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## Tolerance of upland rice cultivars to aluminum and acidic pH

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### Key words:

*Oryza sativa* L.

aluminum susceptibility

aluminum resistance

### ABSTRACT

Although the upland rice has been known by its moderate tolerance to aluminum, the presence of exchangeable aluminum in acidic soils may inhibit and compromise the adequate plant growth. However, there are few reports detailing modern cultivars used by Brazilian farmers with respect to their susceptibility to aluminum toxicity. This study aimed to characterize the cultivars currently used in the upland rice production with respect to their tolerance to aluminum and their growth under low pH conditions without aluminum. The treatments were arranged in a randomized block design, in a 2 x 9 factorial scheme: presence and absence of aluminum in the nutrient solution and nine upland rice cultivars (BRS Monarca, BRS Pepita, BRS Bonança, BRS Primavera, BRS Sertaneja, Maravilha, IAC 202, ANCambará and ANa7007), with four replicates. Based on the distribution of upland rice cultivars in quartiles, they were divided into two groups; aluminum-tolerant group: BRS Pepita, BRS Primavera and ANa7007; and aluminum-susceptible group: BRS Monarca, BRS Bonança, BRS Sertaneja, Maravilha, IAC 202 and ANCambará.

### Palavras-chave:

*Oryza sativa* L.

alumínio susceptibilidade

resistência à alumínio

## Tolerância de cultivares de arroz de terras altas ao alumínio e pH ácido

### RESUMO

Apesar de o arroz de terras altas ser reconhecido por sua moderada tolerância ao alumínio, a presença de alumínio trocável em solos ácidos pode inibir e comprometer o crescimento adequado das plantas; no entanto, poucos são os relatos descrevendo, de forma detalhada, os cultivares modernos utilizados pelos agricultores brasileiros quanto a sua susceptibilidade à toxicidade de alumínio. Objetivou-se neste estudo caracterizar os cultivares atualmente utilizados na produção de arroz de terras altas em relação à tolerância ao alumínio e ao seu crescimento sob cultivo em condição de baixo pH sem alumínio. Os tratamentos foram dispostos em um delineamento em blocos casualizados, em esquema fatorial 2 x 9: presença e ausência de alumínio na solução nutritiva e nove cultivares de arroz de terras altas (BRS Monarca, BRS Pepita, BRS Bonança, BRS Primavera, BRS Sertaneja, Maravilha, IAC 202, ANCambará e ANa7007), com quatro repetições. Com a distribuição dos cultivares de arroz de terras altas em quartis foi possível diferenciar os cultivares em dois grupos. Grupo tolerante ao Al<sup>3+</sup>: BRS Pepita, BRS Primavera e ANa7007; grupo suscetível ao Al<sup>3+</sup>: BRS Monarca, BRS Bonança BRS Sertaneja, Maravilha, IAC 202 e ANCambará.



## INTRODUCTION

Upland rice is considered as a plant moderately tolerant to aluminum ( $\text{Al}^{3+}$ ) (Fageria, 1998) but its growth may be inhibited or reduced in soils with high contents of  $\text{Al}^{3+}$  (Mendonça et al., 2003; Freitas et al., 2006).

The roots of plants under stress by  $\text{Al}^{3+}$  have their growth interrupted and become stunted, breakable, with a few fine ramifications, increased rigidity and thickness of the cell wall and suffer alterations in the membrane proteins (Meriga et al., 2010; Motoda et al., 2010; Sun et al., 2010; Garzon et al., 2011; Guo et al., 2012). Consequently, the roots become inefficient in the uptake of water and nutrients, especially in deeper soil layers (Mendonça et al., 2003; Sun et al., 2010).

Modern upland rice cultivars are less tolerant to  $\text{Al}^{3+}$  in comparison to the traditional ones (Justino et al., 2006) due to the process of genetic improvement, through which the cultivars have lost this characteristic. In this context, there are few reports thoroughly describing the modern cultivars used by Brazilian farmers with respect to their susceptibility to  $\text{Al}^{3+}$ .

