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EFFECTS OF ALUMINIUM TOXICITY ON ROOT AND SHOOT GROWTH OF RICE AND CHICKPEA SEEDLINGS

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Abstract

Increasing concentrations of aluminium progressively declined primary root length and number of lateral roots in rice and chickpea seedlings grown in rhizobox. It also inhibited the root and shoot length, dry weight of root and shoot of rice and chickpea seedlings grown in solution culture. On the other hand, it enhanced shoot/root length ratio and dry weight ratio for both the genera.

Introduction

Free aluminium ions were reported to be the main factor for inhibiting root growth of plants grown in acidic soils (Matsumoto 2000, Ma 2007). Root growth inhibition is the most evident symptom of Al toxicity which can be detected within 30 min to 2 hrs, even at micromolar concentrations of Al (Barceló and Poschenrieder 2002). $AlCl_3$ (50 µM) at pH 4.5 inhibited root growth by 65% in wheat and by 25-50% in oil seed rape and oat (Zheng *et al.* 1998).

Aluminium toxicity adversely affected plant growth in many plants (Gupta *et al.* 2013, Karimaei and Poozesh 2016). The changes in the root and shoot length of *Vigna radiata* showed a gradual decrease with the increase in aluminium oxide (Al_2O_3) from 200 to 1000 ppm (Mahapatra *et al.* 2015).

Rice and chickpea were used as plant materials because reports on the effects of aluminium toxicity on root elongation and plant growth of these two genera are rare. Hence, the present study aimed to assess the influence of aluminium^{3+} stress on root elongation, number of lateral roots, root and shoot growth of rice and chickpea grown in rhizobox and solution culture.

Materials and Methods

Rice (*Oryza sativa* L. var. BRRI Dhan-53) seeds were obtained from Bangladesh Rice Research Institute (BRRI) and that of chickpea (*Cicer arietinum* L. var. BARI Chhola-7) from Bangladesh Agricultural Research Institute (BARI), respectively.

In order to study the root elongation and number of lateral roots starting from germination of seeds, rice and chickpea seedlings were raised in rhizobox (Plates 1 and 2) as described by Marschner and Römheld (1983). Surface sterilized rice and chickpea seeds were germinated on moist filter paper placed in Petridish at a temperature of 30 ± 1°C and 25 ± 1°C, respectively (Samad and Karmoker 2013). The sprouting was considered as the zero hour of age of the seedling. A one-day-old seedling was placed in the rhizobox filled with quartz sand where the radical was in the sand while the plumule was protruding outside through the hole in rhizobox.

The sand of three rhizoboxes with seedlings were moistened with half strength Hoagland solution (Hoagland and Arnon 1950) which was used as control (pH 4.2) and other nine rhizoboxes were moistened with 50, 100 and 150 µM $AlCl_3$ solution (pH 4.2). The length and number of lateral roots traced in the tracing paper was measured and recorded from the 1st to 5th day of germination.

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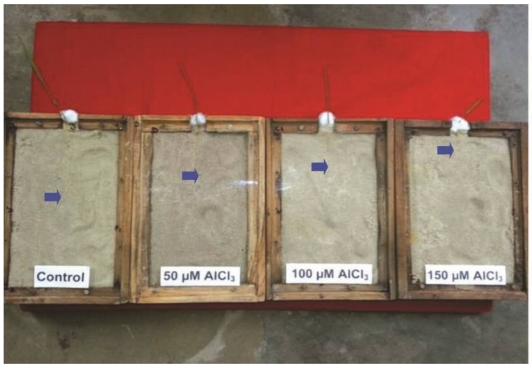

Plate 1. Effects of aluminium toxicity on the root growth of rice seedlings grown in rhizobox.

