Responses of Selected Lowland Rice (*Oryza Sativa* Linnaeus.) Genotypes to Environmental Stress in Badeggi, Niger State, Nigeria

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Abstract:

Rice (Oryza sativa Linnaeus.) production in Nigeria is constrained by abiotic stresses including drought, salinity, and iron toxicity. This study evaluated 30 lowland rice genotypes for tolerance to these stresses using phenotypic, physiological, and agronomic parameters. Drought screening was conducted under field conditions with irrigation withdrawal, while salinity (0, 8, 16 dSm^{-1}) and iron toxicity (0, 150, 300 ppm Fe^{2+}) were evaluated in screen house experiments. Results revealed significant genotypic variability ($p<0.05$) for all traits assessed. Under drought stress, FARO 68 exhibited the highest grain yield (1,227.26 kg/ha) and stress tolerance index (STI=2.10), while FARO 34 was most susceptible. Salinity screening identified FARO 44 and FARO 68 as highly tolerant with lowest salt injury scores (1.00-2.33) and maintained grain yields of 25.03-31.17g at 16 dSm^{-1}. For iron toxicity, Alh Baba, FARO 33, and FARO 44 showed strong tolerance with injury scores ≤1.67 at 300ppm. Correlation analysis identified panicle length and 1000-grain weight as key yield determinants under stress. High heritability (0.77-0.98) and genetic advance estimates for yield traits suggested additive gene action. FARO 16 demonstrated combined tolerance to all three stresses, showing low yield reduction (0.40%) under drought, salinity tolerance at 8 and 16 dSm^{-1}, and iron toxicity score of 1.00 at 150ppm. These tolerant genotypes represent valuable genetic resources for breeding programs targeting stress-prone environments in Nigeria.

Keywords: *Abiotic Stress, Drought Tolerance, Iron Toxicity, Rice Genotypes, Salinity Tolerance.*

Introduction:

Rice (*Oryza sativa* Linnaeus.) is a vital staple food for over half of the world's population, with global production exceeding 700 million metric tons annually (FAO, 2017). In Nigeria, rice is cultivated across various agro-ecological zones, yet production falls short of consumption demands, creating a deficit of approximately 3.8 million metric tons annually (FAO, 2021). This shortfall is largely attributed to abiotic stresses including drought, salinity, and iron toxicity, which are exacerbated by climate change (Ndjiondiop.*et al.,* 2018)
Abiotic stresses are the primary causes of yield losses in agriculture worldwide, with drought and salinity being the most significant constraints to rice productivity (Yang *et al.,* 2019). Drought stress affects rice at all growth stages, with the reproductive phase being particularly sensitive, leading to significant yield reductions (Hopmans *et al.,* 2021). Similarly, salinity affects approximately 30% of the world's rice-growing areas, causing ion toxicity, osmotic stress, and nutrient imbalances ((Ganie *et al.,* 2019). Iron toxicity, prevalent in waterlogged lowland soils, results from the reduction of insoluble Fe^{3+} to soluble Fe^{2+}, causing leaf bronzing, stunted growth, and yield losses up to 100% (Mahender *et al.,* 2019).

The development of stress-tolerant rice varieties is essential for ensuring food security in sub-Saharan Africa (Ganie *et al.,* 2019). Genetic improvement through screening and selection of tolerant genotypes offers a sustainable approach to mitigating stress impacts Barde *et al.,* 2021). However, limited information exists on the combined tolerance of Nigerian rice genotypes to multiple abiotic stresses.

This study aimed to identify lowland rice genotypes tolerant to drought, salinity, and iron toxicity using phenotypic and biochemical tools.

Materials and Methods

Experimental Location

The study was conducted at the National Cereals Research Institute (NCRI), Badeggi, Niger State, Nigeria (09°03'N, 06°07'E; 95 m altitude) in the Southern Guinea Savannah agro-ecological zone. The area has bimodal rainfall (900-1050 mm) between May and October, with mean temperature of 35°C and relative humidity of 52-73%.

Plant Materials

Thirty lowland rice genotypes were obtained from NCRI Rice Breeding Unit, comprising improved FARO varieties, a landrace (Alh Baba), and IR-72 (Table 1). These genotypes represent popular varieties cultivated by Nigerian rice farmers.

