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Genetic Diversity of Local Rice Accessions Cultivated in Guinea Based on Agro-Morphological Traits and Identification of Sources of Tolerance to Iron Toxicity

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Abstract

In Guinea, traditional rice varieties are the most widely cultivated in rural areas despite their low yield and high susceptibility to iron toxicity. Moreover, the introduction of new improved varieties tolerant to iron toxicity poses a serious threat to the preservation of the genetic resources of these traditional varieties, whose genetic diversity remains poorly known. The present study therefore aims at a better valorisation of these local rice cultivars through the evaluation of their agromorphological diversity and the identification of genotypes potentially tolerant or resistant to iron toxicity. Thus, 90 accessions collected in the regions of Kindia and Macenta and six controls susceptible or resistant to iron toxicity (AZUCENA, BOUAKE 189, CK 73, IR64, NERICAL 19 and AURYLUX 6) were evaluated in three replicate alpha lattice designs in two sites (Sérédou and Kilissi) using 16 agromorphological traits. The results showed significant agromorphological variability of the traditional accessions at both sites for all qualitative and most quantitative traits studied. In addition, 30 local cultivars expressed similar or higher grain yields than the resistant or tolerant controls at both sites, of which 12 were found to be stable at both sites. Of the 12 cultivars identified, five were resistant and seven tolerant to iron toxicity. These 12 accessions could be used in the varietal improvement of lowland rice in Guinea Conakry.

Keywords

Local Varieties, Oryza, Genetic Variability, Environmental Stress, Guinea

1. Introduction

Rice is one of the most consumed cereals in the world [1] with a production of over 479.2 million tonnes [2]. Most of this production is in Asia.

Despite a large potential arable land area for rice cultivation of more than 200 million hectares, Africa produces only 29 million tonnes or 4% of world production [3] [4]. The main causes of low rice production are high production costs and low yields due to biotic factors including diseases (blast, helminthosporium, yellow mottle etc.) and weeds, and abiotic factors such as iron toxicity. In Guinea, rice is also the staple food of more than 12 million people. It is grown to nearly 520,000 ha [5]. However, like most irrigated and rainfed lowlands in West Africa, iron toxicity is a major constraint to rice production in lowlands bordered by iron-rich plateaus [6]. It reduces growth, tillering, and soil fertility [7] and consequently grain yields. Yield losses in rice due to iron toxicity are estimated to be between 12% and 100% in West Africa [6] [8] [9] [10]. Indeed, iron is widespread in West African lateritic soils in excessive amounts and thus causes nutritional disorders in rice. Critical levels of iron toxicity are above 500 mg Fe per kg^{-1} of dry weight leaves. However, the level of susceptibility to iron toxicity varies considerably among varieties [11] [12]. While the varieties of *O. sativa* showed growth problems at low external concentrations (less than 10 ppm Fe^{2+}), cultivars of *Oryza glaberrima* subjected to higher doses (500 ppm Fe^{2+}) for 3 days were not affected [13]. In Guinea, iron toxicity is much more prevalent in the lowlands of Lower Guinea and Forest Guinea. Despite the numerous works carried out by the Guinean Agricultural Research Institute in collaboration with Africarice to subdue the effects of this abiotic constraint through the creation of new varieties (ARICA6, ARICA18, NERICAL19, CK73) created by AfricaRice, IRRI and Kilissi that are iron-tolerant or iron-resistant, and through the use of alternative methods such as silica [14] or fertiliser, iron toxicity still hinders the development of rice production in Guinea. Indeed, farmers still face enormous difficulties related to the problem of large-scale dissemination of improved varieties, their adaptability, the availability of silica, the high price of fertiliser, and the lack of development of plains [1]. Therefore, a better response to farmers' expectations is the exploitation of the genetic resources of their local cultivars better adapted to their environments to search for varieties resistant or tolerant to iron toxicity. Thus, the intensification and increase of rice production necessarily requires a better knowledge of the agro-morphological diversity of traditional varieties grown in rural areas. In particular, the level and structure of agromorphological diversity of local accessions must be assessed and genotypes that are potentially tolerant or resistant to iron toxicity must be identified.

2. Materials and Methods

2.1. Material

2.1.1. Study Sites

The experiments were carried out on two sites, Kilissi and Sérédou, indeed, most of the lowlands in these two localities are heavily affected by iron toxicity.

1) Kilissi site

The Kilissi Agricultural Research Station is located in the prefecture of Kindia, 135 km east of the capital Conakry, at an altitude of between 95 and 110 m and with geographical coordinates of 9˚59 north latitude and 12˚49 west longitude. The Prefecture of Kindia has a humid tropical climate characterised by two alternating seasons of equal duration. The dominant winds are the Monsoon and the Harmattan. The rainiest months in 2018 were June, July, and August. The maximum rainfall was recorded in August. The cumulative annual rainfall was 1656.7 mm for the last 10 months of the year. The field experiment was carried out under lowland conditions on an iron toxicity site with ultisol whose physical and chemical characteristics determined following the analysis of a composite sample are recorded in Table 1.

Table 1. Physical and chemical characteristics of Kilissi soil.

Characteristics		Average	Method of analysis
Particle size	Clays (%)	26.48	Densimetry
	Fine silts (%)	-	
	Coarse silt (%)	24.0	
	Fine sands (%)	6.0	
	Coarse sands (%)	49.52	
	FOULAYA	LAS	
Mineral elements	pH (H_2O)	5.6	Electrometry
	pH (KCl)	4.99	Electrometry
	Carbone (%)	1.80	Anne
	M.O (%)	2.89	Anne
	N total (%)	0.22	Kjeldahl
	C/N	12.83	
	CEC (mol·kg^{-1})	7.5	Kapen
	P_total (mol·kg^{-1} sol)	0.9	Colorimetry
	P_total (mol·kg^{-1} sol)	3.00	Colorimetry
	P_2O_5 total mg/kg	0.08	Colorimetry
	P_2O_5 assim. mg/kg	3.6	Colorimetry
	K (mg·kg^{-1})	384	Anne
	Ca (mg·kg^{-1})	41	Anne
	Mg (mg·kg^{-1})	573	Anne
	Fe (ppm ou mg/m^3)	2300	Anne
	Zn (mg·kg^{-1})	5,5	Anne

Source: Foulaya soil laboratory (LAB Sols F.), 2016.