There are only descriptions of the susceptibility of upland rice lines to  $\text{Al}^{3+}$  (Guimarães et al., 2006) and studies restricted to a small number of cultivars, which evaluate one tolerant and one non-tolerant cultivar to  $\text{Al}^{3+}$  (Mendonça et al., 2003; Justino et al., 2006). Therefore, this study aimed to characterize the cultivars currently used in the production of upland rice with respect to their tolerance to  $\text{Al}^{3+}$  and growth cultivated under low pH condition without aluminum.

## MATERIAL AND METHODS

Two experiments were carried out in a greenhouse at the Department of Soils and Environmental Resources of the Faculty of Agronomic Sciences, UNESP, Botucatu, SP.

### Experiment I: Upland rice tolerance to $\text{Al}^{3+}$ toxicity in nutrient solution

The experimental design was in randomized blocks, in a 2 x 9 factorial scheme, with four replicates. The treatments consisted of the presence and absence of  $\text{Al}^{3+}$  in the nutrient solution and nine upland rice cultivars (Embrapa - BRS Monarca, BRS Pepita, BRS Bonança, BRS Primavera, BRS Sertaneja and Maravilha; Agronomic Institute of Campinas (IAC) - IAC 202; Agronorte - ANCambará and ANa7007). The evaluated cultivars were selected among the most used ones in upland rice-producing regions. Embrapa, Agronorte and IAC were contacted and provided this information and the seeds.

The experiment used the nutrient solution described by the study of  $\text{Al}^{3+}$  tolerance of rice plants developed by Furlani & Furlani (1988) and adapted by Zonta (2003), which was composed of 1.42 Ca, 1.51 K, 0.33 Mg, 0.95 N- $\text{NO}_3$ , 0.41 N- $\text{NH}_4$ , 0.01 P, 0.21 S, 0.21 Cl, 0.22 Fe, 0.009 Mn, 0.008 B, 0.00076 Zn and 0.00031 Cu  $\text{mmol L}^{-1}$ . The concentration and source of  $\text{Al}^{3+}$  were 1.48  $\text{mmol L}^{-1}$  and  $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ , respectively.

In order to obtain seedlings for the experiment, the rice seeds were treated with carboxin + thiram (400 mL per 100 kg of seeds) and then placed to germinate in germinators with controlled light (12 h) and temperature (25 °C).

After the period of seed germination, the seedlings were selected with respect to uniformity in form and size and transferred to plastic pots containing 4 L of nutrient solution, at half ionic strength. Polystyrene lids were used to fix the plants in the pots (6 plants  $\text{pot}^{-1}$ ).

At 7 days after transplanting (DAT), the solution was substituted and nutrient solution without dilution was added, which remained under these conditions until 21 DAT. After this period, the treatments with  $\text{Al}^{3+}$  were applied and the plants were cultivated with the treatments until 42 DAT.

During the entire experimental period, the nutrient solution was aerated and the pH was daily monitored, maintained around 4.0 ( $\pm 0.1$ ) and corrected using NaOH (0.1  $\text{mol L}^{-1}$ ) and HCl (0.1  $\text{mol L}^{-1}$ ). The nutrient solution was weekly renewed by adding the respective treatments and the losses through evapotranspiration were daily replenished with demineralized water. Heaters were used in the greenhouse in order to maintain the temperature at approximately 25 °C.

Plants were evaluated for root mean length and diameter (WinRhizo); root dry matter, shoot dry matter and the "S" index of susceptibility to  $\text{Al}^{3+}$ , according to Fisher & Maurer (1978) adapted by Guimarães et al. (2006) for  $\text{Al}^{3+}$  stress, as shown in Eqs. 1 and 2:

$$IS = \frac{Y_i - Y_s}{Y_i \times D} \quad (1)$$

$$D = \frac{1 - Y_{ms}}{Y_{mi}} \quad (2)$$

where:

D - severity of the applied stress;  
 $Y_i$  and  $Y_s$  - root lengths without and with stress, respectively; and,  
 $Y_{ms}$  and  $Y_{mi}$  - mean root lengths of the experiment, with and without stress, respectively.

