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Morphological variation of iron toxicity tolerance in lowland rice (*Oryza sativa* L.) varieties

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Abstract

Rice (*Oryza sativa* L.) is a staple food crop in many countries in Africa. Africa consumes 11.6 million tons of rice per annum and out of 39 rice-producing countries, 21 import 50% to 99% of their rice requirements. The inability to reach the yield potential that would sustain Africa's need for rice is due to many biotic and abiotic constraints that rice production faces. In lowland grown rice, one of the abiotic factors hindering rice production is iron toxicity. Excess uptake of ferrous ($Fe2+$) ions leads to a physiological stress, which results, into poor production. The current study aimed at selection of varieties tolerant to iron toxicity and assessment of the genetic diversity linked to this trait. In a hydroponic experiment conducted in a screen house at Africa Rice Centre in Dar es Salaam, 32 rice varieties were evaluated for tolerance to iron toxicity. The experiment was laid out in a split plot design with iron concentration as the main plot factor and variety as the sub plot factor. Two levels of iron concentration were used: 2 ppm and 300 ppm of $Fe2+$ as control and test concentrations, respectively. Traits observed to gauge tolerance were leaf bronzing (an indicator of iron toxicity), plant height, tillering, number of leaves, shoot weight (above ground), root length and root weight. The varieties ARICA8, and CK801 were found to be tolerant due to low bronzing indices, higher shoot weight, more number of leaves and lack of significant variation in morphology between the two Fe treatments except for the plant height. Correlation analysis depicted negative correlation between leaf bronzing and the other traits measured especially shoot biomass.

Keywords: Iron Toxicity; Tolerance; Genetic Variation; Bronzing

1. Introduction

Rice (*Oryza sativa L*) is the worlds' most important food crop, serving as staple food for more than half of the world population (Gaikwad et al., 2014). It belongs to the family of gramineae and supplies 20 % of the calories consumed by humans. Lowland rice is cultivated on approximately 128 million hectares of irrigated and rain-fed land (Khadka et al., 2013). As many as 100 million hectares show some sort of nutritional constraints to rice growth caused by either deficiencies or toxicities (Keaton et al., 2017). Ferrous iron toxicity is among the constraints and primarily affects lowland rice grown on acid flooded soils that are rich in reducible iron (Bongoua et al., 2013). Increasing significant occurrence of iron toxicity make it a serious long-term threat to lowland rice production. Large areas of wetland ideally suited for rice production remain underused, especially in Asia, South America, West and Central Africa, because of iron toxicity stress (Sikirou et al., 2015).

In West Africa, iron toxicity is widespread throughout the humid forest and Savanna zones in about 30 to 40% of the cultivated lowlands (Aschet al 2005). Rice yield losses due to iron toxicity are reportedly ranging from 12 to 100 %, depending on the severity of the toxicity and the tolerance of the rice cultivars (Venus et al., 2013).

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In Liberia, iron toxicity manifestation is mainly a result of heavy rainfalls and river over flows into the valleys. Stagnant inundation of the iron rich soils ultimately lead to the accumulation of high levels of Fe^{2+} in the soil solution. Rice grown in such environments takes up large amounts of ferrous iron, exceeding plant growth's requirements. As a result, plant metabolism is disturbed and rice yield is dramatically reduced. Data on iron toxicity distribution in Liberia is scanty. According to farmers, "lowlands are abandoned and remain uncultivated due to iron toxicity syndrome". Regarding how widespread the constraint was, the government instituted several management options to minimize iron toxicity in the rice fields such as application of limestone fertilizers, ridges, direct planting, and flushing the plot with fresh water but with little success.

2. Material and methods

2.1. Plant Materials and Location of Study

A hydroponic culture screening experiment was conducted in a screen house at the Africa Rice Centre in Mikocheni, Dares Salaam, and Tanzania. Exact geographical coordinates are as follows: latitude 6° 45' 49.4748'' S, longitude 39° 14' 43.2312'' E and altitude 17 m above sea level. The experiment was conducted from December 2014 to April 2015 followed by lab work at the same location. Thirty-two rice varieties, including tolerant and susceptible checks were screened for tolerance to iron toxicity. The tolerant checks were Suakoko - 8 and Wita- 4, WITA-4, while the susceptible check was IR64.

