



DROUGHT AND IRON TOXICITY TOLERANCE OF LOWLAND RICE (*ORYZA SATIVA* L.) GENOTYPES IN NIGERIA

¹Barde, A. M., ²Gana, A. S., ²Daniya, E., ²Daudu, O. A. Y. and ³Nwosu, D. J.

Federal University of Technology, Minna, Niger State

Corresponding Author's Email: maiwaaziabu@gmail.com, **GSM:** 08133205561

ABSTRACT

This study evaluated thirty lowland rice genotypes for tolerance to drought and iron toxicity under controlled and field conditions at National Cereals Research Institute, Badeggi, Nigeria. A randomized complete block design was used for drought screening. The two experiments: Drought stressed and non-stressed experiments were laid side by side, separated by high bond. The size of the experimental field was 30 x 15 m², gross plot size was 2 x 1 m² with 66 plant population per gross plot and 6 stands per net plot, while iron toxicity was assessed using graded Fe² concentrations (0, 150, and 300 ppm). Significant genotypic variation ($P < 0.05$) was observed for drought response traits including leaf rolling, tip burn, and recovery indices. Genotypes; FARO 15, FARO 44, FARO 57, FARO 68, and FARO 52 demonstrated a superior drought tolerance based on recovery and low stress scores. Iron toxicity screening revealed variability in tolerance, with tolerant genotypes exhibiting reduced leaf bronzing and sustained growth under high Fe² conditions. The findings highlight the potential of selected genotypes as candidates for breeding programs targeting combined stress tolerance in lowland rice-ecosystems.

Keywords: Drought, Tolerance, Leaf, Rolling, Rice, Genotypes

INTRODUCTION

Rice (*Oryza sativa* Linnaeus) belonging to the family Poaceae (Barde *et al.*, 2021) is an important annual crop and one of the major staples in Nigeria. Its cultivation has reached over 167 million hectares with the production of 780 million tons (FAO, 2017). The crop is grown under different environmental conditions in both upland and lowland rainfed ecosystems. Nigeria agricultural land area covers 70.8 million hectares with maize, cassava, guinea corn, yam, beans, millet and rice being the major crop rose from 3.7 million metric tons in 2017 to 4.0 million metric tons in 2018. This production falls short of required quantity for consumption accounting for 57% of the 6.7 million metric tons of rice consumed in the country (FAO, 2021) leaving to a deficit of 3.8 million metric tons which is either imported or smuggled into the country illegally. Biotic and abiotic stresses adversely affect crop growth and productivity. In crops, these abiotic stresses are generated by environmental factors such as drought, salinity and alkalinity, nutrient toxicity or deficiency, flooding and poor drainage, high or low soil pH, high and low temperatures and heavy metals; all are complex and often interacting phenomena and limit crop production worldwide (Almeida *et al.*, 2016).

Abiotic stresses are natural disasters that have detrimental influence on water resources, economy, environment and crop production (Hyunwoo *et al.*, 2021). They are the primary cause of yield losses in agriculture throughout the world and are currently the most common reasons for global food shortages (Ndjondjop *et al.*, 2018). Three-quarter of the most severe abiotic stresses in the last ten years have been in Africa, the continent which already has the lowest level of crop production and stress adaptive capacity. Increase in the incidences of stress and erratic rainfalls have thrown small holder farmers in Africa into deep poverty, hunger and malnutrition (Ndjondjop *et al.*, 2018). The objective of this study is to identify lowland rice genotypes that are tolerant to iron toxicity and drought using phenotypic and biochemical tools.



MATERIALS AND METHODS

Study Area

The National Cereals Research Institute, Badeggi is located in Southern Guinea Savannah agro ecological zone of Nigeria, on an altitude of 95 m above the sea level, Latitude 09°.066148°N and Longitude 06°.08857°E.

Plant Materials

Thirty rice genotypes were sourced from National Cereals Research Institute (NCRI), Badeggi and National Centre for Genetic Resource and Biotechnology (NACGRAB), Ibadan gene banks.