2) Sérédou site

The Regional Agricultural Research Centre of Sérédou (CRRA-Sérédou) is located in Sérédou, one of the sub-prefectures of Macenta. It is located in the south of the prefecture, 38 km from the urban centre, at an altitude of 620 m and with geographical coordinates of 8˚32'37" north latitude and 9˚28'22" west longitude. The growing season begins in April and ends in December with a minimum temperature of 20.8˚C, an average of 25.8˚C and a maximum of 30.8˚C. A rainfall of 1992.4 mm for 179 rainy days was recorded during the trial. The average daily relative humidity and insolation were 77% and 6 hours, respectively. The field experiment was conducted in a lowland with hydromorphic clayey silt soil. The physico-chemical characteristics of the soil are recorded in Table 2.

Table 2. Physico-chemical characteristics of the soil in Sérédou.

Characteristics		Average	Method of analysis
Particle size	Clays (%)	30.48	Densimetry
	Silts (%)	12.0	
	Sands (%)	57.52	
	FOULAYA	LAS	
Mineral elements	ph (H_2O)	5	Electrometry
	ph (KCl)	5.6	Electrometry
	Carbon (%)	1.80	Anne
	M.O (%)	2.95	Anne
	N total (%)	1,61	Kjeldhahl
	C/N	11.59	
	CEC ($mol \cdot kg^{-1}$)	9.4	Kapen
	P_total ($mol \cdot kg^{-1}$ sol)	0.68	Colorimetry
	P_total ($mol \cdot kg^{-1}$ sol)	3.5	Colorimetry
	P_2O_5 total mg/kg	0.72	Colorimetry
	P_2O_5 assim. mg/kg	10.51	Colorimetry
	K ($mg \cdot kg^{-1}$)	375	Anne
	Ca ($mg \cdot kg^{-1}$)	39.5	Anne
	Mg ($mg \cdot kg^{-1}$)	570	Anne
	Fe (ppm ou mg/m^3)	2250	Anne
	Zn ($mg \cdot kg^{-1}$)	5	Anne

Source: Foulaya soil laboratory (LAB Sols F.), 2016.

2.1.2. Plant Material

Ninety local accessions collected from farmers in the prefectures of Kindia and Macenta and six imported improved varieties (AZUCENA, BOUAKE 189, CK 73, IR64, NERICAL 19 and AURYLUX 6) were used as plant material. The imported varieties were selected for their behaviour towards iron toxicity. These improved varieties have already been tested in lowland areas with iron toxicity in the West African subregion, notably in Guinea, Benin, Burkina Faso, Nigeria, Ghana, and Côte d'Ivoire [15].

2.2. Methodology

2.2.1. Experimental Set-Up

Two trials were set up in July 2018 in Kilissi and Sérédou. At each site, the trial was conducted in an alpha lattice design with three replications. Each replication consists of eight blocks containing 12 elementary plots each. The area of an elementary plot was 5 m^2 and the distances between replicates, blocks, and plot were, respectively, 1 m^2, 0.5 cm, and 0.5 cm with a defence zone of 2 m^2 on both sides of the trial. The total area of each trial was 2826.5 m^2 with a length of 59.5 m and a width of 47.5 m.

2.2.2. Conduct of the Trials

The trials were conducted under lowland conditions. A nursery was set up on 24/07/2019 in Kilissi and on 25/07/2019 in Macenta (**Figure 1**). The preparation of the land following the installation of the nursery consisted of clearing, collection, and manual clearing followed by planting in both sites.

Twenty-one-day-old seedlings were transplanted to 5 m^2 plots with two plants per plot with a spacing of 20 cm × 20 cm between the plants and between the rows, *i.e.* 5 m rows per elementary plot for a density of 625 plants per elementary plot (**Figure 2**).

(a) (b) (c)

Figure 1. Stages in the establishment of the rice nursery. (a) Rice sample; (b) Nursery seedlings; (c) Seedlings ready for transplanting.

(a) (b) (c) (d)

Figure 2. Transplanting seedlings in the experimental plot. (a) Plot ready to be transplanted; (b) uprooting of plants; (c) Transplanting of rice; and (d) Transplanted plot.

Maintenance consisted of two manual weedings and one chemical weeding. Regarding fertilisation, 150 kg/ha of NPK fertiliser (15-15-15) was applied one day before transplanting, while 100 kg/ha of urea was applied in two sprays, 35 kg/ha at the beginning of tillering after the first weeding and 65 kg/ha at panicle initiation after the second weeding.

2.3. Data Collection

Observations were made on agro-morphological traits and iron toxicity scores on the leaves of rice plants. The quantitative variables were measured on 10 plants selected from the useful plot and the qualitative variables were observed on the whole plot and scores were noted after visual observations.

2.3.1. Quantitative Variables

To study the effect of the different treatments on the growth and development of rice, nine variables were measured. These are:

- the height of plants at maturity (HPM) measured on 10 plants in the working plot from the base of the plant to the tip of the highest panicle;
- the number of tufts per m^2 (NT/m^2) at the full tillering stage was determined by counting all plants per m^2 in each test plot;
- the number of tillers per clump (NT/T) at 60 days after transplanting was determined by visual counting, which is the tillering ability of the variety. It is one of the most important indicators of good paddy grain yield;
- the number of panicles per m^2 (NP/m^2) at maturity, which gives information on the number of fertile tillers on 1 m^2 per elementary plot and therefore affects yield;
- the total number of grains per panicle (NG/P) evaluated on one panicle per plant sampled with 1 m^2 per variety;
- Grain yield (Rdt, kg/ha) after 85% - 90% maturity of panicles in the field and at 14% moisture. The yield per hectare is obtained in grams by weighing and extrapolated to kg/ha;
- the weight of 1000 seeds (P1000 Grn) was evaluated with an AIDE brand balance and precision Max 5000gx1G Max 11/b.O.10z by counting and weighing;
- the moisture content (TH%) was measured with a digital grain moisture meter, Precision Moistex SS 7 SATAKE, at a moisture content less than or equal to 14%;
- the sowing heading cycle (SSC), which represents the number of days between sowing and the beginning of the first rice plant to be headed (10%);
- the sowing-maturity cycle (SMC), which corresponds to the number of days between sowing and the maturity of the plant when at least 85% to 90% of the panicles have a straw colour.