2.2. Selection of Tolerant Varieties and Experimental setup

To distinguish rice varieties tolerant to iron toxicity from the susceptible ones, the seedlings were treated with toxic levels of iron in a hydroponic experiment as described by (Priya et al., 2013). Seeds were sown into a perforated polystyrene plate floating on the surface of nutrient solution contained in 14 L-plastic trays. For each variety, 6 plants were grown at a rate of two plants per hole. Yoshida standard rice nutrient solution was used as the normal treatment for plant growth. For Fe^{2+} stress treatment, 300 ppm Fe^{2+} was added as $FeSO_4$ to the standard nutrient solution. To maintain acidic conditions, the pH of the solution was adjusted once a week at 5.6-5-7 using 1N NaOH or 1N HCl at the time of solution change (every week). Fe stress treatment was maintained for3weeks.

2.3. Experimental design

The experiment was conducted in a randomized complete block design arranged in a split plot manner with four replications. The main plot had two levels of iron concentration and thirty two (32) varieties were allocated to the sub-plots. Each iron concentration (main plot) was assigned to one tray (28 cm x 31 cm) containing nutrient solution with 2 or 300 ppm Fe^{2+}. All 32 varieties were planted on the same polystyrene float (26 cm x 29 cm) with a spacing of 1.5 cm x 1.5 cm between plants and between varieties. Each variety (sub-plot) occupied 3 holes on the float.

2.4. Environmental Conditions

The experiment was conducted in a screen house at ambient conditions at Africa Rice Centre in Mikocheni. Dar es Salaam, Tanzania. The temperature and relative humidity were recorded using a data logger (Dickson Data Logger TP125) between December 2014 and April 2015. The variables collected in the experiment were leaf bronzing, plant height, number of leaves, number tillers, dry shoot weight, root length dry and root weight.

2.5. Scoring of Leaf Bronzing

The leaf bronzing score was recorded every week starting from the first observation (10 days after imposing the stress) in reference to the scale of the Standard Evaluation system for Rice (IRRI, 2002). A scale varies from score 0 to 9 was set up by our lab and was adopted for iron toxicity severity.

2.6. Number of tillers, number of leaves, and root length

Number of tillers and leaves were collected by counting on each plant and data were recorded. Plant height was measured using a steel ruler from the ground level to the tip of the longest leaf. Root length was measured using the same steel ruler.

2.7. Dry weight of shoot and root

Six plants per variety were harvested fresh at the end of the stress period, at 5 weeks after sowing to determine dry matter accumulation. Separate root and shoot samples were wrapped in an aluminum foil and oven dried at 72^{o}C to constant weight. Then dry weights were determined. To determine trait variation between Fe stress and control, relative performances were calculated follows:

$$\text{Relative reduction} = \frac{DW_{\text{control plant}} - DW_{\text{treated plant}}}{DW_{\text{control plant}}} \text{ x } 100$$

This was calculated for all the parameters except leaf bronzing which was observed only on Fe-treated plants.

2.8. Data analysis

Data analysis was done using Genstat statistical package (15th edition 2015). ANOVA was performed to analyze the experimental data on plant height, number of tillers and leaves, shoot weight, root weight, root length and leaf bronzing. Means separation was done using Duncan Multiple Range test. Correlation analysis was further performed to establish relationship between leaf bronzing and other traits (plant height, tillers, leaves, shoot weight, root weight, root length).

3. Results

3.1. Environmental Conditions during the Experiment

The hydroponic culture experiment was conducted in a screen house for five weeks including three weeks of stress to validate and select varieties, which are tolerant to iron toxicity. Environmental conditions during this period indicated that daily maximum temperature ranged from 45.6oC to 49.1oC while the minimum daily temperature was between 22.9°C and 32.5°C. The highest temperature was recorded in March while the minimum temperature was in December 2014 (Fig. 1). The average minimum and maximum temperature during the growing season were 34.4°C and 39.4°C, which was favorable for rice production. The maximum daily relative humidity (RH) ranged from 89.7% to 99.5% while the minimum daily relative humidity ranged from 26.6% to 28.5%. The highest and lowest relative humidity were both observed in March suggesting large variations of RH. The average minimum and maximum relative humidity during the experimental period was 61.3% and 77.9%, which was favorable for rice production described in (Fig. 1). Plants, the more intense the effect on plant growth was. Thus at week three, leaf bronzing increased and many varieties stopped growing.