For the selection, the cultivars were distributed in quartiles, delimited by the mean root length, without the stress of  $\text{Al}^{3+}$  toxicity, plus 75% of its standard deviation and the mean of its  $\text{Al}^{3+}$  toxicity susceptibility index, minus 25% of its standard deviation. Thus, the lower the IS, the less affected the plants are by the stress level induced by  $\text{Al}^{3+}$  toxicity.

The data of the other variables were subjected to analysis of variance by F test and the means were compared by the Scott-Knott test, for cultivars, and F test for the comparison between the presence and absence of  $\text{Al}^{3+}$  treatments, both at 0.05 probability level.

### Experiment II: Upland rice cultivation in aluminic soil

The experimental design was in randomized blocks, with four replicates, and the treatments were the same nine upland rice cultivars used in Experiment I. However, they were cultivated in pots containing aluminic soil ( $\text{m}\% > 50\%$ ) and evaluated for the number of panicles per plant, grain production, shoot dry matter and harvest index of the cultivars under stress by  $\text{Al}^{3+}$ . The harvest index was determined through the relationship of grain production/shoot dry matter production.

The soil used in the experiment was of low natural fertility and aluminic, classified as Dark Red Latosol, with medium sandy texture, which showed the following chemical characteristics: 7 mg dm<sup>-3</sup> of P-resin; 15 g dm<sup>-3</sup> of organic matter; 4.1 of pH in CaCl<sub>2</sub>; 0.7, 5, 3, 69, 11 and 78 mmol c dm<sup>-3</sup> of K, Ca, Mg, H + Al, Al<sup>3+</sup> and CEC, respectively; and 55.8% of saturation by Al<sup>3+</sup>.

The data were subjected to analysis of variance and the means were compared by the Scott-Knott test at 0.05 probability level.

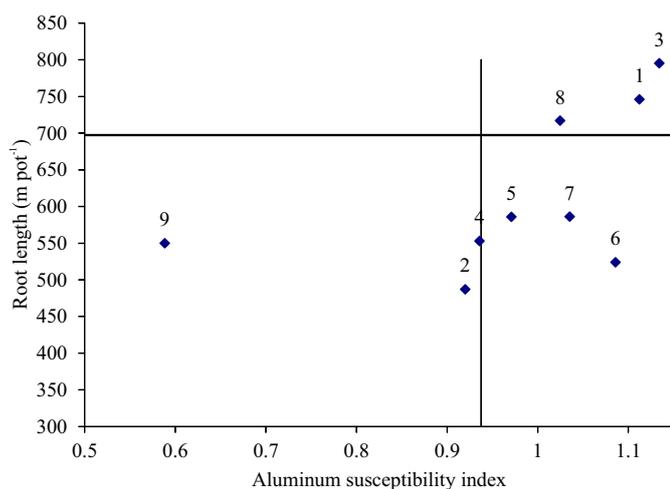
## RESULTS AND DISCUSSION

The cultivars were divided into two groups: the first one was composed of BRS Pepita, BRS Primavera and ANa7007, whose Al<sup>3+</sup> susceptibility index of the root growth was lower than 0.93, being considered as tolerant to Al<sup>3+</sup>, while the second group was composed of the cultivars BRS Monarca, BRS Bonança, BRS Sertaneja, Maravilha, IAC 202 and ANCambará, which obtained Al<sup>3+</sup> susceptibility index higher than 0.93, thus being considered as susceptible to Al<sup>3+</sup> (Figure 1).

The cultivars BRS Monarca, BRS Bonança and ANCambará stand out for their higher root growth when grown in the absence of Al<sup>3+</sup>, i.e., only under the condition of high acidity (pH 4.0). It is worth remembering that the lower the Al<sup>3+</sup> susceptibility index, the less affected the cultivar is by the deleterious effects of the Al<sup>3+</sup>.

It is interesting to note that the division by quartiles separated only three cultivars as tolerant to Al<sup>3+</sup>, according to the adopted criteria. Thus, although upland rice is considered as a plant moderately tolerant to Al<sup>3+</sup> (Fageria, 1998), its growth can be influenced by Al<sup>3+</sup>, confirming the results reported by Ferreira et al. (1995), Mendonça et al. (2003) and Freitas et al. (2006).