Table 1: Rice Genotypes Used in the Study

S/N	Name of Genotype	Year of release	Year of registration	Yield potential (t/ha)
1.	FARO 4	1959	1991	2-4
2.	FARO 15	1974	1991	3-4
3.	FARO 16	1974	1991	2-4
4.	FARO 17	1974	1991	2-4
5.	FARO 18	1974	1991	3-4
6.	FARO 19	1974	1991	2-3
7.	FARO 20	1974	1991	2-3
8.	FARO 21	1974	1991	2-3
9.	FARO 22	1974	1991	2-4
10.	FARO 24	1974	1991	3-4
11.	FARO 26	1982	1991	2-3
12.	FARO 27	1982	1991	2-3
13.	FARO 30	1986	1991	5-8
14.	FARO 31	1986	1991	5-8
15.	FARO 32	1986	1991	4-7
16.	FARO 33	1986	1991	4-7
17.	FARO 34	1986	1991	4-7
18.	FARO 44	1990	1991	2-8
19.	FARO 50	1990	1991	5-6
20.	FARO 51	1998	1991	5-6
21.	FARO 52	2001	1991	6-7
22.	FARO 57	2005	2005	9
23.	FARO 60	2011	2011	8
24.	FARO 61	2011	2011	7
25.	FARO 62	2011	2011	4
26.	FARO 66	2017	2017	6-7
27.	FARO 67	2017	2017	6.7
28.	FARO 68	2022	2022	11.8
29.	ALH BABA	Land-race	-	3-4
30.	IR 72	-	-	2-3

Source: National Cereals Research Institute (NCRI), National Centre for Genetic Resources and Biotechnology (NACGRAB) and National Agricultural Seeds Council (NASC).



Soil Sampling and Analysis

A composite sampling method was employed in collecting 15 soil samples at 15cm incremental depth from the soil surface to 30 cm depth from the NCRI rice research field. These samples were analyzed in the NCRI Central Service Laboratory using methods described by the Association of Official Analytical Chemists (AOAC, 2012) to determine the levels of iron toxicity, pH level, sodium, potassium, calcium and magnesium concentrations and status of nutrients in the soil nutrient status.

Table 2: Analysis of Soil Samples Obtained from NCRI Rice Research Field Badeggi in 2024

Parameters	0-15cm	15-30cm
Sand (g kg ⁻¹)	849.6	832.4
Silt (g kg ⁻¹)	105.6	82.8
Clay (g kg ⁻¹)	44.8	84.8
USDA Textural Class	Sandy loam	Sandy loam
pH (H ₂ O)	46.4	46.5
Organic Carbon (g kg ⁻¹)	5.9	6.8
Organic Matter (g kg ⁻¹)	10.2	11.8
Total Nitrogen (g kg ⁻¹)	1.5	1.0
Available Phosphorus (mg/Kg)	250.0	268.8
Exchangeable Bases (Cmol/Kg)		
Calcium (Ca ²⁺)	2.48	2.88
Magnesium (Mg ²⁺)	4.63	5.90
Sodium (Na ⁺)	0.17	0.13
Potassium (K ⁺)	0.15	0.20
Exchangeable Acidity (Cmol/Kg)	0.05	0.08
Cation Exchange Capacity (Cmol/Kg)	7.48	9.19
Fe (mgKg ⁻¹)	446	437

Experimental Design

The treatments consisted of thirty (30) genotypes of lowland rice arranged in a Randomized Complete Block Design (RCBD) with three (3) replications. The two experiments: Drought stressed and non-stressed experiments were laid side by side, separated by high bond. The size of the experimental field was 30 x 15 m², gross plot size was 2 x 1 m² with 66 plant population per gross plot and 6 stands per net plot.

Drought screening followed randomized complete block design (RCBD) with three (3) replications while iron toxicity evaluation used a completely randomized design with Fe² treatments (0, 150, 300 ppm) replicated four (4) times.

Data Collection and Analysis

Five rice plants were randomly tagged in each net plot to determine the following plant height, panicle length, numbers of tillers, days to 50% flowering, flag leaf attitude, numbers of effective tillers, numbers of seed per panicles, panicle exertion, 1000 grain weight, and grain yield. Leaf rolling, leaf drying and phenotypic acceptability were observed after withdrawing water from the water-stressed experiment. The standard evaluation system (SES) provided by the International Rice Research Institute, (2023) was adopted for iron toxicity.

