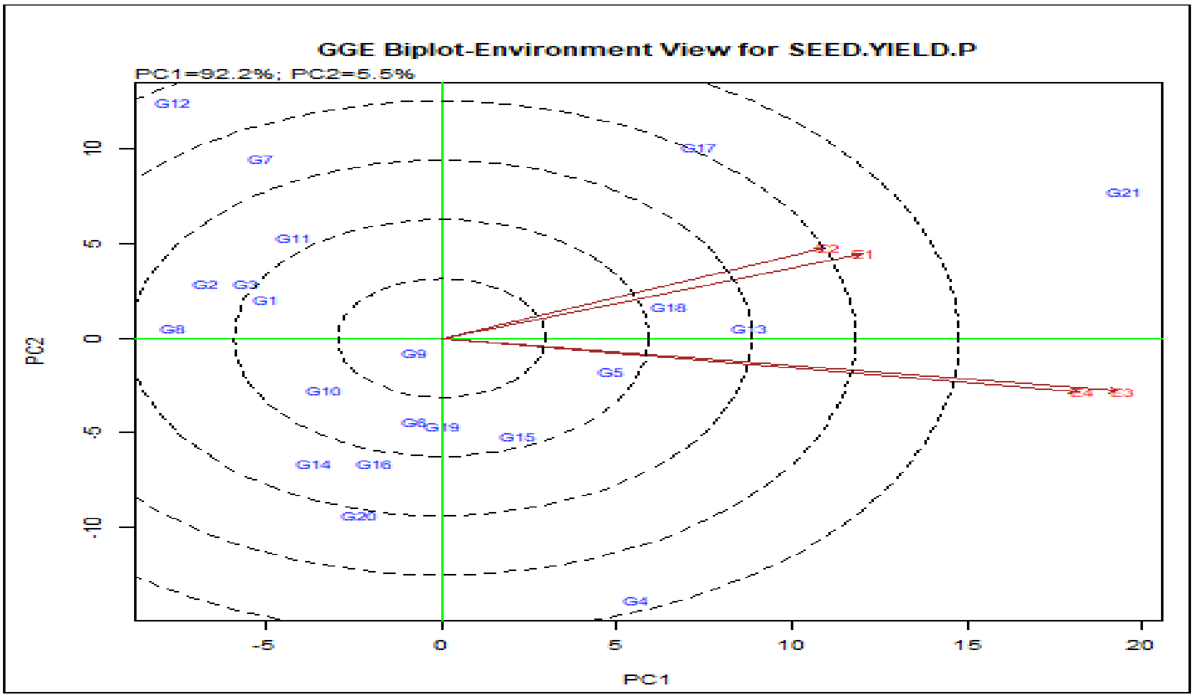

Fig. 5. GGE Biplot-Environment View for SEED. YIELD.P.

Which-Won-Where In the Environments.