The distribution of the cultivars in quartiles (root growth) was used to separate them with respect to the tolerance to Al<sup>3+</sup>; however, from this point on, the cultivars will be evaluated considering their efficiency under stress by Al<sup>3+</sup>, as well as in



1 - BRS Monarca, 2 - BRS Pepita, 3 - BRS Bonança, 4 - BRS Primavera, 5 - BRS Sertaneja, 6 - Maravilha; 7 - IAC 202; 8 - ANCambará and 9 - ANa7007

Figure 1. Distribution of the cultivars in quartiles delimited by the root length in 0 mg dm<sup>-3</sup> of aluminum and by the susceptibility index of root growth to aluminum toxicity, at the points determined by the mean root length (without Al<sup>3+</sup>) + 75% of its standard deviation and by the mean root susceptibility index to aluminum - 25% of its standard deviation

cultivation in the absence of Al<sup>3+</sup>, since they were cultivated at pH 4.0, which is close to the pH at which the upland rice crop is cultivated especially in recently deforested areas.

The cultivar BRS Monarca showed higher shoot and root dry matter production when cultivated in the presence and absence of Al<sup>3+</sup> (Table 1). On the other hand, comparing the cultivation in the presence and absence of Al<sup>3+</sup>, the shoot dry matter production of the cultivars BRS Monarca, Maravilha and ANa7007 were lower in the presence of Al<sup>3+</sup>.

The cultivars BRS Pepita and ANa7007 were classified as tolerant to Al<sup>3+</sup> according to the method of separation by quartiles (Figure 1); hence, it can be noted that, in comparison to the other cultivars, these two produce lower amount of shoot dry matter. Thus, it is possible that this variable is little influenced by Al<sup>3+</sup> toxicity caused to the roots. Therefore, this variable is probably not indicated for the classification of cultivars regarding their tolerance to Al<sup>3+</sup>.

The cultivars BRS Pepita, Maravilha and ANa7007 obtained lower root dry matter production when cultivated in the presence and absence of Al<sup>3+</sup>; however, among the cultivars, only BRS Pepita was not different in the comparison of cultivation in the presence and absence of Al<sup>3+</sup>.

It is known that root dry matter production is negatively influenced by the action of Al<sup>3+</sup> (Roy & Bhadra, 2014). Despite the lower root dry matter production in the presence of Al<sup>3+</sup> (Table 1), the cultivars BRS Pepita and ANa7007 were considered as tolerant through the separation in quartiles (Figure 1). Thus, the methodology of separation into quartiles is important to distinguish the cultivars and it is basically a relationship between root length in the presence and in the absence of Al<sup>3+</sup>. Therefore, both cultivars showed lower difference between the root growth in the presence and absence of Al<sup>3+</sup> in comparison to the others.

It is also necessary to consider that, before root dry matter shows a decrease caused by Al<sup>3+</sup> toxicity, this phytotoxic element acts first in root elongation and, consequently, leads to lower root length (Sun et al., 2010; Roy & Bhadra, 2014).

The cultivars BRS Monarca, BRS Bonança and ANCambará showed greater root length when grown in the absence of Al<sup>3+</sup> in comparison to the others (Table 2). This behavior can contribute to explaining the classification of the cultivar BRS Monarca as susceptible to Al<sup>3+</sup> (Figure 1), since there was great amplitude between the root growth in the absence and presence of Al<sup>3+</sup>, evidencing the damaging action of Al<sup>3+</sup>.

Table 1. Shoot and root dry matter production of upland rice cultivars grown in the presence (+Al<sup>3+</sup>) and absence (-Al<sup>3+</sup>) of aluminum