Experimental Procedures

Drought Stress Evaluation

Field experiments were conducted under irrigated conditions using Randomized Complete Block Design (RCBD) with three replications. Two adjacent plots (drought-stressed and non-stressed) were established. For drought-stressed plots, irrigation was withdrawn for four weeks starting four weeks after transplanting (WAT), while non-stressed plots received irrigation at 4-day intervals. Data on leaf rolling, leaf tip burning, phenotypic acceptability, and plant recovery were recorded using Standard Evaluation System (SES) scales (1-9) (IRRI, 2023).

Salinity Stress Evaluation

Hydroponic screening was conducted using nutrient solution with salinity levels of 0, 8, and 16 dSm^{-1} (EC) in completely randomized design with four replications. Salt injury scores were recorded at 7, 14, and 21 days after salt treatment (DAST) following IRRI (2023) standards (IRRI , 2023). Based on hydroponic performance, five tolerant and five susceptible genotypes were further evaluated in pot experiments using NaCl-amended soil (0, 8, 16 dSm^{-1}).

Iron Toxicity Evaluation

Iron toxicity screening employed three Fe^{2+} concentrations (0, 150, 300 ppm) applied as ferrous sulfate in pots containing 10 kg soil. Iron toxicity symptoms (leaf bronzing) were scored at 7, 14, and 21 days after treatment using 1-9 SES scales. Chlorophyll content was measured using SPAD-502 meter at 2, 4, and 6 weeks after stress.

Data Collection

Growth parameters included plant height (cm), number of tillers, days to 50% flowering, panicle length (cm), flag leaf length (cm), panicle exertion (cm), seeds per panicle, 1000-grain weight (g), and grain yield (kg/ha). Stress-specific indices included Stress Tolerance Index (STI), Tolerance Index (TOL), Mean Productivity (MP), and Geometric Mean Productivity (GMP) calculated using standard formulas (Mahfuz *et al.,* 2015).

Data Analysis

Data were subjected to analysis of variance (ANOVA) using STAR software (IRRI, 2014). Means were separated using Duncan's Multiple Range Test (DMRT) at $p<0.05$. Correlation analysis and heritability estimates were computed following established methods (Piepho and Mohring, 2000). Drought indices were calculated using iPASTIC online tool (Pour-Aboughadareh *et al.,* 2019).

Results and Discussion

Soil Characteristics

Soil analysis revealed sandy loam texture with moderate acidity (pH 4.64-4.65) and low organic carbon (0.59-0.68%). Available phosphorus was moderate (25-27 mg/kg), while iron concentrations were high (>430 mg/kg), indicating susceptibility to iron toxicity.

Drought Stress Response

Significant genotypic differences ($p<0.05$) were observed for all drought-related traits. Under drought stress, days to 50% flowering ranged from 95.00 (FARO 33) to 145.67 days (FARO 15), while plant height varied from 38.35 cm (FARO 15) to 75.13 cm (FARO 24). Yield parameters showed substantial reduction under stress, with grain yield ranging from 385.50 kg/ha (FARO 34) to 1,227.26 kg/ha (FARO 68) (Table 2).

Drought tolerance indices revealed substantial variation among genotypes. FARO 68 exhibited the highest STI (2.10), MP (1238.88), and GMP (1238.83), confirming its superior performance under both stressed and non-stressed conditions. Conversely, FARO 34 showed the lowest STI (0.21) and yield (385.50 kg/ha). The high performance of FARO 68 aligns with its recent release (2022) and high yield potential (11.8 t/ha), suggesting effective breeding for drought tolerance. FARO 21 demonstrated remarkable stability with only 0.19% yield reduction, indicating strong drought avoidance mechanisms. These findings are consistent with previous reports on drought tolerance screening in rice where STI effectively identified high-yielding tolerant genotypes (Ndikuryayo *et al.,* 2023).

Correlation analysis under drought stress identified 1000-grain weight ($r=0.39^*$) and panicle length ($r=0.36^*$) as significant yield determinants, while phenotypic acceptability showed negative correlation ($r=-0.18$), suggesting that visual stress symptoms can serve as rapid screening tools for susceptibility. These relationships align with established knowledge that panicle traits and grain weight are key contributors to yield stability under stress (Pantuwan *et al.,* 2012).