Traits measured included leaf rolling, tip burn, phenotypic acceptability, and recovery. Data were subjected to analysis of variance (ANOVA) using Statistical Tools for Agricultural Research (STAR), (IRRI, 2014), and means separated using Duncan Multiple Range Test at 5% probability.

RESULTS AND DISCUSSIONS

Drought Stress Response

Analysis of variance (ANOVA) showed the significant ($P < 0.05$) differences across the 30 rice genotypes for all drought-related parameters, suggesting substantial genetic variability. At four



weeks after withdrawal of water (4 WAWS), phenotypic acceptability scores ranged from 3.00 to 7.67. Genotypes such as FARO 57 and Alh Baba recorded the lowest scores (3.00), indicating strong tolerance, whereas FARO 62, FARO 32, and FARO 34 recorded higher scores (7.67), reflecting susceptibility.

Leaf rolling scores ranged from 1.67 to 6.33. FARO 26 and FARO 57 exhibited minimal leaf rolling (1.67), suggesting superior drought avoidance mechanisms, while FARO 19, FARO 22, FARO 34, FARO 62, and FARO 66 showed severe rolling (6.33). Tip burn scores followed a similar trend, with tolerant genotypes maintaining lower values.

At six weeks after stress imposition (6WAWS), stress effects intensified. FARO 68 demonstrated exceptional tolerance with a phenotypic acceptability score of 1.00 and minimal leaf rolling (1.00). Conversely, FARO 52 exhibited high susceptibility with a score of 7.67.

Recovery assessment further differentiated genotypes. FARO 15, FARO 30, FARO 44, FARO 51, FARO 52, FARO 57, FARO 60, FARO 68, and IR-72 recorded the lowest recovery scores (1.00), indicating strong resilience. In contrast, FARO 17 showed the poorest recovery (score = 9.00), confirming high susceptibility. Leaf rolling is a common adaptive response of plants exposed to water deficit. This physiological adjustment helps limit water loss by reducing leaf surface exposure, decreasing stomatal conductance, and lowering transpiration, thereby conserving moisture under drought conditions (Fukai and Cooper, 1995). The occurrence of leaf rolling has therefore been recognized as an important indicator of drought tolerance in crops. However, variation among genotypes suggests that this characteristic is governed by multiple genetic and physiological factors, as some plant lines with limited leaf rolling may still exhibit poor drought performance. Furthermore, the extent of leaf rolling and leaf drying has been positively associated with the capacity of plants to recover following drought stress (Efisue *et al.*, 2009). Consequently, these traits remain valuable selection criteria in breeding programs aimed at developing drought-tolerant rice cultivars. Recovery plays very critical role in drought tolerance (Semwal and Khanna-Chopra, 2020). Several genotypes showed high survival after drought. The high capacity for recovery played a significant role in survival of these genotypes.

The observed variability among genotypes highlights the role of genetic factors in drought adaptation. Tolerant genotypes such as FARO 57 and FARO 68 exhibited minimal leaf rolling and low tip burn, indicating efficient water conservation and cellular stability. Leaf rolling is a key adaptive trait that reduces transpiration, while recovery ability reflects resilience and capacity to resume growth after stress.

The superior performance of certain genotypes may be attributed to enhanced water use efficiency, deeper root systems, and better osmotic adjustment. These findings align with previous reports that drought tolerance in rice is strongly associated with physiological stability and recovery capacity.