Cultivars	Shoot dry matter (g pot <sup>-1</sup> )		Root dry matter (g pot <sup>-1</sup> )	
	-Al <sup>3+</sup>	+Al <sup>3+</sup>	-Al <sup>3+</sup>	+Al <sup>3+</sup>
BRS Monarca	8.1 aA	7.1 aB	2.3 aA	2.1 aA
BRS Pepita	4.1 cA	3.8 bA	1.2 cA	1.0 cA
BRS Bonança	6.5 bA	6.0 aA	2.0 bA	1.7 bB
BRS Primavera	6.7 bA	6.2 aA	1.9 bA	1.6 bB
BRS Sertaneja	6.6 bA	5.9 aA	1.9 bA	1.4 bB
Maravilha	5.0 cA	4.1 bB	1.5 cA	1.0 cB
IAC 202	6.3 bA	6.1 aA	1.7 bA	1.7 bA
ANCambará	6.4 bA	5.8 aA	1.9 bA	1.6 bB
ANa7007	4.6 cA	3.5 bB	1.2 cA	0.6 dB
CV (%)	9.0		9.7	

Means followed by different letters, uppercase in rows and lowercase in columns, differ statistically at 0.05 probability level by Scott-Knott tests, respectively

Table 2. Root length and diameter of upland rice cultivars grown in the presence (+Al<sup>3+</sup>) and absence (-Al<sup>3+</sup>) of aluminum

Cultivars	Root length (m pot <sup>-1</sup> )		Mean diameter (mm)	
	-Al <sup>3+</sup>	+Al <sup>3+</sup>	-Al <sup>3+</sup>	+Al <sup>3+</sup>
BRS Monarca	745.8 aA	227.9 bB	0.199 aA	0.306 aB
BRS Pepita	487.0 bA	206.6 bB	0.178 bA	0.248 cB
BRS Bonança	795.2 aA	233.2 bB	0.175 bA	0.252 cB
BRS Primavera	552.7 bA	229.6 bB	0.204 aA	0.255 cB
BRS Sertaneja	585.9 bA	229.0 bB	0.207 aA	0.264 cB
Maravilha	524.0 bA	168.4 bB	0.198 aA	0.278 bB
IAC 202	586.0 bA	208.5 bB	0.208 aA	0.300 aB
ANCambará	716.7 aA	254.2 bB	0.178 bA	0.247 cB
ANa7007	549.8 bA	331.8 aB	0.177 bA	0.165 dA
CV (%)	12.4		6.6	

Means followed by different letters, uppercase in rows and lowercase in columns, differ statistically at 0.05 probability level by Scott-Knott tests, respectively

On the other hand, it is observed that the cultivar ANa7007 in the presence of Al<sup>3+</sup>, despite showing lower shoot and root dry matter production (Table 1), has the greatest root length among all cultivars when grown under stress by Al<sup>3+</sup> (Table 2), confirming its selection as tolerant to Al<sup>3+</sup> (Figure 1).

The cultivar ANa7007 showed the lowest root diameter in both types of cultivation (absence and presence of Al<sup>3+</sup>) (Table 2); this behavior can contribute to explaining the low root dry matter production of this cultivar (Table 1).

The root diameter referring to the cultivation in the absence of Al<sup>3+</sup> can be considered as a reference for comparison (Table 2) due to the increment in root diameter caused by Al<sup>3+</sup> toxicity (Motoda et al., 2010). Hence, comparing the cultivars in the presence and absence of Al<sup>3+</sup>, the effect of root thickening favored by the toxicity occurred for almost all the cultivars, except for ANa7007.

The cultivar BRS Monarca stands out for the increment of 0.107 mm in mean root diameter, in the comparison of cultivated in the presence and absence of Al<sup>3+</sup>, and it was the highest value observed among the nine tested cultivars (Table 2). Therefore, this variable can also support the selection of this cultivar as susceptible to Al<sup>3+</sup>.

Given the presented results and in general, the cultivars BRS Monarca, BRS Bonança, BRS Primavera, BRS Sertaneja, IAC 202 and ANCambará obtained adequate growth without the presence of Al<sup>3+</sup> and at acidic pH (4.0); thus, these cultivars are interesting for cultivation in soils with acidic pH, but without high content of Al<sup>3+</sup>, while the cultivars BRS Pepita and Maravilha obtained lower growth when cultivated in the presence of Al<sup>3+</sup>.