Table 1: Grain yield of selected rice genotypes under drought stress

Genotype	Yp	Ys	RC	TOL	MP	GMP	STI	Ranking based on STI
FARO 68	1250.51	1227.26	1.86	23.25	1238.88	1238.83	2.1	1
FARO 16	1182	1177.25	0.4	4.76	1179.62	1179.62	1.9	2
FARO 15	1134.75	1107.5	2.4	27.26	1121.12	1121.04	1.72	3
FARO 19	1111.76	1097.25	1.3	14.51	1104.5	1104.48	1.67	4
FARO 44	1080	1059.75	1.88	20.25	1069.88	1069.83	1.56	5
FARO 67	1068.26	1044.5	2.22	23.76	1056.38	1056.31	1.52	6
FARO 52	1053.5	1043.25	0.97	10.24	1048.37	1048.36	1.5	7
FARO 51	1024.01	1003.76	1.98	20.25	1013.88	1013.83	1.4	8
FARO 27	1012.5	996.75	1.56	15.75	1004.63	1004.59	1.38	9
FARO 61	1119.75	879.75	21.43	240	999.75	992.52	1.34	10
FARO 66	993.75	954.5	3.95	39.26	974.12	973.92	1.3	11
FARO 60	995.51	938.25	5.75	57.26	966.88	966.45	1.28	12
FARO 20	936.5	922.01	1.55	14.49	929.25	929.22	1.18	13
FARO 57	932.25	915.5	1.8	16.76	923.87	923.83	1.17	14
FARO 21	917.75	916.01	0.19	1.74	916.88	916.87	1.15	15
FARO 30	914.51	898.76	1.72	15.75	906.63	906.6	1.12	16
FARO 62	912.26	898.76	1.48	13.5	905.51	905.48	1.12	17
FARO 17	905.75	864.26	4.58	41.49	885	884.76	1.07	18
FARO 50	895.01	863.25	3.55	31.76	879.13	878.98	1.05	19
Alh Baba	857	813.75	5.05	43.25	835.37	835.09	0.95	20
FARO 22	741	691.76	6.65	49.25	716.38	715.95	0.7	21
FARO 24	701.51	668	4.78	33.51	684.75	684.54	0.64	22
IR72	589.25	575.75	2.29	13.5	582.5	582.46	0.46	23
FARO 31	583.5	546.75	6.3	36.75	565.13	564.83	0.44	24
FARO 33	538.25	471.26	12.45	66.99	504.75	503.64	0.35	25
FARO 4	501.75	471	6.13	30.75	486.38	486.13	0.32	26
FARO 18	457.76	444.26	2.95	13.5	451.01	450.95	0.28	27
FARO 26	453.5	415.01	8.49	38.49	434.25	433.82	0.26	28
FARO 32	411	391.5	4.74	19.5	401.25	401.13	0.22	29
FARO 34	400.25	385.5	3.68	14.75	392.87	392.8	0.21	30

Yp= Irrigated condition, Ys= Drought stressed condition, RC =Relative change, TOL = Tolerance index, MP = mean productivity, GMP = geometric mean productivity, STI = stress tolerance index

Salinity Stress Response

Agronomic and mean grain yield performance of 30 selected rice genotypes studied under three levels of salt concentration are presented in Table 3. There was significant ($p < 0.05$) difference among the varieties for all the parameters studied except shoot length. However, effect of concentration was only significant ($p < 0.05$) for tiller count and panicle length. There was also significant Genotype x salt concentration interaction for all parameters studied, except shoot length, tiller count 1 and seed per panicle (Table 3). The longest shoot length (62.78 cm) was observed in FARO 68 while the shortest (23.28 cm and 23.61 cm) were recorded for FARO 44 and FARO 52 respectively. The tallest plants at 6WAS were FARO 24 (65.81 cm) and FARO 66 (61.76 cm) had the significantly ($p < 0.05$) tallest plants while FARO 44 (49.12 cm) plants were the shortest. The highest number of tillers (8.72, 8.33 and 8.28) was recorded for FARO 30, FAROs 66 and IR-72 respectively, while the least (4.56) number of tillers was observed in FARO 33.