Table 3: Drought Indices and Recovery of 30 Genotypes of Rice at Badeggi, 2024

Varieties	4 weeks after withdrawal of water			6 weeks after withdrawal of water			Recovery scores		
	Phenotypic acceptability	Lea f roll	Tip burn	Phenotypic acceptability	Lea f roll	Tip burn	Phenotypic acceptability	Leaf roll	Tip burn
FARO 4	4.33	3.67	3.00	4.33	5.00	5.67	5.00	7.00	7.00
FARO 15	4.33	3.67	3.00	2.33	2.33	1.67	1.00	3.00	3.67
FARO 16	5.67	5.00	5.00	5.67	4.33	6.33	7.00	7.00	6.33
FARO 17	4.33	3.00	3.67	4.33	4.33	7.00	9.00	9.00	9.67
FARO 18	7.00	5.67	5.00	4.33	4.33	3.67	2.33	5.00	3.67
FARO 19	5.00	6.33	5.67	5.00	5.00	5.00	1.00	7.00	4.33
FARO 20	4.00	4.33	4.33	3.67	3.67	3.67	5.00	3.00	1.00
FARO 21	6.33	5.00	5.67	4.33	4.33	5.00	4.33	3.00	3.67
FARO 22	8.33	6.33	7.00	4.33	5.00	4.33	6.33	5.00	5.67
FARO 24	3.67	3.00	3.67	3.67	4.33	3.67	5.67	5.00	1.00
FARO 26	4.33	1.67	3.00	3.67	3.67	4.33	3.00	3.67	3.00
FARO 27	5.67	4.33	3.67	3.67	4.33	3.67	4.33	4.33	3.67
FARO 30	6.33	5.67	5.00	4.33	4.33	5.00	1.67	2.33	1.00
FARO 31	5.00	3.00	3.67	3.00	3.67	2.33	3.67	5.67	2.33
FARO 32	7.67	5.67	4.33	5.67	3.67	5.67	3.00	3.67	4.33
FARO 33	5.00	4.33	5.00	5.00	1.67	5.00	3.00	3.00	4.33
FARO 34	7.67	6.33	7.00	6.33	6.33	5.67	5.67	4.33	6.33
FARO 44	4.33	4.33	3.67	2.33	2.33	1.00	1.67	1.67	2.33
FARO 50	4.33	3.67	3.67	3.00	3.67	3.00	3.00	5.00	3.00
FARO 51	7.00	5.67	5.67	5.00	5.00	7.00	1.00	1.67	1.00
FARO 52	6.33	4.33	5.67	7.67	5.00	5.00	1.67	3.00	3.00
FARO 57	3.00	1.67	1.67	6.33	3.67	6.33	1.00	2.33	2.33
FARO 60	4.33	3.00	3.00	4.33	2.33	2.33	1.67	6.33	2.33
FARO 61	6.33	4.33	5.67	5.00	5.00	5.00	4.33	6.33	4.33
FARO 62	7.67	6.33	5.67	5.00	5.67	3.67	6.33	4.33	5.00
FARO 66	7.00	6.33	7.00	6.33	6.33	5.67	2.33	6.33	2.33
FARO 67	6.33	5.00	4.33	4.33	4.33	4.33	4.33	7.00	4.33
FARO 68	4.33	2.33	3.00	1.00	1.00	1.67	1.00	2.33	3.00
IR 72	5.67	3.67	3.67	2.33	2.33	3.67	1.00	1.67	3.00
Alh. Baba	3.00	2.33	1.67	6.33	3.67	4.33	4.33	3.67	3.00
Mean	5.47	4.33	4.40	4.42	4.02	4.36	3.47	4.40	364

Iron Toxicity Response

The result of soil analysis indicated a high iron concentration ($>430 \text{ mg kg}^{-1}$), confirming predisposition to iron toxicity. Under controlled treatments (0, 150, 300 ppm Fe^{2+}), genotypes exhibited varying levels of tolerance.

At elevated iron levels (300 ppm), susceptible genotypes displayed severe leaf bronzing, reduced shoot length, and stunted growth. Tolerant genotypes maintained relatively low bronzing scores ($<30\%$ leaf area affected) and sustained physiological activity. Visual scoring revealed that tolerant genotypes limited oxidative damage and maintained better growth performance. The Iron stress study revealed substantial genotypic variability in rice responses to Fe^{2+} stress across phenotypic, physiological, and 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). Across all observation periods, several genotypes, consistently recorded high stress scores



(≥ 9.00), indicating poor tolerance to Fe toxicity/stress. In contrast, some genotypes frequently recorded minimal injury scores suggesting greater tolerance.

The manifestation of leaf bronzing, rolling and tip burn is a classical physiological response to iron toxicity, as excessive Fe^{2+} accumulation stimulates oxidative stress within leaf tissues (Mamadou *et al.*, 2021; Stein *et al.*, 2014). 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) and Sikirou *et al.*, (2015).