3.2. Effects of Fe2+ stress on the varieties tested

The progresses of Fe2+ stress on the varieties tested at different stages were shown at week one, the reduction of plant growth was visible on leaf number and leaf width. At week two, leaf-bronzing symptoms appeared on Fe-treated plants, plant height, and shoot biomass were strongly reduced. The longer the duration of Fe2+ treatment on the plants, the more intense the effect on plant growth was. Thus at week three, leaf bronzing increased and many varieties stopped growing. Plants, the more intense the effect on plant growth was. Thus at week three, leaf bronzing increased and many varieties stopped growing.

3.3. Variation of plant height, leaf number, tiller number and root length among the varieties and Fe treatments

After three weeks of exposure to Fe stress (300 ppm Fe2+), plant height of tested varieties for the control treatment ranged from 47.5 cm (Saro 5) to 90.5 cm (Shaka102) with a mean of 68.6 cm while for the Fe2+ treatment, average plant height was 48.9 cm with the highest height attained by CK 90 (68.67 cm) and the lowest by Saro5 (34.2 cm). The range of leaf number under control treatment was between 6.5 (CK 73) and 12.6 (IR 64) with a mean of 9.9 while for Fe treatment the range was between 4.5 (Botry) and 7.3 (Shaka 102) with a mean of 6.1. Tiller number for control plants ranged from 0.0 (CK 73) to 1.9 (Orylux4) with a mean of 0.8 while under Fe2+ treatment, the range was from 0.0 (IR64) to 0.5 (Jasmine 85) with a mean of 0.1. Root length under control treatment ranged from 15 cm (Jasmine 85) to 26.5 cm (Tog 16771) with a mean of 19.3 cm. In the Fe treatment, the range was from 9.2 cm (Kalamata) to 17.63 cm (72-5) with a mean of 12.6 (Table 1).

Table 1 Effect of Fe^{2+} stress on variables plant height, tiller number, leaf number and root length at the third weeks of Fe treatment