The number of tillers varied among the genotypes. It ranged from 6.11 for FARO 33 to 10.00 in FARO 30. Flag leaf length varied among genotypes from 21.33 cm for IR-72 to 39.58 cm for FARO 24. Panicle exertion also varied from 1.22 cm for FARO 60 to 6.56 cm in FARO 44 followed by 5.22 cm in IR -72. The significant reduction in tiller count and panicle length observed at 16 dSm^{-1} in this study is consistent with the findings of (Zakari and Shuaibu, 2025), who argued that salt-induced osmotic stress reduces the metabolic energy available for reproductive development.

Toxicity Stress Response

The results (Table 4) of the mean grain yield and other agronomic performance of selected rice genotype studied under three levels of iron concentration showing significant differences ($P < 0.05$) among the genotypes for all the parameters studied. The highest shoot length (45.08 cm) at 3WAS was recorded for FARO 24 while the lowest shoot length (29.51 cm) was observed in FARO 67. The highest plant height (75.36 cm) was recorded for FARO 24 while the lowest plant height (55.34cm) was observed in FARO 26. Tillers were counted 6WAS and FARO 51 recorded the highest number of tiller (10.56) while the lowest (5.56) was recorded for Alh Baba (Table 4).

The highest plant height (123.52 cm) under iron (Fe^{2+}) concentration was recorded for FARO 24 and the lowest (68.89 cm) was recorded for FARO 26. Tiller count range between (7.44) tillers for FARO 33 and (13.56) for FARO 51 followed by (13.00) for FARO 52. The longest flag leaf length (55.68 cm) was observed in FARO 52 while the shortest flag leaf length (24.39 cm) was recorded for FARO

44 Flag leaf traits are critical for grain filling, and similar reductions under Fe stress were also reported by (Sikirou *et al.,* 2015). Panicle exertion ranged between (1.00 cm) for FARO 60 and FARO 24 and (5.67 cm) for FARO 26. The most tolerant genotypes to 1st, 2nd and 3rd to iron injury scores (1.00 to 1.89) were recorded for Alh Baba, FARO 33 and FARO44 while the lowest performed genotypes under iron concentration (4.33 to500) were observed in FAROs 67, 60, 50, 26 and 24. Days to 50% flowering varied among genotypes from (79.56 days) recorded for FARO 44 to (95.00 days) observed in FARO 51. The highest number of panicles (9.11) was counted in FARO 60 while FARO 52 recorded the least (5.11) panicle count. Alh Baba had the longest (26.30 cm) panicle length while the shortest panicle length (17.56 cm) was observed in FARO 26. 1000 grain weight varied among genotypes between (23.90g) recorded for FARO 26 to (28.76g) for FARO 51 followed by (28.38 g) for Alh Baba. The differential severity of symptoms in this study reflects genotypic differences in Fe exclusion or detoxification capacity a trend also observed in the screening experiments by (Engel *et al.,* 2012; Sikirou *et al.,* 2015). The Iron stress study revealed substantial genotypic variability in rice responses to Fe^{2+} stress across agronomic parameters. This variability is consistent with the wide genetic diversity in iron-stress tolerance previously reported in lowland rice (Audebert, and Sahrawat, 2000; Becker and Asch, 2005). This is in agreement with earlier studies showing that some genotypes maintain yield under stress by conserving photosynthetic efficiency and minimizing Fe uptake (Audebert, and Fofana, 2009).

Combined Stress Tolerance

Summary of performance of rice varieties under multiple stresses (Table 5). Comparative analysis across stresses identified genotypes with multiple stress tolerance. FARO 16 exhibited tolerance to all three stresses: low drought yield reduction (0.40%), salinity tolerance at 8 and 16 dSm^{-1}, and iron toxicity score of 1.00 at 150ppm. FARO 68 demonstrated excellent drought and salinity tolerance but moderate iron toxicity tolerance. FARO 44 showed strong salinity and iron toxicity tolerance with moderate drought tolerance. Alh Baba performed well under salinity and iron toxicity but was drought susceptible.