Notably, Alh Baba, FARO 33, FARO 44, FARO 52, FARO 61, FARO 60 and IR-72 showed consistently low injury scores, which aligns with reports describing varietal differences in root oxidation power (ROP) and iron plaque formation as mechanisms mitigating Fe uptake (Wu *et al.*, 2014). These genotypes likely possess stronger ROP or improved internal detoxification, similar to the tolerant cultivars *Azucena* and *Suwandel*, reported in earlier literature. Some genotypes such as FARO 22, FARO 67 and FARO 68 were moderately tolerant at 150ppm, but displayed susceptibility at 300ppm. This dosedependent decline supports findings from Sahrawat *et.al.*, (1999), who noted that tolerance thresholds vary among genotypes and may be exceeded at high Fe concentration. Survival patterns at 7, 14, and 21 DAIT further validated the phenotypic scoring.

Genotypes such as Alh Baba, FARO 16, FARO 31, FARO 34, FARO 44, FARO 52, FARO 60–62, FARO 67 and FARO 68 survived both 8dSm^{-1} and 16dSm^{-1} equivalent Fe stress levels. Conversely, FARO 18, FARO 19, FARO 20, FARO 21 and FARO 67 demonstrated poor survival under severe stress. Complete mortality of FARO 38 at 150ppm and FARO 34 at 300ppm reinforces their classification as highly susceptible. These findings corroborate the patterns reported by Audebert (2006), where susceptible genotypes often rapidly decline after Fe accumulation surpasses physiological detoxification capacity.

The study reported a significant reduction in chlorophyll content after stress, especially at 300ppm. The observed declined up to 20% in some genotypes is consistent with the chlorosis and pigment breakdown that accompanies Fe-induced oxidative damage (Becker and Asch, 2005; Stein *et al.*, 2014). Alh Baba and FARO 44 maintained comparatively high chlorophyll levels and low injury scores across all stress levels, signifying stronger anti-oxidative defense mechanisms. Similar genotype-specific resilience was documented by Dufey *et al.*, (2009), who emphasized the role of enhanced catalase/peroxidase activity in tolerant rice.

Genotypes such as FARO 24, FARO 26, FARO 50, FARO 60 and FARO 67 recorded high iron injury scores, reflecting poor tolerance. These injury scores align with significant reductions in chlorophyll, supporting the idea that Fe toxicity impairs photosynthetic capacity through ROS accumulation, as reported by Aung and Masuda (2020). The study showed that Fe stress negatively affected shoot length, plant height, tiller production, number of seeds per panicle and grain yield. This aligns with the general consensus that Fe toxicity reduces biomass accumulation and reproductive success (Audebert and Sahrawat, 2000; Sikirou *et al.*, 2015). FARO 24 consistently produced the tallest plants across all concentrations, even at 300 ppm, indicating strong resilience or avoidance mechanisms. Meanwhile, FARO 26 and FARO 67 frequently produced the shortest plants, consistent with their poor physiological performance.

Tiller reduction under Fe stress is well documented as an early indicator of toxicity. In the present findings, FARO 51 and FARO 52 maintained high tiller numbers even under 300ppm concentrations while Alh Baba and FARO 24 recorded reductions. This partially agrees with Lin-Bo *et al.*, (2016), who reported genotype-specific impacts of Fe stress on tiller initiation depending on hormonal and resource allocation dynamics.

Flag leaf length decreased significantly in susceptible varieties (e.g., FARO 26 and FARO 44), whereas tolerant genotypes such as Alh Baba and FARO 52 maintained longer flag leaves. Flag leaf traits are critical for grain filling, and similar reductions under Fe stress were also reported by Sikirou *et al.*, (2015). Panicle exertion and number of seeds per panicle were also negatively affected at high Fe concentrations, especially in susceptible genotypes (FARO 52, FARO 67). Impaired panicle exertion is a known symptom caused by Fe-induced hormonal disruptions or impaired carbohydrate translocation.