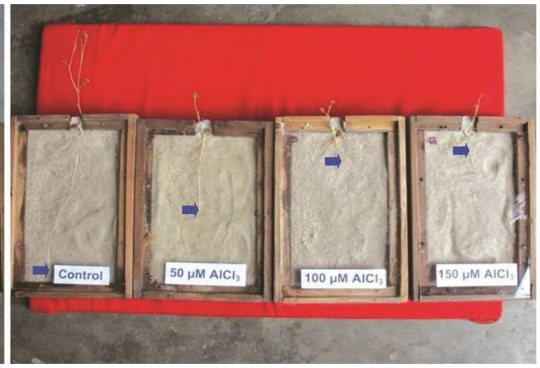

Plate 2. Effects of aluminium toxicity on the root growth of chickpea seedlings grown in rhizobox.

Surface sterilized rice and chikpea seeds were germinated in half strength Hoagland solution for 48 hrs. Then the germinated seeds were transferred to light bank. Rice seedlings were grown at a day/night temperature of $30^oC \pm 1^oC/25^oC \pm 1^oC$ and day/night length of 14/10 hrs. Chickpea seedlings were grown at a day/night temperature of $25^oC \pm 1^oC/18^oC \pm 1^oC$ and day/night length of 10 h/14 hrs. Light intensity was 160 µ-einstein $m^{-2}s^{-1}$. The solution was replenished every 48 hrs. The solution was continuously aerated through bubbler with the help of air compressor (Hoagland and Arnon 1950). Seven-day-old seedlings were transferred to half strength Hoagland solution (control) and 10, 50, 100 and 150 µM $AlCl_3$ solution made in half strength Hoagland solution. The pH of all solutions including control were adjusted to 4.2 with 0.2N H_2SO_4. Length of root and shoot of the seedlings were measured in cm with a scale at 3, 6, 24, 48, 72 and 96 hrs of aluminium treatment.

The root and shoot samples were collected and dried in an oven at 75^oC for 72 hrs to a constant weight. Dry weights of the samples were recorded with an electronic balance. Data obtained in this investigation was analyzed statistically (Steel *et al*. 1997).

Results and Discussion

$AlCl_3$ (50 µM) decreased primary root length of rice by 24.4 to 59.0% from 1 to 5 day of treatment. Similarly, 150 µM $AlCl_3$ caused a 31.7 to 70% inhibition of primary root length of rice from 1 to 5 day of application (Fig. 1). In chickpea seedlings, exposure to 100 and 150 µM $AlCl_3$ resulted in 64.5 to 82.6% and 66.0 to 83.0% inhibition of primary root length of chickpea, respectively, from 1 to 5 day of treatment (Fig. 2). $AlCl_3$ (50 µM) decreased the number of lateral roots of rice from 50.0 to 48.0% from 1 to 5 day of treatment. Similar magnitude of inhibition of the number of lateral roots of rice was recorded at 150 µM $AlCl_3$ application (Fig. 3). In chickpea seedlings, $AlCl_3$ (100 µM) caused an inhibition of the number of lateral roots by 80.0 to 77.0% from 2 to 5 day of treatment (Fig. 4). Similarly, Meda and Furlani (2005) found that Al^{3+} reduced the root elongation by 50% in tropical leguminous plant. Ryan *et al.* (1993) showed that 20 µM $AlCl_3$ inhibited root elongation of corn root by 50.0%. Decrease in the number of lateral roots would decrease the ion absorption area of the root system.

The root length decreased with the increase in $AlCl_3$ concentration from 10 to 150 µM. The highest inhibition from 43.4 to 61.6% of the root length was exerted by 150 µM $AlCl_3$ over a period of 3 to 96 hrs of treatment (Fig. 5a). $AlCl_3$ (50 µM) decreased the shoot length of rice by 8.8 to 22.3% from 3 to 96 hrs of treatment (Fig. 5b). On the other hand, aluminium, at a concentration of 10 µM, increased shoot/root length ratio of rice by 14.2 to 47.2% from 3 to 96 h of treatment. The maximum stimulation of shoot/root length ratio was recorded at 150 µM $AlCl_3$ which ranged from 45.8 to 76.4% from 3 to 96 hrs of application (Fig. 5c).