The identification of FARO 16 as a multi-stress tolerant genotype is particularly valuable for breeding programs targeting diverse stress-prone environments. This genotype's combined tolerance may result from overlapping stress response pathways, including osmotic adjustment and antioxidant defense mechanisms (Liu *et al.,* 2024). The multi-stress tolerance observed in FARO 16 aligns with recent findings that some rice genotypes possess broad-spectrum stress tolerance through shared signaling pathways (Sackey *et al.,* 2025).

Table 3: Mean values of agronomic traits of rice as influenced by varieties and different salt concentrations

Treatment	Shoot length 3WAS	Plant height 6WAS	Tiller count 6WAS	Plant height 12WAT	Tiller count 12WAT	Flag leaf length	Panicle exertion	Days to 50% flowering	Seed/ panicle	Panicle length	1000 grain weight	Grain yield
Genotype												
FARO 24	34.60	65.81^{a}	6.61^{cd}	112.67^{a}	8.44^{b}	39.58^{a}	2.78d^{e}	71.00^{g}	3.89^{c}	21.41^{ab}	24.51^{cd}	26.16^{bc}
F ARO 30	26.33	50.86^{d}	8.72^{a}	81.18^{d}	10.00^{a}	29.34^{bc}	4.11bc d	87.33^{e}	6.44^{a}	20.99^{ab}	28.86^{ab}	26.56^{bc}
F ARO 32	24.72	50.90^{d}	6.61^{cd}	86.71^{c}	8.33^{b}	30.89^{b}	4.56^{bc}	97.67^{a}	4.00^{bc}	17.93^{cd}	28.13^{b}	26.93^{bc}
F ARO 33	24.94	57.29^{c}	4.56^{e}	91.37^{bc}	6.11^{d}	24.02^{de}	4.11^{bcd}	71.22^{g}	4.00^{bc}	18.13^{cd}	28.41^{b}	30.87^{ab}
F ARO 44	23.28	49.12^{d}	6.06^{d}	74.33^{e}	7.67^{bc}	21.99^{e}	6.56^{a}	88.44^{d}	5.33^{a}	19.31^{bc}	29.66^{a}	26.70^{bc}
F ARO 52	23.61	50.08^{d}	7.33^{bc}	76.56^{de}	9.11^{ab}	25.42^{cde}	4.56^{bc}	91.78^{b}	5.44^{a}	19.21^{bc}	24.86^{cd}	29.37^{b}
F ARO 60	26.72	55.13^{c}	6.44^{cd}	96.23^{b}	6.33^{cd}	28.51^{bc}	1.22^{f}	89.89^{c}	3.67^{c}	19.62^{abc}	23.72^{d}	16.17^{d}
F ARO 66	28.39	61.76^{b}	8.33^{ab}	93.52^{b}	7.78^{bc}	28.39^{bcd}	2.56^{ef}	84.56^{f}	5.22^{ab}	22.26 a	25.56c	28.76^{b}
F ARO 68	62.78	60.49^{b}	7.94^{ab}	78.29^{de}	7.89^{b}	22.04^{e}	3.22^{cde}	88.67^{d}	3.78^{c}	18.82^{bcd}	29.06^{ab}	34.18^{a}
IR 72	26.28	49.29^{d}	8.28^{a}	63.33^{f}	8.44^{b}	21.33^{e}	5.22^{ab}	68.44^{h}	5.44^{a}	16.17^{d}	24.90^{cd}	23.20^{c}

*, **,= Significant at $P < 0.05$, $P < 0.01$, respectively. Means followed by the same letters in column are not significantly different ($P > 0.05$) , ns = not significance