		Plant height (cm)		Leaf number		Tiller number		Root length (cm)	
No.	Varieties	Control	Fe^{2+}	Control	Fe^{2+}	control	Fe^{2+}	Control	Fe^{2+}
1	SARO5	47.5a	34.2a-c	10.7a-d	7.0d	1.1a-h	0.4b-f	18.1a-c	12.1a-f
2	IR64	53.6a-b	36.1a-d	12.6de	6.3cd	1.6g-h	0.0a	16.4ab	10.1ab
3	IR841	55.8a-c	36.6a-d	10.9a-d	6.6d	1.2c-h	0.5f	19.4a-c	12.1a-f
4	TXD88	53.3a-b	36.7a-d	12.5de	6.0b-d	1.2d-h	0.0a	20.4a-d	12.9a-g
5	SAHEL201	57.6a-d	37.5a-c	11.5c-e	6.4d	1.4e-h	0.1a-c	22c-e	11.8a-f
6	YUNKENG	52.9a-b	38.5a-e	7.2a-c	6.0c-d	0.0a	0.2a-f	18.2a-c	13.3a-h
7	NL23	53.8a-b	39.2a-f	7.6a-c	5.6b-d	0.2a-d	0.1a-c	18.7a-c	12.4a-f
8	ARICA6	62.3b-f	39.9a-f	11.2b-e	5.5b-d	0.8a-h	0.0ab	16.5a-b	9.6ab
9	ARICA7	54.8a-b	40.3a-f	11.3c-e	6.4d	1.3d-h	0.0ab	15.6a	12.2a-f
10	ARICA1	57a-d	41.0a-f	9.4a-d	7.1d	1.2b-h	0.2a-f	15.2a	11.0a-d
11	ARICA2	63.1b-f	41.6a-f	7.8a-c	5.5b-d	0.2a-d	0.0ab	15.2a	12.9a-g
12	ORYLUX4	64.6b-f	42.9a-g	15.2d	6.7d	1.9h	0.1a-c	17.7a-c	10.3ab
13	WITA4	58.7a-e	43.2a-h	9.5a-d	6.4d	0.5a-g	0.2a-f	19.9a-c	14.2b-n
14	YUNYINE	62b-f	43.6a-h	7.9a-c	5.2b-d	0.0a	0,0a-d	15.1a	10.8a-d
15	ARICA3	63.7b-f	43.8a-h	10.8a-d	5.2b-d	1.1b-h	0.1a-c	19.3a-c	12.2a-f
16	JASMINE85	56.8a-d	45.4b-h	9.6a-d	7.0a-h	0.8a-h	0.5f	15.0a	10.4ab
17	ARICA8	72.2f-h	49.2b-i	10.7a-d	6.2c-d	1.2c-h	0.0a-c	18.5a-c	11.2a-d
18	ORYLUX6	76.7g-i	50.0c-i	10.7a-d	6.1c-d	0.9a-h	0.0a-d	18.5a-c	10.7a-c
19	CK73	68.6d-g	50.8a	6.5a	2.3a	0.0a	0.0a	17.5a-c	11.5a-d
20	FOFIFA172	67.4c-g	50.9c-j	7.8a-c	5.5b-c	0.5a-f	0.0a-d	22.0c-e	15.7e-h
21	TOG16771	70.5e-g	51.8c-j	11.3b-e	5.8b-d	1.5f-h	0.2a-f	26.5u	13e-g
22	72-5	67.7c-g	53.3d-j	11.1b-e	6.0b-d	1a-h	0.0ab	22.9c-e	17.6h
23	KALAMATA	84.4ij	55.8e-j	7.8a-c	5.8b-d	0.3a-e	0.1a-e	21.8b-e	9.2a
24	SUAKOKO8	82.1h-j	56.5f-j	9.3a-c	6.2c-d	0.6a-g	0.0a-d	20.1a-d	11.4a-e
25	NL19	86.1ab	56.9f-j	8.3a-d	6.3cd	0.2a-d	0.0a-d	21.0o-u	15.0c-h
26	BOTRY	85.7i-j	61.0g-j	7.9a-c	2.2a	0.4a-f	0.0ab	21.3b-d	13.1a-g
27	CK801	81.5h-j	61.2g-j	7.4a-c	6.2c-d	0.1a-c	0.0a-d	20.3a-d	16.9gh
28	TOG6635	82.5h-j	61.6h-j	10.0a-d	6.2c-d	1.2c-h	0.0ab	21.2b-d	16.1f-h
29	SUPA	90.3j	63.1b-h	7.3a-c	4.4bc	0.1ab	0.0a	21.2b-d	9.3a
30	TOG6241	83.h-j	65.06b-i	9.8a-d	4.1b	0.9a-h	0.1a-c	25.2de	15.9e-h
31	CK90	87.1ij	68.j	6.8ab	6.6d	0.00a	0.0a-d	19.6a-c	15.2d-h
32	SHAKA102	90.5j	66.5ij	8.4a-d	7.3a-i	0.5a-f	0.4b-f	18.9a-c	13.7a-h
	Mean	68.61	48.9	9.6	6.13	0.8	0.1	19.37	12.66
	SE	7.1	10.80	2.55	1.12	0.64	0.24	3.11	2.61
	CV%	10.5	23.4	26.6	19.0	82.1	232.5	16.0	20.7

Numbers followed by the same letter (s) in columns are not significantly different at $P \leq 0.05$ using Duncan Multiple Range test

3.4. Variation of dry shoot weight and root weight among the varieties and Fe treatments

The study found that there were significant differences among the varieties. Shoot dry weight under control treatment ranged from 0.41 g (ARICA 7) to 1.5 g (NL 19) with a mean of 0.92 g while for Fe treatment shoot weight ranged from 0.12 g (CK 73) to 0.41 g (ARICA 8). On the other hand, root dry weight for control ranged from 0.06 g (ARICA 1) to 0.48 g (Orylux 4) with a mean of 0.26 g whereas, for Fe treatment, the range was from 0.04 g (CK 73) to 0.16 g (ARICA 8) with a mean of 0.10 g (Table 2). On average, 28.7 % reduction was observed in plant height between control and Fe stress. This was the greatest reduction since leaf number was reduced by only 0.33 %, shoot weight by 71.7 %, root weight by 61 % and root length decreased by 34.6 %.