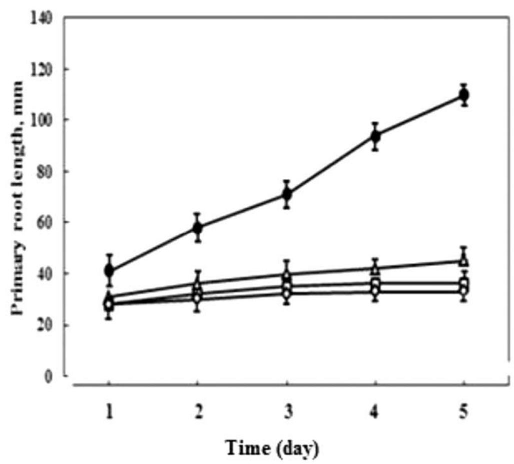

Fig. 1. Effects of different concentrations of aluminium on the primary root length of rice seedlings grown in rhizobox. ● represents control; Δ 50 µM Al; □ 100 µM Al; ◊ 150 µM Al. Each value is the mean of three replicates ± standard error.

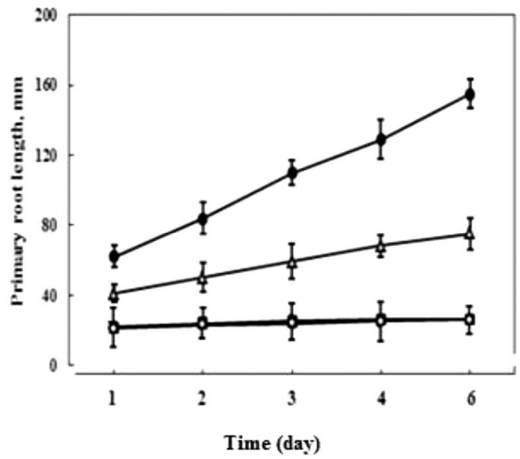

Fig. 2. Effects of different concentrations of aluminium on primary root length of chickpea seedlings grown in rhizobox. Otherwise as Fig. 1.

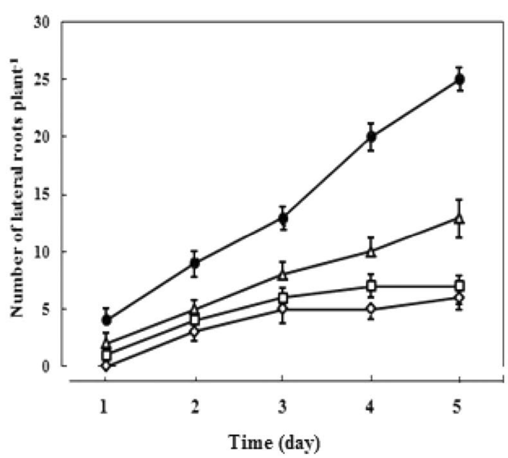

Fig. 3. Effects of different concentrations of aluminium on the number of lateral roots of rice seedlings grown in rhizobox. Otherwise as Fig. 1.

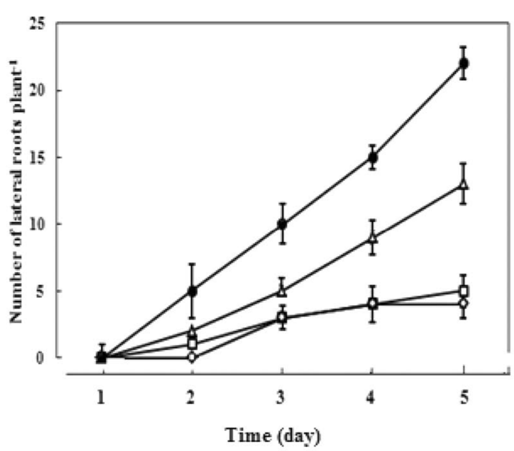

Fig. 4. Effects of different concentrations of aluminium on the number of lateral roots of chickpea seedlings grown in rhizobox. Otherwise as Fig. 1.