Mean	30.17	55.07	7.09	85.42	8.01	27.15	3.89	83.90	4.72	19.39	26.77	26.89
SE	14.92	1.58	0.63	2.62	0.79	2.21	0.74	0.54	0.62	1.41	0.61	2.40
CV	104.89	6.07	18.95	6.50	21.04	17.26	40.18	1.35	27.71	15.46	4.81	18.93
Salt concentration												
0dsm (Control)	25.82	56.06^{a}	7.63^{a}	86.90	8.27	26.62 ab	4.27a	84.30	5.00	18.60^{b}	27.33	30.39^{a}
8dsm	27.91	55.78^{ab}	6.50^{ab}	86.73	7.87	29.03 a	3.93ab	83.57	4.57	21.04^{a}	26.49	25.84^{b}
16dsm	36.77	53.39^{b}	7.13^{ab}	82.63	7.90	25.81 b	3.47b	83.83	4.60	18.52^{b}	26.48	24.44^{b}
Mean	30.17	55.07	7.09	85.42	8.01	27.15	3.89	83.90	4.72	19.39	26.77	26.89
SE±	8.29	1.69	0.44	3.71	0.51	1.78	0.53	2.55	0.40	0.81	0.64	1.61
CV%	106.39	11.90	24.40	16.81	24.56	25.35	53.26	11.76	32.92	16.24	9.28	23.21
Interaction												
Genotype x Salt Concentration	Ns	**	**	**	Ns	**	**	**	ns	**	**	**

Table 4: Means for agronomic parameters of rice genotypes grown under three levels of iron (Fe^{2+}) concentration in a screen house at Badeggi 2025

Genotype	S/L3WAS (cm)	Plant height 6WAS (cm)	TC 6WAS	PH 12WAS (cm)	TC 12WAS	Flag leaf length (cm)	Panicle exertion	Days to 50% flowering	Seeds per panicle	Panicle length (cm)	1000 grain weight (g)	Grain Yield (g)
Alh Baba	36.94^{bcd}	71.74^{ab}	5.56^{d}	114.48^{b}	9.56^{cde}	44.17^{a}	2.78^{bc}	88.67^{bc}	7.67^{abcd}	26.30^{a}	28.38^{a}	43.04^{b}
FARO 24	45.08^{a}	75.36^{a}	7.67^{bcd}	123.52^{a}	8.33^{de}	41.29^{a}	1.00^{d}	86.67^{c}	6.56^{cde}	23.73^{abc}	24.31^{e}	52.50^{a}
F ARO 26	30.91^{ef}	55.34^{e}	9.17^{ab}	68.89f	10.22^{cd}	25.91^{cd}	5.67^{a}	93.00^{ab}	8.56^{abc}	17.56^{e}	23.90^{e}	36.13^{bcd}
F ARO 33	40.84^{abc}	73.29^{a}	6.76^{cd}	96.00^{d}	7.44^{e}	32.38^{bc}	2.33^{cd}	92.22^{ab}	6.89^{bcde}	24.10^{ab}	26.66^{bc}	41.58^{b}
F ARO 44	33.89^{def}	62.59^{cde}	8.56^{abc}	80.19^{e}	10.33^{cd}	24.39^{d}	4.56^{a}	79.56^{d}	5.89^{de}	20.98^{cd}	27.50^{ab}	35.27^{bcd}
F ARO 50	32.91^{def}	58.87^{de}	9.17^{ab}	78.26^{e}	11.33^{bc}	27.06^{bcd}	4.78^{a}	92.22^{ab}	8.89^{ab}	20.81^{cd}	25.12^{de}	39.33^{bc}
F ARO 51	35.62^{cde}	60.77^{de}	10.56^{a}	76.22^{ef}	13.56^{a}	29.92^{bcd}	4.78^{a}	95.00^{a}	8.33^{abc}	20.56^{de}	28.76^{a}	38.44^{bc}
F ARO 52	36.41^{bcde}	63.86^{bcd}	8.67^{abc}	88.67^{d}	13.00^{ab}	55.68^{b}	4.33^{ab}	92.67^{ab}	5.11^{e}	20.86^{cd}	26.28^{bcd}	37.13^{bcd}
F ARO 60	42.08^{ab}	70.25^{abc}	8.39^{abc}	106.48^{c}	9.78^{cd}	33.14^{b}	1.00^{d}	88.67^{bc}	9.11^{a}	20.44^{bcd}	25.72^{cd}	29.77^{d}
F ARO 67	29.51^{f}	59.08^{de}	7.22^{bcd}	104.59^{c}	8.56^{de}	32.36^{bc}	1.44^{cd}	92.00^{ab}	6.00^{de}	24.64^{a}	25.11^{de}	32.08^{cd}
Mean	36.42	59.17	8.17	93.73	10.21	32.43	3.27	90.07	7.30	22.10	26.17	38.53