Table 2 Effect of Fe^{2+} on shoot dry weight and root dry weight of varieties exposed to control Fe and 300 ppm Fe^{2+} for three weeks

		Shoot dry weight (g)		Root dry weight (g)	
No.	**Varieties**	**Control**	**Fe^{2+}**	**Control**	**Fe^{2+}**
1	SARO5	1.10b-k	0.25a-c	0.45h-k	0.09ab
2	IR64	0.52a-b	0.19ab	0.11a-c	0.07ab
3	IR841	0.85a-j	0.25a-c	0.18a-f	0.08ab
4	TXD88	1.06a-k	0.22a-c	0.21a-g	0.08ab
5	SAHEL201	0.49a-b	0.19ab	0.15a-e	0.09ab
6	YUNKENG	0.65a-g	0.22a-c	0.07ab	0.08ab
7	NL23	0.58a-f	0.15a	0.09ab	0.06a
8	ARICA6	0.96a-k	0.22a-c	0.16a-f	0.09ab
9	ARICA7	0.41a	0.21a-c	0.07ab	0.12a-c
10	ARICA1	0.62a-g	0.26a-c	0.06a	0.08ab
11	ARICA2	0.56a-e	0.25a-c	0.11a-c	0.09ab
12	ORYLUX4	0.95a-k	0.23a-c	0.48j-k	0.07ab
13	WITA4	0.65a-g	0.22a-c	0.13a-d	0.13a-d
14	YUNYINE	0.44ab	0.16ab	0.11a-c	0.05a
15	ARICA3	0.94a-k	0.21a-c	0.20a-f	0.08ab
16	JASMINE85	0.72a-h	0.24a-c	0.17z-f	0.08ab
17	ARICA8	1.51jk	0.41a-f	0.36e-k	0.16a-f
18	ORYLUX6	1.15c-k	0.19ab	0.23a-h	0.06a
19	CK73	0.54a-d	0.12a	0.11a-c	0.04a
20	FOFIFA172	0.92a-k	0.39a-f	0.15a-e	0.11a-c
21	TOG16771	1.23f-k	0.31a-e	0.44h-k	0.13z-d
22	72-5	0.51a-c	0.29a-d	0.25i-a	0.11ab
23	KALAMATA	1.16d-k	0.25a-c	0.24a-h	0.14a-e
24	SUAKOKO8	0.69a-h	0.23a-c	0.19a-f	0.15a-e
25	NL19	1.56k	0.28a-d	0.43g-k	0.11a-c
26	BOTRY	1.27g-k	0.23a-c	0.33c-j	0.07ab
27	CK801	1.32h-k	0.36a-f	0.30-j	0.14a-e
28	TOG6635	1.22e-k	0.38a-f	0.47i-k	0.13a-d
29	SUPA	1.09b-k	0.28a-c	0.35d-k	0.09ab
30	TOG6241	0.80a-i	0.30a-d	0.55k	0.12a-c
31	CK90	1.41i-k	0.28a-c	0.38f-k	0.12a-b
32	SHAKA102	1.35h-k	0.27a-c	0.48j-k	0.11a-c
	Mean	0.92	0.25	0.26	0.10
	SE	0.36	0.6	0.13	0.05
	CV%	41.9	24.8	74	52.8

Numbers followed by the same letter (s) in columns are not significantly different at P≤0.05 using Duncan Multiple Range test

3.5. Variation of leaf bronzing among the varieties

The first symptoms of Fe toxicity on the leaf were observed after ten days of Fe treatment (300 ppm Fe2+). However, varieties produced different degree of symptoms over the period. Leaf bronzing score after three weeks of Fe stress ranged from 1.8 (ARICA 1) to 6 (Suakok 8) with a mean of 3.6. Suakoko 8 which was used as one of the tolerant check showed a leaf bronzing score higher than the sensitive check IR64 (Table 3).