Grain yield declined significantly with increasing Fe concentration. FARO 24 remained the top yielder at all stress levels (53.77 g in control, 56.40 g at 150ppm and 47.33 g at 300ppm), demonstrating robust tolerance mechanisms that translated into stable productivity. 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). Genotypes such as FARO 44, FARO 26, FARO 60 and FARO 67 recorded the lowest yields under stress, matching their high injury scores and reduced physiological performance.

Iron toxicity tolerance observed in selected genotypes suggests effective regulation of iron uptake and detoxification. Tolerant genotypes likely employ mechanisms such as iron exclusion at the root level, compartmentalization within vacuoles, and enhanced antioxidant activity to mitigate oxidative stress.

Leaf bronzing, a key indicator of iron toxicity, was significantly reduced in tolerant genotypes, confirming their ability to limit Fe² accumulation. The high iron levels in the experimental soil further validate the robustness of the screening process.

CONCLUSION AND RECOMMENDATION

The study showed substantial variability among rice genotypes in response to drought, and iron toxicity. Identified tolerant genotypes could offer significant potential for improving rice productivity under adverse environmental conditions. The significant genetic variability observed across all stress conditions provides a strong foundation for breeding programs. Genotypes such as FARO 57, FARO 68, and FARO 44 demonstrated combined tolerance to multiple stresses, making them valuable candidates for developing climateresilient rice varieties. Integrating these genotypes into breeding programs could enhance productivity in stress-prone environments, particularly in sub-Saharan Africa where abiotic stresses are intensifying due to climate change.

REFERENCES

- Almeida, D. M., Almadanim, M. C., Lourenco, T., Abreu, I. A., Saibo, N. J. M. & Oliveira, M. M. (2016). Screening for Abiotic Stress Tolerance in Rice: Salt, Cold and Drought. In: Duque P.(ed) Environmental Responses in Plants. *Methods in Molecular Biology*, **1398**: 155-182. doi: 10.1007/978-1-4939-3356-3_14.
- Association of Analytical Chemists (AOAC). (2012). INC. Suite 400, 2200 Wilson Boulevard, Arlington, Virginia, 22201 USA. 2(2), pp4. <http://www.eoma.aoac.org>.
- Audebert, A. & Sahrawat, K. L. (2000). Mechanisms for Iron Toxicity tolerance in lowland rice. *Journal of Plant Nutrition*, **23**: 1877-1885.
- Audebert, A. (2006). Iron toxicity in rice: A comprehensive review. *Plant and Soil*, **285**(12): 207-230. <https://doi.org/10.1007/s.11104-006-0020-0>.
- Aung, M. S. & Masuda, H. (2020). Iron biofortification of rice: A review of the approaches and challenges in developing iron-rich rice varieties. *International Journal of Agricultural Sustainability*, **18**(4): 370-381. <https://doi.org/10.1080/147>.
- Barde, A. M., Mohammed, M. S., Oyekunle, M., Usman, I. S. & Shaahu, A. (2021). Estimation of Genetic Variability, Heritability and Genetic Advance in Rice (*Oryza sativa* L.) Genotypes. *International Journal of Research and Innovation in Applied Science*, **6**(1): 2454-6194.
- Becker, M. & Asch, F. (2005). Iron toxicity in rice: What is the effect of iron toxicity in rice and how can it be managed? *Field Crops Research*, **94**(1): 129-140. DOI. 10.1016/j.fcr.2004.10.011.
- Becker, M. & Asch, F. (2005). Iron toxicity in rice: What is the effect of iron toxicity in rice and how can it be managed? *Field Crops Research*, **94**(1): 129-140. DOI. 10.1016/j.fcr.2004.10.011.
- Dufey, J. E. (2009). Iron toxicity in rice: Mechanisms and management. *Field Crops Research*, **112**(1): 1-12. DOI: 10.1016/j.fcr.2009.03.008.