SE±	1.83	2.45	0.6895	2.38	0.6592	2.15	0.5154	1.51	0.617	0.933	0.387	2.43
CV (%)	10.65	7.99	17.90	5.38	13.69	14.04	33.47	3.55	17.93	8.96	3.14	13.37
Fe conc.												
Control	35.17^{b}	63.84^{b}	8.75	91.17	10.47	30.99	3.07	89.73	7.73	21.63	26.46	41.76^{a}
150 ppm	35.06^{a}	63.45^{b}	7.95	93.38	10.13	32.60	3.20	90.50	7.27	22.18	25.92	38.42^{ab}
300 ppm	39.17^{b}	68.21^{a}	7.81	96.64	10.03	33.70	3.53	89.97	6.90	22.49	26.14	35.40^{b}
Mean	36.42	65.17	8.17	93.73	10.21	32.43	3.27	90.07	7.30	22.10	26.17	38.53
SE±	1.50	2.09	0.497	4.71	0.602	1.93	0.517	1.37	0.4713	0.803	0.460	1.92
CV (%)	16.00	12.42	23.54	19.47	22.84	23.06	61.25	5.90	25.00	14.08	6.81	19.35
Interaction												
Genotype x Iron Conc.	***	***	***	***	***	***	***	***	***	***	***	***

Means in having the same letters in the same column are not significantly different (P > 0.05), *** = Significantly different at P < 0.00

Table 5: Summary of performance of rice varieties under multiple stresses

		Performance in stressed environments				
Genotype		Drought	Salinity	Iron toxicity		Inference
FARO 68		Highest yield (1,227.26 kg/ha) and higher recovery indices.	Highly tolerant; lower salt injury scores and longer shoots.	Poor phenotypic acceptability at 150 ppm, but scored well (1.00) at 300 ppm.		Best overall for combined drought and salinity.
FARO 44		High recovery index.	Highly tolerant; recorded least salt injury scores (1.00 - 2.33).	Highly tolerant; recorded least iron toxicity score (1.00) at both 150 and 300 ppm.		Multi-stress tolerant (Salinity and Iron Toxicity).
FARO 24		Taller plants (75.13 cm).under stress	Highly tolerant; taller plants across all salt levels.	Highly tolerant; produced taller plants at 300 ppm iron.		Growth-resilient across all three stresses.
FARO 16		Low yield reduction (0.40%) and high STI.	Tolerant to salt at 8 and 16 dSm^{-1}.	Tolerant; recorded iron toxicity score of 1.00 at 150 ppm.		Multi-stress tolerant (Drought, Salinity, and Iron).
Alh Baba		Low drought recovery score.	Tolerant at 8 and 16 dSm^{-1} concentrations.	Highly tolerant; least iron toxicity scores (1.00) at 150 and 300 ppm.		Dual-stress tolerant (Salinity and Iron).

Conclusion:

This study successfully identified rice genotypes with varying levels of tolerance to drought, salinity, and iron toxicity stresses. FARO 68 demonstrated superior performance under drought (STI=2.10) and salinity (injury score 2.33 at 16 dSm^{-1}), making it an excellent candidate for drought and saline environments. FARO 44 showed exceptional tolerance to both salinity and iron toxicity (injury scores ≤2.33), while FARO 16 emerged as a multi-stress tolerant genotype with combined tolerance to all three stresses. These genotypes represent valuable genetic resources for rice breeding programs aimed at developing resilient varieties for stress-prone environments in Nigeria and other sub-Saharan African countries. The high heritability and genetic advance estimates for yield traits suggest that direct selection for stress tolerance traits will be effective.

Recommendations

Based on the findings, FARO 68, FARO 16, and FARO 19 are recommended for cultivation in drought-prone areas and as parental materials in drought tolerance breeding programs; FARO 44, FARO 68, and FARO 30 are recommended for saline environments and as salinity tolerance donors; Alh Baba, FARO 33, and FARO 44 are recommended for iron-toxic lowland soils and as sources of iron toxicity tolerance; FARO 16, showing tolerance to all three stresses, should be prioritized for breeding programs targeting multiple stress environments; and Multi-location field trials should be conducted to validate the performance of identified tolerant genotypes under natural stress conditions.

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