In chickpea seedlings, 50 µM $AlCl_3$ decreased the root length by 7.3 to 41.6% from 3 to 96 hrs of treatment (Fig. 6a). $AlCl_3$, at a concentration of 100 µM, decreased the shoot length of chickpea by 9.0 to 28.8% from 6 to 96 hrs of treatment (Fig. 6b). On the contrary, the shoot/root length of chickpea seedlings was found to increase by all the concentrations of Al (10-150 µM) used. 100 and 150 µM $AlCl_3$ increased the shoot/root length by 19.9 to 48.0% and 31.9 to 65.0%, respectively, from 3 to 96 hrs of treatment (Fig. 6c).

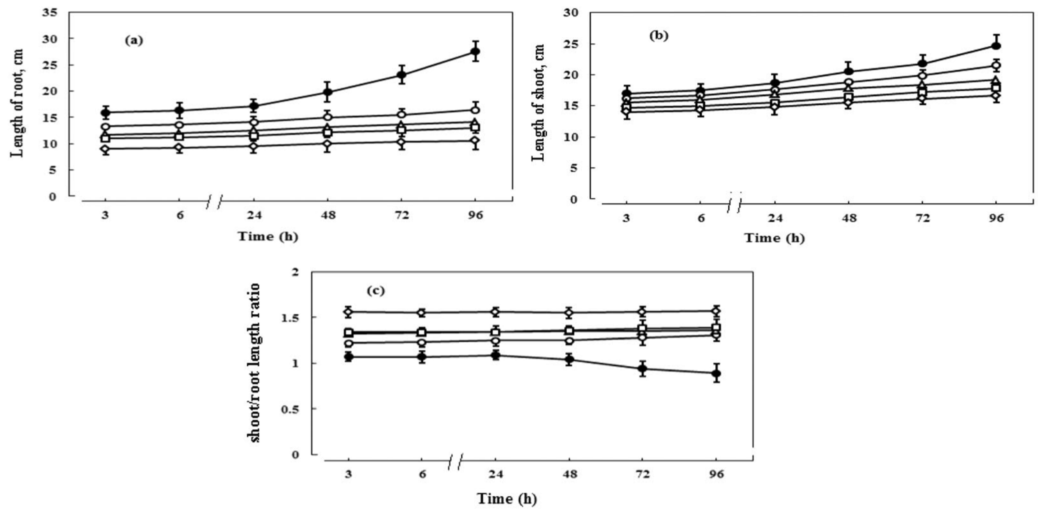

Fig. 5. Effects of different concentrations of aluminium on the (a) root length, (b) shoot length and (c) shoot/root length ratio of rice seedlings grown in solution culture. ● represents control; ○ 10 µM Al; Δ 50µM Al; □ 100µM Al; ◊ 150µM Al. Each value is the mean of three replicates ± standard error.

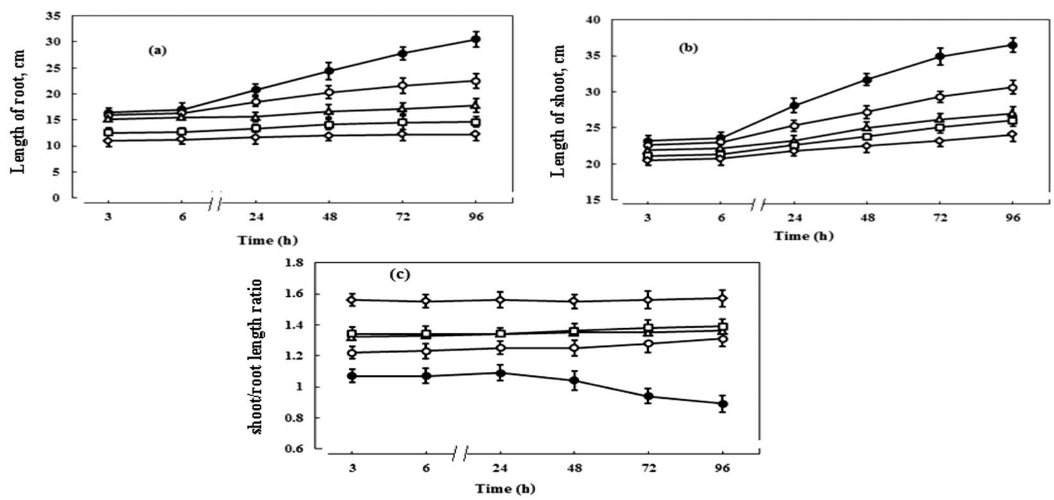

Fig. 6. Effects of different concentrations of aluminium on the (a) root length, (b) shoot length and (c) shoot/root length ratio of chickpea seedlings grown in solution culture. Otherwise as Fig. 5.