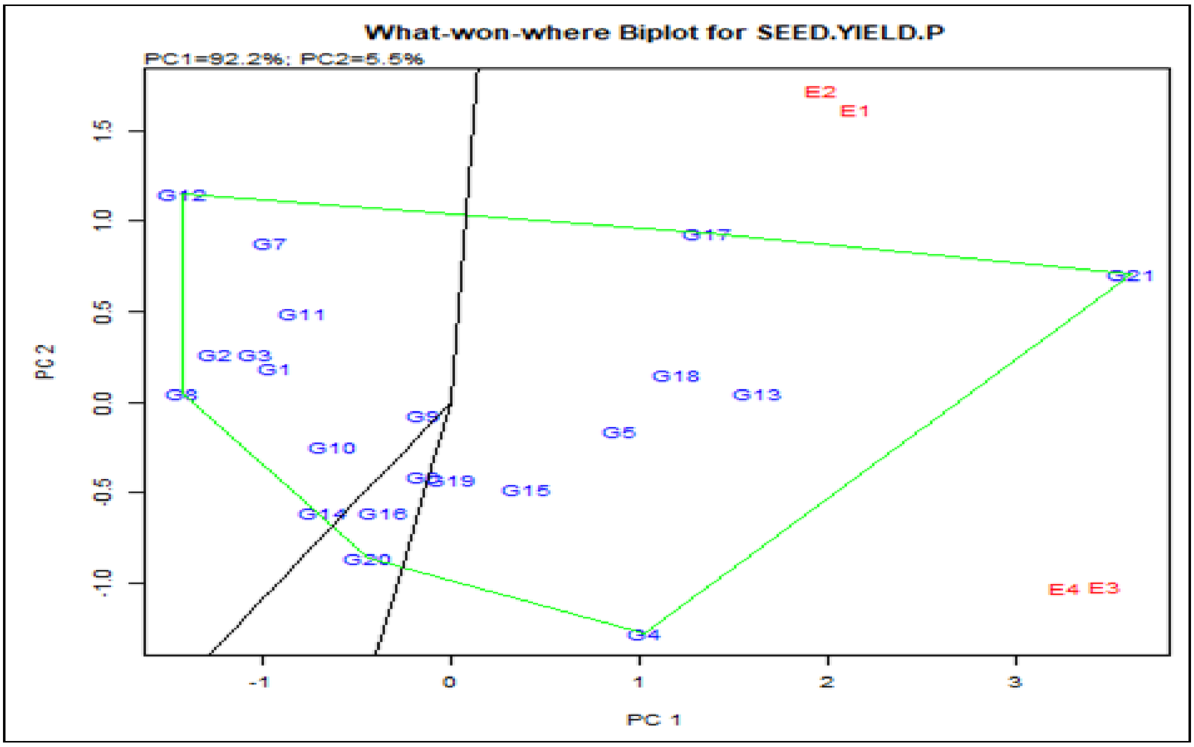

Fig. 6. WHAT-WON-WHERE Biplot for SEED.YIELD.P.

GGE biplot of the primary (PC1, 92.2%) and secondary axes (PC2, 5.5%) for environment centered analysis of seed yield.

A similar result was reported by Yan *et al.* (2000) and Fiseha *et al.* (2015), who stated that varieties are more desirable if it is located closer to the ideal varieties. The concentric circles on the biplot helped to visualize the length of the environment vectors which were proportional to the standard deviation within the respective environments and are a measure of the discriminating ability of the environments (Asnake *et al.,* 2013). Therefore an environment is more desirable and discriminating when it is located closer to the center circle and that was observed in E2 and E4 in this study, as they were the ideal environments and as such, they were considered stable environments. E1 and E3 were far from the ideal environments and as such, they were considered unstable environments; and this result is in line with (Ding *et al.,* 2007) who reported that an environment is more desirable and discriminating when located closer to the center circle or to an ideal environment. The yield variation among varieties indicates that selection should be based on mean performances in the respective environments and changes in yield performance with the environment (Fiseha *et al.,* 2015).

Which varieties won where in the environments?

The four environments fell into four sectors with some varieties displaying outstanding performance, and the bi-plot showed that five varieties from among the other varieties were high yielding in favorable environments and hence were termed the best varieties among the rest varieties.The polygon view of the GGE-biplot shows which varieties won in each environment. The polygon is formed by connecting the varieties that are further away from the biplot origin such that all other varieties are contained within the polygon. 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 yields are separated into different sectors. The best varieties with the highest values for seed yields were Swana sub 1. Faro 66, Faro 67, Faro 44 and Faro 37, while the varieties with the least values for seed yield are as follows; Faro 15, Faro 19, Faro 20, Faro 22, Faro 33 and Faro 26.

Conclusion

The field experiment involved the use of AMMI model to identify stable and unstable environments, evaluate variety performance and identify varieties by environment stability interactions. GGE biplot was used to identify mega environments, varieties by environment stability interactions and identification of ideal varieties and environments.

According to the GGE bi-plot, the rice-growing environments were grouped into four: The first environment containing the favorable environment with vertex E2 (FPFW); the second environment also containing the favorable environment with winner varieties E4(SPFW); and the third and fourth environments containing medium to low environments E3 (FPE), and E1 (SPE) respectively. According to the GGE biplot, nine varieties, namely; Faro 66, Faro 52, Faro 67, Faro 16, Swana sub 1, Faro 44, Faro 37 and Faro 24 were found in favorable environments, while eight varieties, namely; Faro 15, Faro 16, Faro 57, Faro 22, Faro 20, Faro 50, Nicro 49, and Faro 33 had low seed yield and were found in the unfavorable environments. The stable varieties were adaptive to wider areas and gave high seed yields consistently across the four locations.

The GGE biplot provided an excellent graphical presentation of the data; it gave a reliable graphical display of the yield stability of varieties in different environments, ranked environments based on the relative performance of a given cultivar, identified the best cultivar in each environment., identified mega environments and evaluated environments based on discriminating ability. Therefore, the varieties × environment (GGE) biplot was able to identify which varieties perform best in a given environment and also which varieties had the highest stability across the four different locations. It is therefore recommended, that according to the stability of these varieties in the four different environments, Faro 37, Faro 44, Faro 66 , Faro 67 and Swana sub 1 which had higher yield and were most stable in terms of seed yield and also found doing well in freshwater habitats (E2 and E4) should be adopted by farmers in this flood prone environments. Hence freshwater environment is the ideal environment and is hereby recommended to rice farmers in this agro ecological zone.

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