Table 3 Iron toxicity symptom on rice genotypes after being exposed to 300 ppm Fe^{2+} for three weeks

Variety	Leaf bronzing score
ARICA1	1.8
SARO5	2.2
ARICA7	2.3
CK801	2.5
SAHEL	2.5
TXD88	2.5
JASMINE	2.5
ARICA8	2.8
NL23	2.8
ORYLUX4	3.1
ORYLUX6	3.1
SHAKA201	3.1
ARICA6	3.2
IR64	3.3
YUNKENG	3.3
YUNYINE	3.5
CK90	3.5
TOG6635	3.5
TOG16771	3.5
IR841	3.6
ARICA3	3.7
ARICA2	3.8
WITA4	4.0
NL19	4.2
FOFIFA172	4.4
72-5	4.5
BOTRY	4.9
KALAMATA	5.0
SUPA	5.1
TOG6241	5.5
CK73	5.9
SUAKOKO 8	6.0
Mean	3.67
SE	0.99
CV%	54.5

3.6. Correlation of leaf bronzing with the other traits

Correlation matrix of the traits revealed positive correlations between traits except with leaf bronzing which was negatively correlated with all the other traits. Plant height was significantly and positively correlated to shoot dry weight and root length while number of leaves was highly significantly correlated with number of tillers. Shoot, dry weight was significantly correlated with root length and root weight while root length was significantly correlated to root weight. Leaf bronzing was significantly correlated only with shoot dry weight (Table 4). It means that varieties with high leaf bronzing had small shoot biomass.

Table 4 The correlation matrix Pearson between morphological traits of 32 varieties

	Plant height	Number of Leaves	Number of Tillers	Shoot dry wt (g)	Root Length (cm)	Root dry wt (g)	Leaf bronzing
Plant height	1.000						
Nb of leaves	0.406	1.000					
Nb of Tillers	0.197	0.848**	1.000				
Shoot wt (g)	0.547*	0.449	0.348	1.000			
Root L (cm)	0.600*	0.491	0.346	0.678*	1.000		
Root wt(g)	0.478	0.438	0.394	0.654*	0.577*	1.000	
Leaf bronzing	-0.402	-0.487	-0.407	-0.523*	-0.478	-0.345	1.000

3.7. Analysis of variance (ANOVA) for 32 rice varieties

Analysis of variance was conducted to estimate the effects of variety (Var), Fe concentration and the interaction between variety and Fe concentration (Var x Fe Conc) on the variation of the different traits measured (Table 5). The results indicated that Fe concentration showed highly significant and very highly significant difference among the traits measured. Similarly very highly significant differences among varieties were revealed for all traits. On the other hand, non-significant differences were observed for the Fe concentration x variety interaction for plant height and root length. Tiller number and leaf bronzing showed very highly significant differences for the interaction while leaf number and shoot dry weight showed highly significant differences.

Table 5 Summary of ANOVA table showing variation in mean squares and F probability among varieties

Source of variation	Df	Plant Height (cm)	Leaf Number	Tiller Number	Root length (cm)	Root Dry Weight (g)	Shoot Dry Weight (g)	Bronzing
Rep	3	766.25***	2.16 ns	0.40 ns	52.49**	0.054*	1.78***	12.58***
Fe Conc.	1	24391.79***	736.10***	28.05***	2846.69***	1.49**	27.78***	833.49***
Var.	31	1014.59***	9.71***	0.69***	3.28***	0.05***	0.29***	2.20***
Fe Conc. *Var	31	43.70 ns	7.9**	0.59***	1.17 ns	0.03*	0..18**	2.20***
Error (Var)	3.73							
Total	250							

Where: ***= P<0.001, ** = P<0.01, * = P<0.05 significant levels at indicated P and ns = not significant level