2.3.2. Qualitative Variables

Seven variables were assessed from sowing to maturity. They were assessed on all plants. They were:

- Panicle exertion (PE) which expresses the good or bad exit of the panicle from the plant. Thus, emergence was considered good if the distance between the base of the panicle leaf and the beginning of the secondary branching was greater than or equal to 10 cm.
- Plant vigour (PV), which was observed 21 and 42 days after sowing to differentiate robust green plants with active growth and good balance from stunted and stunted plants.
- The description of foliar symptoms of iron toxicity on the plant. For the observation of iron symptoms on rice leaves, the IRRI index scale was used for the assessment of iron toxicity [16] as recorded in **Table 3**. The generalized linear model [16] was used to test the effect of iron on yield. In addition, the assessment of iron toxicity symptoms (ITSS) was done by naked eye observation of the plants and the use of a 1 - 9 scale based on the International Rice Research Institute (IRRI) standard rice rating system: a score of 0 indicates normal growth and tillering, 9 indicates that almost all plants were dead or dying [17]. Plants were observed three times during the growth period (21DAR, 60DAR, and 90DAR) so that when iron toxicity symptoms were expressed on the foliage to monitor toxicity. Iron toxicity scores were recorded in all plots.
- Rice blast (RP) is the major disease of rice in South Saharan Africa (SSA). It is caused by *Pyriculariosis oryzae*, a fungus that attacks all organs of the plant: leaves, neck, nodes, panicle, rachis, and stems. Observations were made on the leaves that are most susceptible.

Table 3. IRRI scale for describing iron toxicity symptoms in the field (field damage to rice plants).

N˚	Scores	Description
1	Zéro: 0	Normal growth and tillering
2	One: 1	Near normal growth and tillering; reddish-brown spots or orange discoloration on older leaf tips
3	Three: 3	Three (3) Near normal growth and tillering; reddish-brown, purple, or orange discolouration on older leaves
4	Five: 5	Five (5) Delayed growth and tillering; many discoloured leaves
5	Seven: 7	Growth and tillering cease; most leaves discoloured or dead
6	Nine: 9	Nearly all plant dies or total plant death

2.4. Data Analysis

The data collected were processed with the Excel spreadsheet and XLSTAT-Pro 7.1 software. The Excel spreadsheet was used to produce histograms of the distribution of the accessions for the qualitative variables, and XLSTAT-Pro 7.1 was used for the analysis of variance (ANOVA) based on a linear model to evaluate the level of variability of the material and to identify the discriminating characteristics and the Newman and Keuls test of separation of means at the threshold $\alpha = 5\%$ to compare the performance of the varieties within each site and between sites.

3. Results

3.1. Kilissi Site

3.1.1. Variation of Qualitative Characteristics of Rice Accessions

At the level of the qualitative traits studied, a great variability was observed within the accessions. Thus, the score of iron toxicity symptoms varied from 0 to 9 and that of particularity from 0 to 5. For blast, most cultivars (62.5%) in the collection scored 0 and a minority (1.8%) scored 5. For iron toxicity, 20.48% of the plants scored 0 and a small proportion (5.9%) scored 9. For plant vigour, the score also varied from 0 to 5, with plants scoring 0 representing 1.73% and those scoring 5 representing 34.73% of the collection. Figure 3 shows the distribution diagrams of the accessions for each of the qualitative variables studied.

3.1.2. Variation of Quantitative Traits of Local Rice Accessions

1) Average performance of the local rice accessions evaluated

The characters studied discriminate significantly between accessions at the 1 and 5% thresholds, except for the height of plants at maturity (HPM), the number of panicles per plant (NP/P) and the number of seeds per panicle (NG/P), thus reflecting the existence of significant agro-morphological diversity within the collection (Table 4).

The coefficient of variation values ranged from 6.29% to 33.52% for moisture content and number of tillers per clump, respectively. The lowest values of the coefficient of variation were observed for "moisture content (6.29%) and panicle length (8.96%)". The smallest significant difference was 0.411 for moisture content and 133.575 for yield.

The number of seeds per panicle varied from 46 for the least seed-producing variety to 155 for the most seed-producing. For yield, the lowest was 1143.66 kg/ha on average for the least productive accessions against 4475.33 kg/ha on average for the most productive accessions for an overall average of 2719.63 kg/ha. The number of days from sowing to flowering varied from 80 to 128 days.

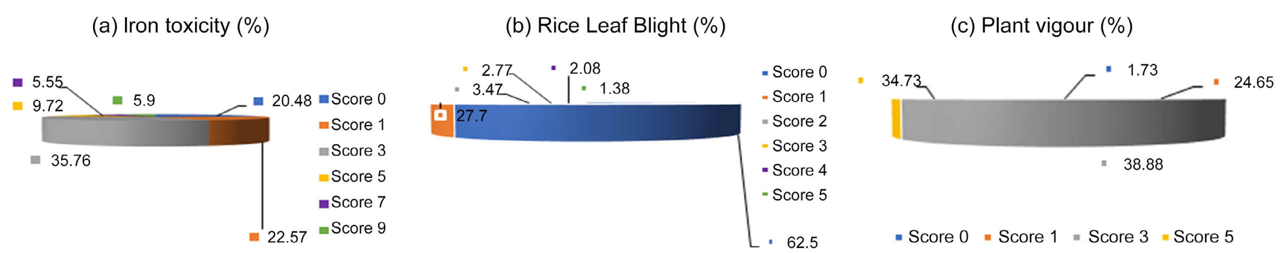

Figure 3. Proportions of the modalities according to the qualitative traits. Legend: On the IRRI scale for iron toxicity: score 0: resistant plants, score 1: very tolerant, score 3: tolerant, score 5: sensitive, score 7: very susceptible (stunting), and score 9: very susceptible (death of plants).

Table 4. Results of the analysis of variance of the 11 quantitative variables measured.