Even in the presence of Al<sup>3+</sup>, the cultivar BRS Monarca showed good dry matter production (Table 1); in spite of that, it showed small root growth when cultivated under these conditions (Table 2), being strongly affected by this phytotoxic ion. In contrast, the cultivar ANa7007 stood out as tolerant to Al<sup>3+</sup> (Figure 1) due to the high root growth obtained under stress by Al<sup>3+</sup> (Table 2); however, it showed the lowest shoot and root dry matter production among the evaluated cultivars (Table 1). Therefore, it is suggested to study methodologies for the selection of cultivars tolerant and susceptible to Al<sup>3+</sup> in order to increase the efficiency of the test and obtain greater understanding about the reflex of the variables root dry matter and root length on grain production, since not always

a plant is able to produce large amount of root dry matter or the shoots are able to convert this produced dry matter into grains; ultimately, this is the objective of the rural producer.

To reinforce the results of the Experiment I (nutrient solution), a second experiment was conducted with the same cultivars; however, they were grown in pots with aluminic soil (Table 3).

The cultivars BRS Primavera and ANa7007 showed higher grain production and also low shoot dry matter production, demonstrating good harvest index. These results reinforce the definition of the cultivars BRS Primavera and ANa7007 as tolerant to Al<sup>3+</sup> (Figure 1), which showed interesting agronomic characteristics for high yield (Table 3).

As to the cultivars BRS Sertaneja and Maravilha, selected as susceptible to Al<sup>3+</sup> based on the experiment in nutrient solution (Figure 1), despite obtaining the highest shoot dry matter production among the tested cultivars (Table 3), they showed low grain production and, consequently, the worst harvest index among the cultivars. Therefore, their definition as susceptible to Al<sup>3+</sup> is reinforced. These results were similar to those reported by Mendonça et al. (2003) and Justino et al. (2006), who also observed the susceptibility of the cultivar Maravilha to Al<sup>3+</sup>.

These results demonstrate that shoot dry matter production may not be efficient in the selection of the cultivars, because the cultivar BRS Sertaneja showed higher shoot dry matter production, but its grain production was lower compared with the cultivars that produced less shoot dry matter (Table 3).

Lastly, studies like these are initially important since they are basic experiments, i.e., it is the first study to be conducted aiming to obtain possible characteristics of tolerance to Al<sup>3+</sup> in cultivars. However, it is important to evaluate the studied cultivars in field experiments and in different regions, because it is the only way to permanently differentiate the cultivars with respect to their tolerance to Al<sup>3+</sup>.

Table 3. Number of panicles plant<sup>-1</sup>, grain production, shoot dry matter and harvest index of upland rice cultivars grown in aluminic soil

Cultivars	Panicles plant <sup>-1</sup>	Grain production (g pot <sup>-1</sup> )	Shoot dry matter	Harvest index
BRS Pepita	18.5 b	50.0 b	45.7 c	1.0 c
BRS Bonança	14.7 c	42.2 c	46.2 c	0.9 d
BRS Primavera	15.2 c	62.0 a	51.0 b	1.2 b
BRS Sertaneja	18.7 b	48.5 b	58.2 a	0.8 d
Maravilha	15.5 c	47.0 c	60.2 a	0.7 d
IAC 202	16.2 c	53.2 b	51.2 b	1.0 c
ANCambará	14.5 c	46.7 c	53.2 b	0.8 d
ANa7007	32.0 a	59.5 a	39.2 d	1.5 a
CV (%)	8.2	5.6	8.5	13.9

Means followed by different letters for each parameter differ by the Scott-Knott test at 0.05 probability level

## CONCLUSIONS

1. With the distribution of the upland rice cultivars in quartiles, it was possible to differentiate them in two groups. Al<sup>3+</sup> tolerant group: BRS Pepita, BRS Primavera and ANa7007; Al<sup>3+</sup> susceptible group: BRS Monarca, BRS Bonança BRS Sertaneja, Maravilha, IAC 202 and ANCambará.

2. The cultivars BRS Primavera and ANa7007 show higher grain production when cultivated in aluminic soil.

3. The cultivars BRS Monarca, BRS Bonança, BRS Primavera, BRS Sertaneja, IAC 202 and ANCambará have adequate growth when cultivated in nutrient solution with acidic pH (4.0) and in the absence of Al<sup>3+</sup>.

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