$AlCl_3$ (10-150 µM) decreased the length of rice and chickpea seedlings (Plates 3 and 4). The maximum inhibition of length of rice seedlings was observed at 150 µM $AlCl_3$ which ranged from 30.1 to 48.0% from 3 to 96 hrs of application (Table 1). Similarly, $AlCl_3$ (10 and 150 µM) decreased the length of chickpea seedlings. 100 µM $AlCl_3$ inhibited the length of chickpea seedlings by 15.2 to 39.4% from 3 to 96 hrs of exposure (Table 2).

Plate 3. Effects of aluminium toxicity on the root and shoot length of rice seedlings grown in solution culture.

Plate 4. Effects of aluminium toxicity on the root and shoot length of chickpea seedlings grown in solution culture.

Table 1. Effects of different concentrations of aluminium on the length of rice seedlings grown in solution culture. Each value is the mean of three replicates ± standard error.

Treatment	Length of seedling (cm)					
	Duration of treatment (hrs)					
	03	06	24	48	72	96
Control	32.9 ±0.186	33.8 ±0.250	35.9 ±0.246	40.3 ±0.295	44.9 ±0.273	52.3 ± 0.326
10 µM $AlCl_3$	29.5 ±0.221	30.3 ± 0.189	31.7 ±0.167	33.8 ±0.141	35.4 ±0.124	37.9 ±0.278
50 µM $AlCl_3$	27.2 ±0.282	28.0 ± 0.291	29.3 ±0.152	30.9 ±0.138	32.0 ±0.158	33.3 ±0.130
100 µM $AlCl_3$	25.7 ±0.190	26.2 ± 0.317	27.0 ±0.171	28.7 ±0.127	29.7 ±0.135	30.8 ± 0.242
150 µM $AlCl_3$	23.0 ±0.263	23.5 ± 0.232	24.3 ±0.228	25.5 ±0.276	26.4 ±0.180	27.2 ± 0.317

Table 2. Effects of different concentrations of aluminium on the length of chickpea seedlings grown in solution culture. Each value is the mean of three replicates ± standard error.

Treatment	Length of seedling (cm)					
	Duration of treatment (hrs)					
	03	06	24	48	72	96
Control	39.6 ±0.164	40.6 ±0.246	48.9 ±0.175	56.1 ±0.209	62.7 ±0.159	67.0 ±0.248
10 µM $AlCl_3$	38.5 ±0.153	39.3 ±0.196	43.8 ±0.164	47.5 ±0.251	50.9 ±0.182	53.1 ±0.146
50 µM $AlCl_3$	37.1 ±0.140	37.7 ±0.187	38.8 ±0.172	41.7 ±0.168	43.4 ±0.154	44.8 ±0.191
100 µM $AlCl_3$	33.6 ±0.166	34.0 ±0.179	36.0 ±0.180	37.9 ±0.173	39.6 ±0.163	40.6 ±0.184
150 µM $AlCl_3$	31.5 ±0.171	31.9 ±0.188	33.4 ±0.157	34.5 ±0.195	35.4 ±0.220	36.3 ±0.253

Kinraide *et al.* (1985) reported that a 60% reduction in the root growth was observed in 2-day-old Dayton barley exposed to less than 1 µM Al. Mahapatra *et al.* (2015) found that Al decreased the root and shoot length of *Vigna radiata*.