Variables	Minimum	Maximum	Mean	CV%	P-value	LSD 5%
CSE (Jrs)	80	128.333	104.653	12.156	0.012*	7.269
HPM (cm)	27	134.495	93.575	18.75	0.164^{NS}	10.187
NT/m²	5	25	10.573	29.162	0.015*	1.727
NT/T	3	23	9.052	33.518	0.057*	1.687
NP/P	2	14.5	7.908	32.361	0.164^{NS}	1.420
NG/P	46	155	93.543	24.717	0.234^{NS}	11.573
LP (cm)	15	26.66	21.891	8.995	0.075*	1.127
Rdt (kg/ha)	1143.667	4475.333	2719.634	33.033	0.014*	133.575
P1000 Grns (g)	18.333	34.333	28.024	10.735	0.007**	1.729
TH (%)	7.9	13.267	11.944	6.289	0.004**	0.411
CSM (jrs)	79.333	164.5	135.974	12.194	0.007**	9.629

Legend: SSC: sowing cycle heading, HPM: plant height at maturity, NT/m²: number of clumps per m², NT/T: number of tillers per clump, NP/m²: number of panicles per m², NG/P: number of grains per panicle, LP: panicle length, Rdt (kg/ha): yield, P1000 Grns: 1000 seed weight, TH: moisture content, CSM: sowing maturity cycle, *: significant difference at 5%, **: significant difference at 1%, NS: non-significant difference, F: Fisher's value, CV: coefficient of variation, LSD: smallest significant difference at 5% level.

2) Influence of the environmental factor on the variations of the quantitative traits

The results of the analysis of variance of the Kilissi site using the Newman and Keuls test of significance of the means presented in Table 5 reveal that the variables sowing epiposition cycle, 1000 grain weight, yield t/ha, and moisture content significantly discriminate the accessions. On the other hand, the variables height of plants at maturity, number of clumps per m², number of tillers per clump, number of seeds per panicle, and panicle length did not show a significant difference between accessions.

3) Comparison of yields of local accessions and controls for the identification of the best accessions

The yields of the control varieties (Table 6) and the 15 best local cultivars identified (Table 7) at Kilissi show that some of the local accessions evaluated were affected by iron toxicity while others tolerated iron in the lowlands and gave good yields similar to or better than the controls. Yields of the control varieties ranged from 2164 kg/ha for the Bouaké189 variety to 4438 kg/ha for the CK73 variety. As for the local accessions identified, they obtained yields ranging from 3315.33 kg/ha for the Patem accession to 4475.33 kg/ha for the Gbai-bai accession with an overall average of 3898.36 kg/ha.

The comparison of the yields of the local cultivars with the controls is shown in Figure 4. Only three local cultivars have similar yields to the best controls (Orulux 6 and CK 73).

Table 5. Results of the Newman and Keuls test for significance of means in Kilissi site.

Variables	Rep. 1	Rep. 2	Rep. 3	Pr > F	CV %
CSE (jrs)	96.667 a	96.543 a	83.214 b	0.012*	12.15
HPM (cm)	83.640 a	87.337 a	77.130 a	0.164NS	18.75
NT/m²	10.573 a	10.287 ab	8.837 b	0.015*	29.16
NT/T	8.755 a	8.755 a	7.582 a	0.057NS	33.52
NP/m²	7.271 a	7.447 a	6.337 a	0.164NS	32.36
NG/P	78.635 a	89.596 a	82.510 a	0.234NS	32.36
LP (cm)	19.876 a	19.920 a	17.657 a	0.075NS	8.99
Rdt (kg/ha)	2428.010 ab	2672.777 a	2083.929 b	0.014*	33.03
P1000 Grain (g)	26.250 a	25.074 ab	21.694 b	0.007**	10.74
TH (%)	11.068 a	10.867 a	9.251 b	0.004**	6.29
CSM (jrs)	125.563 a	123.734 a	105.184 b	0.007**	12.19

Legend: SSC: sowing cycle heading, HPM: plant height at maturity, NT/m^2: number of tufts per m^2, NT/T: number of tillers per tuft, NP/m^2: number of panicles per m^2, NG/P: number of grains per panicle, LP: panicle length, Rdt (kg/ha): yield, P1000 Grain: 1000 grain weight, TH: moisture content, SSC: sowing cycle maturity, *: Significant, **: highly significant, NS: not significant, Rep.: Replication.

Table 6. Performance of control varieties in terms of yields.

N°	Varieties	Yields (kg/ha)			Mean	Iron toxicity	Significance
		Rép. 1	Rép. 2	Rép. 3			
1	AZUCENA	3964	3667	3980	3870	1	T
2	BOUAKE 189	0	2164	0	2164	3	S
3	CK73	4250	5179	3886	4438	0	R
4	IR64	2378	3211	0	2795	3	S
5	NERICAL19	4150	3250	3911	3770	1	T
6	ORYLUX6	4050	4259	4925	4411	0	R

Legend: score 0: R: resistant; score 1: T: tolerant, score 3: S: susceptible.

Table 7. Performance of local accessions identified in terms of yield.

N°	Varieties grown	Average yield				Significance
		Rep. 1	Rep. 2	Rep. 3	Mean	
1	Commando	4217 ac	4376 b	4527 ab	4373.33	HS
2	Bokary	4148 c	4142 bc	2451 a	3580.33	HS
3	Citoyen	3863 ab	4142 b	2451 bc	3485.33	S
4	Komasataie	4526 ab	3905 b	3375 bc	3935.33	HS
5	Diforêt	4187 ad	4013 ac	3861 abc	4020.33	HS
6	Bonbondo	3540 abc	4495 ab	3603 b	3879.33	S
7	Dawoutaie	4574 a	3890 ac	3816 a	4093.33	HS
8	Fouledy	3549 abc	3728 a	3325 c	3534.00	S

Continued

9	Podêt	4193 a	3170 abc	4664 bc	4009.00	HS
10	Yamalopou	5385 abc	3753 ac	3325 a	4154.33	HS
11	Patem	2235 ac	3887 a	3824 a	3315.33	S
12	Salikouta	4525 ac	3184 ac	4609 bc	4106.00	HS
13	Gbai-gbai	5167 a	4833 ab	3426 ac	4475.33	HS
14	Koyan	3621 a	3279 a	3453 ab	3451.00	HS
15	Coyady	4461 bc	3361abc	4367 cb	4063.00	HS
	Mean	**4146.06**	**3877.2**	**3671.8**	**3898.36**	
	LSD 5%		**2.238**			
	CV%		**58.939**			

Legend: Means assigned the same letter in the same column or row are not significantly different at the 5% threshold by the SDPP calculation. Letters in the upper case refer to rows and those in the lower case to columns. S = Significant; NS = Non Significant, HS = Highly Significant, Rep. = Replication.