4. Discussion

Excessive iron uptake has adverse effects on the vegetative growth of rice. It interferes with accumulation of dry matter by destruction of cells in the leaves due to the formation of reactive oxygen species (Tamuly et al., 2016). In this study, the effect of iron Fe2+ stress on all parameters was highly significant. Reduction of plant height, leaf and tiller number, shoot and root biomass and root length was observed over the three weeks of Fe stress, confirming that iron toxicity greatly affect rice plants by compromising their growth. This finding is consistent with previous studies, which showed that growth traits affected are number of tiller, shoot height, dry weight and decreased dry weight in varieties (Nyamangyoku et al., 2013). In addition, (Priyanga et al., 2012) recorded similar reductions for all traits. Growth reduction under Fe2+ treatment was observed in all the varieties tested but the range was variable. Some varieties showed lower reductions and fewer symptoms than others did. Overall, a significant variation was observed between the varieties tested concerning their relative performances under Fe toxicity stress. Leaf bronzing score is generally considered as an indicator of Fe toxicity stress level (Sikirou et al., 2015) and it has been often used to select rice varieties tolerant to Fe toxicity. In this study, eight varieties had a leaf bronzing score below 3: ARICA 1, Saro 5, ARICA 7, TXD88, Sahel201, CK801, NL23 and ARICA8 suggesting that they may have some tolerance to Fe toxicity. In terms of biomass accumulation under stress varieties ARICA8, FOFIFA172, TOG6635, CK801, TOG16771, TOG6241, 72-5, NL19, Shaka102, and CK90 had shoot and root biomass above the average. Taken together, CK801 and ARICA 8, which had both low leaf bronzing score and high biomass under stress, could be considered as tolerant to Fe toxicity in our experimental conditions. Surprisingly some of the tolerant checks (Suakoko 8 and WITA4) used in this experiment did not perform well. This is contrary to previous findings, which assert that in field and trials, these varieties combined high yield with iron toxicity tolerance (Sikirou et al., 2015). During the early stages of the experiment, it was observed that the roots of Suakoko 8 were quickly reaching the bottom of the trays while the other varieties' roots were elongating at a slower rate. It is suspected that the deep root character of Suakoko8, which in the field is beneficial, could have been detrimental in hydroponic conditions. Indeed, in field conditions, iron toxicity layer is within the first 2-15 cm and varieties that have short root systems are usually susceptible to iron toxicity while traditional varieties with deep root systems tend to be tolerant to Fe toxicity (Otoidobiga et al., 2015). In hydroponic culture, there is no possibility of escape or avoidance by going deeper.

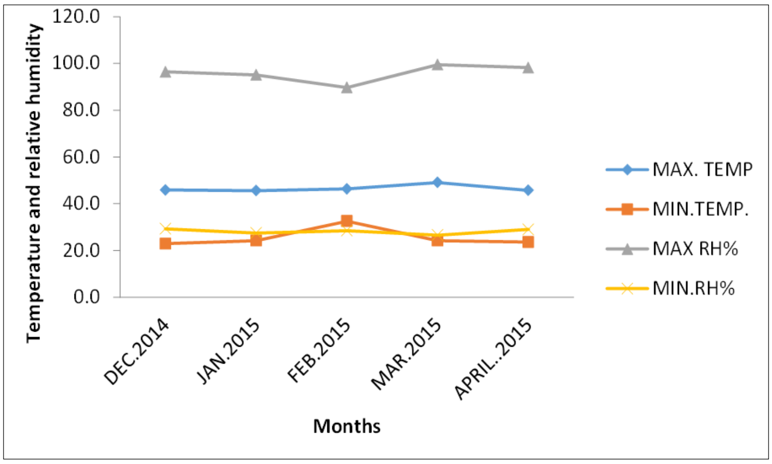

Figure 1 Maximum and minimum temperature and relative humidity during the experimental period

5. Conclusion

The present work helped in strengthening the background of genetic variation for Fe toxicity tolerance among varieties tested. It was observed, that varieties CK801 and ARICA8 were tolerant to iron toxicity as proven by their better performances under Fe toxicity stress. In addition, varieties CK801 and ARICA8 performed well in our study and helped to increase the rice ability in iron toxicity test. Moreover, molecular markers used in this study were also able to distinguish the different rice species.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

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