Aluminium, at concentrations of 10 and 50 µM, decreased the dry weight of root of rice seedlings by 33.3 to 55.6% from 3 to 96 hrs of treatment (Fig. 7a). In rice seedlings, a maximum of 40.0 to 44.5% inhibition in the shoot dry weight was observed following 150 µM Al treatment (Fig. 7b). On the contrary, 10 µM Al increased shoot/root dry weight ratio of rice by 20.0 to 40.0% from 3 to 96 hrs of application (Fig. 7c).

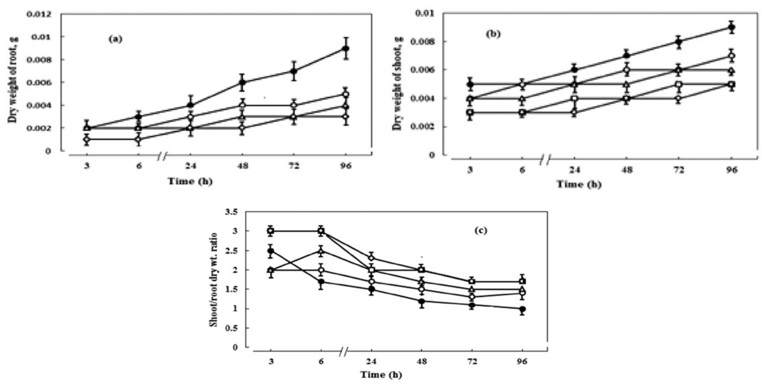

Fig. 7. Effects of different concentrations of aluminium on dry weight of the (a) root, (b) shoot and (c) shoot/root dry weight ratio of rice seedlings grown in solution culture. Otherwise as Fig. 5.

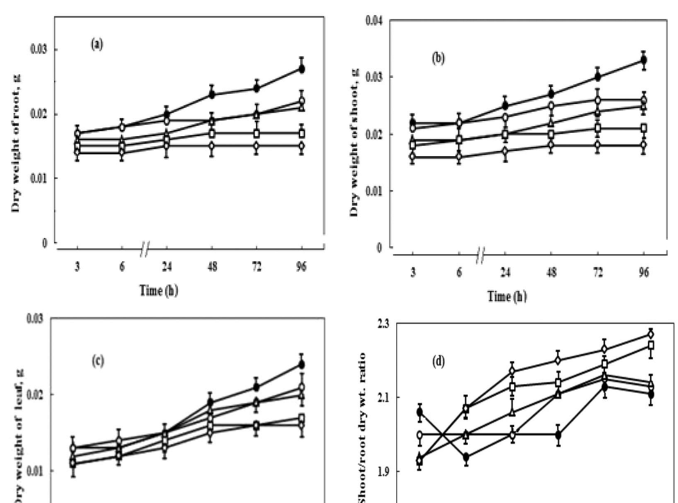

Fig. 8. Effects of different concentrations of aluminium on dry weight of the (a) root, (b) stem, (c) leaf and (d) shoot/root ratio of chickpea seedling grown in solution culture. Otherwise as Fig. 5.

Similarly, in chickpea seedlings, 100 and 150 µM Al caused 11.8 to 44.4% inhibition of the root dry weight from 3 to 96 hrs of application (Fig. 8a). The dry weight of shoot of chickpea seedlings decreased gradually with the increase in Al concentrations from 10 to 150 µM. A maximum of 27.3 to 45.5% inhibition of the dry weight of stem was recorded at 150 µM Al at 3 to 96 hrs of treatment (Fig. 8b).

In chickpea, the maximum stimulation of shoot/root dry weight ratio was observed following 150 µM Al treatment which ranged from 6.3 to 12.4% over a exposure period of 96 hrs (Fig. 8d). Similarly, Al decreased the dry weight of cultured cells of tobacco (Abdel-Basset *et al.* 2013). On the contrary, Symeonidis *et al.* (2004) found that Al increased the dry weight of melon (*Cucumis melo*).

Aluminium stress induced decrease in primary root length and number of lateral roots in rice and chickpea seedlings and inhibition of long term root growth cause a decrease in root surface area. The decrease in root surface area would lead to a decrease in absorption of ions.

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