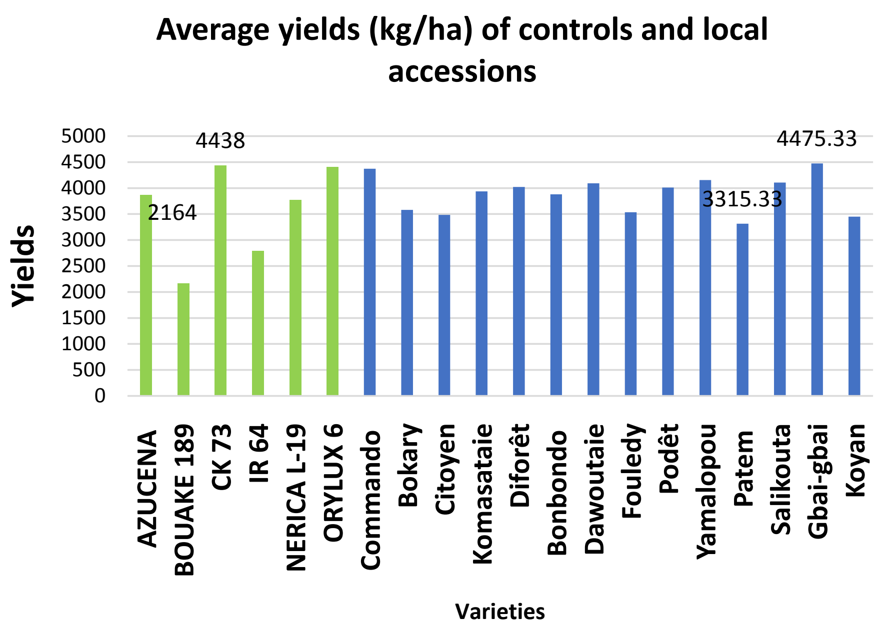

Figure 4. Variation in yields of local accessions identified in Kilissi.

3.2. Sérédou Site

3.2.1. Variation of Qualitative Traits of Local Rice Accessions

In Sérédou, a great variability was observed within the accessions for the qualitative traits (Figure 5). Thus, iron toxicity symptoms varied from 0 to 9 with 34.3% of the plants in the collection scoring 0 and a very small proportion (1.04%) scoring 9. For blast disease, the score varied from 0 to 5 with a majority of plants (65.63%) scoring 0 and a minority (1.29%) scoring 5. As for plant vigour, the score also varied from 0 to 5, with a large proportion of plants in the collection (36.45%) scoring 5 and a small proportion (6.25%) scoring 0.

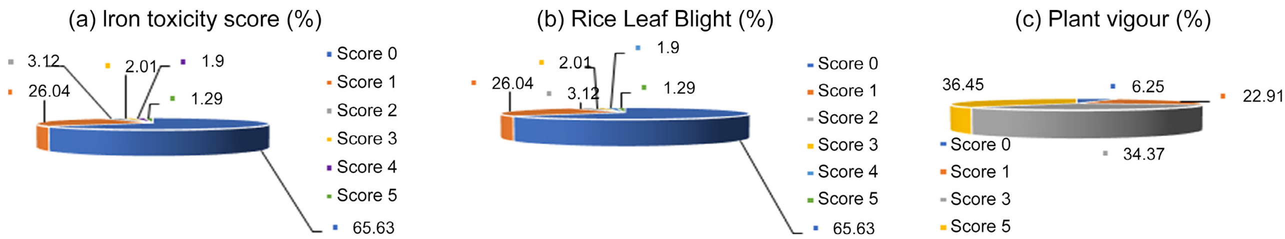

Figure 5. Proportions of the modalities according to the qualitative characteristics. Legend: Using the IRRI scale for iron toxicity: score 0: resistant plants, score 1: very tolerant, score 3: tolerant, score 5: susceptible.

3.2.2. Variation of Quantitative Traits of Local Rice Accessions

1) Average performance of rice accessions evaluated in Sérédou

The analysis of variance (Table 8) shows that the parameters observed in this site significantly discriminate the accessions studied at the threshold of 1 and 5%. This result reveals the existence of an essential agro-morphological diversity within the collection for the characters studied.

The number of days for the sowing epiposition cycle varied from 81.66 days for short-cycle accessions to 130 days for long-cycle accessions. As for the number of grains per panicle, it varied from 99.33 grains for the least seed-productive accessions to 165.33 grains for the most seed-productive accessions. For grain yield, the lowest was 1555.66 kg/ha for the least productive accessions against 5886 kg/ha for the most productive ones with an average of 3349 kg/ha. The sowing maturity cycle varied from 103.33 days for the short-cycle varieties to 165 days for the long-cycle accessions. These variations reflect a very large difference between accessions. As for the coefficient of variation, the extreme values are 18.79% and 35.97% for the parameters observed. The smallest significant difference varies between 0.36 and 6.25.

2) Influence of the environmental factor on the variations of the quantitative traits

The results of the analysis of variance of the Sérédou site with the Newman and Keuls test of significance of means presented in Table 9 reveal that the variables significantly discriminate the accessions. The coefficient of variation varied from 19.79 for moisture content to 35.97% for grain yield.

3) Comparison of yields of local accessions and control and identification of the best accessions

The performance of the control varieties and the 15 best local accessions identified in the site are recorded in Table 10 and Table 11, respectively. The control varieties obtained yields ranging from 1554.67 kg/ha for variety CK73 to 3587.67 for the variety ORYLUX 6. As for the 15 local accessions identified, the yield obtained varied from 2836.33 kg/ha (Yamalopou accession) to 5886.3 kg/ha (Kagbowoletaie accession) with an overall average of 4535.7 kg/ha.