- Efisue, A. A., Tonggoona, P., Derera, J. & Ubi, B. E. (2009). Screening Early-Generation Progenies of Interspecific Rice Genotypes for Drought-Stress Tolerance during Vegetative Phase. *Journal of Crop Improvement*, **23**: 174-193.
- Engel, K., Asch, F. & Becker, M. (2012). Classification of Rice Genotypes Based on their Mechanisms of Adaptation to Iron toxicity. *Journal of plant Nutrient Soil Science*, **175**(6): 871-881.
- FAO (2017). Food and Agriculture Organization of the United Nations Statistics division. <https://openknowledge.fao.org/handle/20.500.14283/i7658en>
- FAO (2021). Food and Agriculture Organization of the United Nations. Nigeria at a glance. Faostat.
- Fukuai, S. & Cooper, M. (1995). Development of drought-resistant cultivars using physiomorphological traits in rice. *Field Crops Research*, **40**(2): 67-86.
- Hyunwoo, K., Venkataramana, S., Mohammed, M. & Le, D.T. (2021). The Future of Rice Farming: A Review of Natural and Eco-Friendly Practices, *International Journal of Environment and Climate Change*, **13**(11): 4240-4249.
- IRRI (2014). Statistical Analysis for Agricultural Research (STAR. Biometrical and breeding informatics (PBGB) division, International Rice Research Institute, Los Banos, Laguna
- IRRI, International Rice Research Institute, (2023). Standard Evaluation System for rice 4th Edition, International Rice Research Institute, Manila, The Philippines.
- Islam, M. A., Raffi, S. A., Hossain, M. A. & Hassan, A. K. (2015). Analysis of Genetic Variability, Heritability and Genetic Advance for Yield and Yield Associated Traits in some promising advanced lines of rice. *Progressive Agriculture*, **26**: 2631.
- Lin-Bo, W., Yoshiaki, U., Shang-Kun, L. & Michael, F. (2016). Shoot tolerance mechanisms to iron toxicity in rice (*Oryza sativa* L.), *Plant Cell Environment*, **40**(4): 570-584. DOI: 10.1111/pce.12733.
- Lin-Bo, W., Yoshiaki, U., Shang-Kun, L. & Michael, F. (2016). Shoot tolerance mechanisms to iron toxicity in rice (*Oryza sativa* L.), *Plant Cell Environment*, **40**(4): 570-584. DOI: 10.1111/pce.12733.
- Mamadou, L., Barry, N. S., Mahamadi, H. O., Kiswendsida, R. N., Sawa, C., Moussa S., Pauline, B. & Mahamadou, S. (2021). Genetic Diversity of Local Rice Accessions Cultivated in Guinea Based on Agro-Morphological Traits and Identification of Sources of Tolerance to Iron Toxicity. *Agricultural Sciences*, **12**(10): 275-286.
- Ndjiondiop, M. N., Wambugu, P. W., Sangare, J. R. & Gnirikoua, K. (2018). The effects of drought on rice cultivation in sub-Sahara Africa and its mitigation: A Review. *African Journal of Agricultural Research*, **13**(25): 1257-1271.
- Semwal, V. K. & Khanna-Chopra, R. (2020). Enhanced oxidative stress, damage and inadequate antioxidant defense contributes towards insufficient recovery in water deficit stress and heat stress combination compared to either stress, alone in *Chenopodium album* (Bathua). *Physiology and Molecular Biology of Plants*, **26**(7): 1331-1339.
- Sahrawat, K. L. Datta, S. & Sing, B. N. (1999). Nitrogen responsiveness of low land rice varieties under irrigated conditions in West Africa. *Intl. Res. Notes*. **24**(2): 30-42.
- Sikirou, M., Saito, K., Achigan-Dako, E. G., Dramé, K. N., Adam, A. & Venuprasad, R. (2015). Genetic Improvement of Iron Toxicity Tolerance in Rice-Progress, Challenges and Prospects in West Africa. *Plant Production Science*, **18**(4): 423-434.
- Stein, A. J. & Meenakshi, J. V. (2014). Iron-biofortified rice improves the iron status of women and children in Bangladesh and Indonesia: A randomized controlled trial. *The Journal of Nutrition*, **144**(12): 1992-1998. DOI:10.3945/jn.114.189202.
- Wu, L., Zhang, L., Yang, X. & Xie, Y. (2014). Iron toxicity in rice and its physiological and biochemical mechanisms. *Plant and Soil*, **382**(1-2): 105-120.