Toxicity scores ranged from 0 for resistant varieties to 5 for susceptible varieties. Figure 6 shows the yield variations of the local accessions and control varieties. These local cultivars had similar or much higher grain yields than the controls used. Except for the four local cultivars, all other 11 accessions showed a higher yield than the best control Orulux 6.

Table 8. Results of the analysis of variance of the 11 quantitative variables measured.

Variables	Minimum	Maximum	Mean	CV%	LSD 5%
CSE (jrs)	81.667	130.000	93.667	19.195***	3.585
HPM (cm)	48.333	140.667	98.604	26.813***	6.099
NT/m²	7.333	28.000	19.840	27.104***	2.167
NT/T	7.333	15.333	10.434	23.458***	0.868
NP/m²	96.000	183.667	127.889	21.956***	6.258
NG/P	99.333	165.333	110.753	19.641***	4.568
LP (cm)	16.667	28.333	21.958	21.568***	1.25
Rdt (kg/ha)	1555	5886	3349	35.972***	0.616
P1000 Grain (g)	20.133	26.033	22.116	18.885***	0.709
TH (%)	10.600	13.533	11.735	18.797***	0.366
CSM (jrs)	103.333	165.000	125.240	19.015***	4.354

Legend: SSC: sowing cycle heading. HPM: plant height at maturity. NT/m²: number of clumps per m². NT/T: number of tillers per clump. NP/m²: number of panicles per m². NG/P: number of seeds per panicle. LP: panicle length. Rdt (kg/ha): yield. P1000 Grain: 1000 seed weight. TH: moisture content. CSM: sowing maturity cycle. %. CV: coefficient of variation. ***: very highly significant ($pr < 0.0001$). LSD: smallest significant difference at 5% level.

Table 9. Results of the Newman and Keuls test for significance of means in Kilissi site.

Variables	Replication 1	Replication 2	Replication 3	CV %
CSE (jrs)	97.417a	97.833 a	95.225 a	19.195**
HPM (cm)	122.792 a	104.135 b	86.126 c	26.813**
NT/m²	23.042 a	20.448 ab	18.847 b	27.104**
NT/T	11.472 a	10.938 ab	10.171 b	23.458**
NP/m²	137.153 a	116.615 b	142.000 a	21.956**
NG/P	113.542 ab	109.979 b	118.595 a	19.641**
LP (cm)	24.597 a	22.698 b	21.387 b	21.568**
Rdt (kg/ha)	3845 a	3438 a	3220 a	35.972**
P1000 Grn (g)	22.846 ab	22.354 b	23.230 a	18.885**
TH (%)	12.198 a	11.941 a	12.207 a	18.797**
CSM (jrs)	130.417 a	130.688 a	127.324 a	19.015**

Legend: SSC: sowing cycle heading HPM: plant height at maturity. NT/m²: number of tufts per m². NT/T: number of tillers per tuft. NP/m²: number of panicles per m². NG/P: number of grains per panicle. LP: panicle length. Rdt (kg/ha): yield. P1000 Grn: weight of 1000 grains. TH: moisture content. CSM: sowing maturity cycle. CV: coefficient of variation. **: highly significant ($Pr \le 0.001$).

Table 10. Performance of control varieties in terms of yield.

N°	Local accessions	Yields (Kg/ha)			Mean	IT score	Sign.
		Replication 1	Replication 2	Replication 3			
1	AZUCENA	1896	2980	2990	2622	1	T
2	BOUAKE 189	2876	2105	2100	2360.33	5	S
3	CK73	1297	1688	1679	1554.67	1	T
4	IR64	2928	2634	2736	2766	5	S
5	NERICAL19	2768	3168	3269	3068.33	1	T
6	ORYLUX6	3345	4268	3150	3587.67	1	T

Legend: Score 1: T: tolerant; Score 5: S: susceptible, Sign.: Significance, IT: Iron toxicity score.

Table 11. Performance of local accessions identified in terms of yield.

Local accessions	Replication				Significance
	Rep. 1	Rep. 2	Rep. 3	Mean	
Dawoutaie	5316 a	4668 ab	6128 b	5370.67	HS
Ceciletaie	4876 bc	3989 ab	3734 bc	4199.67	HS
Fayancetun	3968 b	2068 c	2764 a	2933.33	NS
Kounfini	4427 ac	3904 bc	5526 ac	4619.00	S
Chogo-chogo	5068 a	4026 a	5619 b	4904.33	S
Laminy malé	5319 bc	4311 b	5166 c	4932.00	NS
Benzamin	5543 b	5964 c	4747 bc	5418.00	S
Tomaï	4533 ab	5326 ab	5326 a	5061.67	S
Foulamara	4831 c	4648 ac	4965 c	4814.67	HS
Soitogba	5718 c	5126 ac	4680 b	5174.67	S
Commando	3667 b	3068 a	3126 bc	3287.00	S
Salikouta	5311 a	5667 c	4807 a	5261.67	S
Bokary	2706 c	3678 bc	3626 c	3336.67	S
Yamalopou	2164 b	2377 ab	3968 a	2836.33	NS
Kagbowoletaie	5854 ab	5577 bc	6227 b	5886.00	HS
Mean	**4620.13**	**4293.13**	**4693.95**	**4535.7**	
LSD 5%		**0.616**			
CV%		**35.972**			

Legend: Means with the same letter in the same column or row are not significantly different at the 5% threshold by the SDPP calculation. Letters in the upper case refer to rows and letters in the lower case refer to columns. S = Significant; NS = Non Significant; HS = Highly Significant, Rep. = Replication.

3.2.3. Selection of the Best Performing Accessions in Both Sites

Of the 30 best local cultivars identified in the Kilissi and Sérédou sites, the 12 best performing and stable accessions in terms of yield, tolerance, or resistance to iron toxicity were selected. Indeed, these accessions listed in Table 12 have

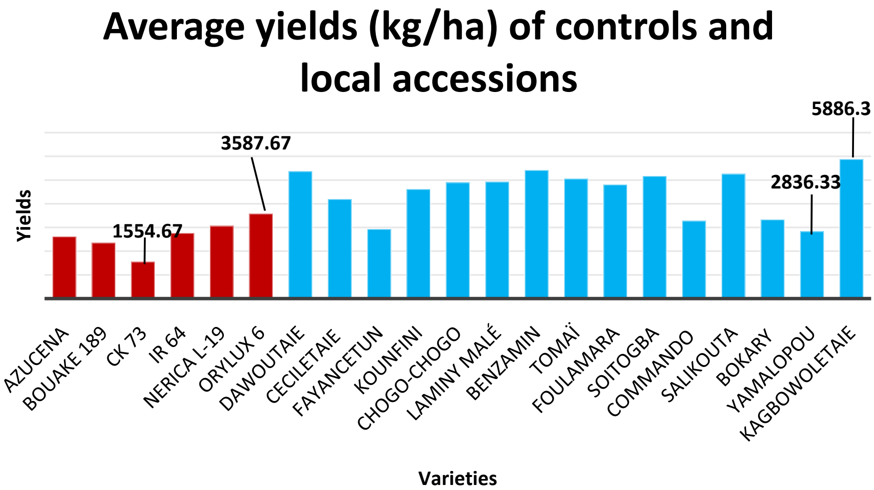

Figure 6. Yield variation of local rice accessions in the Sérédou site.

Table 12. Local accessions selected in both sites.

N˚	Local accessions	Yields (Kg/ha)		Mean yields (Kg/ha)	Iron toxicity score
		Kilissi	Sérédou		
1	Citoyen	3485.33	4728.67	4107	0
2	Komassataie	3934.66	5390	4662.33	0
3	Gbai-gbai	4475.33	2680.33	3577.83	1
4	Foulamara	2687.5	4814.67	3751.08	0
5	Coyady	4063	2276.33	3169.66	1.5
6	Diforêt	4020.33	3931.33	3975.83	0
7	Koyan	3451	4040.33	3745.66	1
8	Patem	3315.33	4035	3675.16	1.5
9	Podet	4009	2572.33	3290.66	1
10	Chogo chogo	1483	4904.33	3194.66	1
11	Commando	4373.33	3287	3830.17	1
12	Dawoutaie	4093.33	5370.67	4732	0
	Overall average			**3809.34**	

average yields in both sites ranging from 3169.66 kg/ha (Coyady accession) to 4662.33 kg/ha (Komassataie accession). Three cultivars were found to be resistant to iron toxicity (score 0) and nine are tolerant to abiotic stress with scores between 1 and 1.5. Indeed, these accessions were the most stable in terms of yield in both sites.

4. Discussion

The minimum and maximum values showed important deviations. The high coefficients of variation for most of the characters and the presence of several modalities for some qualitative characters reflect the existence of a great morphological variability within the studied accessions. The discrimination of these accessions especially by the variables such sowing-maturity cycle, number of grains per panicle, number of clumps per m^2, 1000 grain weight, and yield shows that these could be used as important agronomic traits to effectively differentiate between the local accessions evaluated. The results obtained are similar to those reported by [10] [18]. In the collection, regarding iron toxicity symptoms, the plants reacted differently and showed typical symptoms of iron toxicity for both sensitive and tolerant accessions. No symptoms were reported on the resistant ones. These symptoms appeared on the leaf blades in the form of brown spots characteristic of bronzing, which spread to the plots containing the sensitive and tolerant varieties. In these plots affected by iron toxicity, a decrease in leaf biomass and leaf water content was also observed. According to [19], leaf and root dry weight are the most sensitive parameters to iron toxicity in the early stages of plant development. In our study, the amount of biomass has decreased the dry weight of the leaves will necessarily decrease and this will lead to a strong reduction in the growth of the plants in the plots. In the presence of excess iron, the iron concentration in the rice plant increases considerably. As observed earlier, iron is distributed differently among the organs accumulation mainly in the roots. Although the iron concentration in the roots is the highest, the iron content in the sheaths and blades of treated plants remains relatively high. It is accepted that the critical threshold for iron toxicity in Asian rice species is 700 $mg \cdot kg^{-1}$ D.M. [20]. The iron concentration measured in the plots where our plants were grown reaches up to 2300 $mg \cdot kg^{-1}$ M.S, indicating that this threshold is largely exceeded and that the stress conditions have been met. Among the local varieties evaluated, some are susceptible and others tolerant or resistant and showed more pronounced toxicity symptoms for the morphological parameters studied. The different responses of the varieties can be explained either by the implementation of different resistance mechanisms by the plants or by different levels of resistance for the same resistance mechanism [21]. In both sites (Kilissi and Sérédou), 30 accessions were identified including 15 accessions per site based on their iron resistance, yields, and the choice made by farmers according to certain criteria such as size, grain colour, senescence and tillering. Of these 30 accessions, 12 were selected for their stability in terms of yield and low sensitivity to iron toxicity. These selected accessions had higher yields than the control varieties. Rice plots with many more symptoms often have low yields, whereas plots with fewer symptoms or no symptoms at all have higher yields. Yields are variable depending on the degree of toxicity of the varieties tested. All varieties had significantly lower yields under iron toxicity stress. The iron toxicity constraint induced a high yield loss ranging from 15% to 25% of the potential yield. [18] found a yield loss of 43%, [22] reported a loss of 59.5%. According to [23], the yield loss of rice varies from 12% to 100% in West Africa under iron toxicity conditions. Previous studies realized by [24] on the genetic diversity of 204 accessions of O. glabberima cultivated under iron toxicity also reported different tolerance levels to iron toxicity stress.

5. Conclusion

The agro-morphological characterisation has contributed to a better knowledge of the genetic resources. The traditional varieties from the two study areas (Kindia and Macenta) represent a fairly large genetic potential. From the results obtained, it appears that there is a great variability within the accessions and a high potential of cultivars tolerant or resistant to iron toxicity. Thus, 30 local accessions with similar or higher grain yields than the controls were identified in the two sites, of which 12 proved stable in the two environments (Kilissi and Sérédou). In view of the problems posed by iron toxicity in lowland rice, the 12 local accessions selected could serve as a basic material for rice breeding for resistance or tolerance to this abiotic stress. In addition, genetic characterisation of these cultivars using molecular markers and identification of QTLs associated with iron resistance could complement and strengthen the results of this study.

Data Availability

The data used to support the findings of this work are available upon request from the corresponding author.

Authors' Contributions

This work was carried out in collaboration between both authors. MLB & MS wrote the protocol, wrote the first version of the manuscript, MLB & NS, performed the statistical analysis., NS & MHO reviewed the experimental protocol and corrected all versions of the manuscript, SC ensured monitoring work at the Guinea Agronomic Research Research Institute and correcting the first versions of the manuscript. NS, MHO, KRN, PBK & MS provided guidance, protocol validation and final manuscript version.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] CTA (2013) Secteur du riz. Post bus 3806700, AJ Wageningen, Pays Bas, 12 p.

[2] FAO (2017) Suivi du Marché du Riz (SMR). Rapport, Vol XX, Ed 1, 10.

[3] Futakuchi, K., Sié, M. and Wopereis, M.C.S. (2011) Rice Breeding Strategy at Africa Rice. In: Yanagihara, S., Ed., *Next Challenges in Rice Development for Africa: Workshop for New Collaboration between JIRCAS and AfricaRice.* JIRCAS Working Report No. 70. Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Japan, 1-14.

[4] Africarice (2013) La science rizicole pour la sécurité alimentaire à travers le renforcement de l'agriculture familiale et l'agro-industrie en Afrique. 3*ème Congrès du riz en Afrique*, Yaoundé, 21-24 Octobre 2013, 296 p.

[5] ANASA (2012) National Agency for Agricultural and Food Statistics. Summary Report, Conakry, 11 p.

[6] Abifarin, A.O. (1988) Grain Yield Loss Due to Iron Toxicity. *WARDA Technical Newsletter*, **8**, 1-4.

[7] Bode, K., Döring, O., Lüthje, S., Neue, H.U. and Böttger M. (1995) The Role of Active Oxygen in Iron Tolerance of Rice (*Oryza sativa* L.). *Protoplasman*, **184**, 249-255. https://doi.org/10.1007/BF01276928

[8] Gunawardena, I., Virmani, S.S. and Sumo, F.J. (1982) Breeding Rice for Tolerance to Iron Toxicity. *Oryza*, **19**, 5-12.

[9] Masajo, T.M., Alluri, K., Abifarin, A.O. and Janakiram, D. (1986) Breeding for High and Stable Yields in Africa. *International Conference on Wetland Utilization for Rice Production in Subsaharan Africa*, Ibadan, Oyo State (Nigeria), 4-8 November 1985, IITA, 107-114.

[10] Abifarin, A.O. (1989) Progress in Breeding Rice for Tolerance to Iron Toxicity. WARDA Annual Report, 34-39.

[11] Peng, X.X. and Yamauchi, M. (1993) Ethylene Production in Rice Bronzing Leaves Induced by Ferrous Iron. *Plant and Soil*, **149**, 227-234. https://doi.org/10.1007/BF00016613

[12] Panda, B.B., Sharma, S., Mohapatra, P.K. and Das, A. (2014) Iron Nutrition vis-à-vis Aconitase Activity and Ferritin Accumulation in Tropical Indica Rice Cultivars Differing in Grain Iron Concentration. *American Journal of Plant Sciences*, **5**, 2829-2841. https://doi.org/10.4236/ajps.2014.518299

[13] Tadano, T. and Yoshida, S. (1978) Chemical Changes in Submerged Soils and Their Effect on Rice Growth. In: *Soils and Rice*, International Rice Research Institute, Los Baños, 399-421.

[14] Barry, M.L., Sawadogo, N., Ouédraogo, M.H., Nanéma, K.R., Barry, M.B., Bationo-Kando, P. and Sawadogo, M. (2019) Effect of Silica on Rice Agromorphological Diversity under Iron Toxicity Conditions in Lowland Rice of Guinea Conakry. *European Scientific Journal*, **15**, 118-130. https://doi.org/10.19044/esj.2019.v15n3p118

[15] ECOWAS, UEMOA and CILSS (2016) Regional Catalogue of Plant Species and Varieties. 1-3.

[16] International Rice Research Institute (IRRI) (2002 Standard Evaluation System for Rice (SES). Manila, 56 p.

[17] International Rice Research Institute (IRRI) (1988) Hybrid Rice. *Proceedings of the First International Symposium on Hybrid Rice*, Changsha, 6-10 October 1986, 305 p.

[18] Diatta, S., Audbert, A., Sahrawat, K.L. and Traore, S. (1998) Controlling Iron Toxicity of Rice in Lowlands. In: *WARDA's Achievements in the West African Savanna*

Zone, *Management and Development of Lowlands in Mali*, CIRAD CA, Sikasso, 21-25.

[19] Fageria, N.K. and Rabelo, N.A. (1987) Tolerance of Rice Cultivars to Iron Toxicity. *Journal of Plant Nutrition*, **10**, 653-661. https://doi.org/10.1080/01904168709363598

[20] Yamauchi, M. (1989) Rice Bronzing in Nigeria Caused by Nutrient Imbalances and Its Control by Potassium Sulfate Application. *Plant Soil*, **117**, 275-286. https://doi.org/10.1007/BF02220722

[21] Dufey, I., Bertin, P. and Mahillon, J. (2008) QTL Analysis for Resistance to Iron Toxicity in Cultivated Rice Ecophysiology and Plant Breeding Unit. Publication du Sud. 2 bte 1 B-1348 Louvain-la-Neuve (Belgium), 2 p.

[22] Aboa, K. and Dogbe, S.Y. (2006) Effect of Iron Toxicity on Rice Yield in the Amou-Oblo Lowland in Togo. Iron Toxicity in Rice-Based Systems in West Africa.

[23] Tamaung, M. (2006) Physiological Mechanisms of Iron Toxicity Tolerance in Lowland Rice. Thesis in Partial Fulfillment of the Requirements for the Academic Degree of Master of Science, Faculty of Agriculture Rheinische Friedrich-Wilhelm's-Universitätzu Bonn, 67 p.

[24] Mayaba, T., Sawadogo, N., Ouédraogo, M.H., Sawadogo, B., Aziadekey, M., Sié, M. and Sawadogo, M. (2020) Genetic Diversity of African's Rice (*Oryza glaberrima* Steud.) Accessions Cultivated under Iron Toxicity. *Australian Journal of Crop Science*, **14**, 415-421. https://doi.org/10.21475/ajcs.20.14.03.p1851