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EFFECT OF ALUMINIUM TOXICITY ON THE ACCUMULATION AND DISTRIBUTION OF K^+, Na^+, Cl^- AND NO_3^- IN *ORYZA SATIVA* L. AND *CICER ARIETINUM* L.

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Abstract

Aluminium (10 to 150 μM) decreased K^+ accumulation in the root and shoot of rice and the root, stem and leaves of chickpea seedlings. On the other hand, Al, at a concentration of 10, 50, 100 and 150 μM increased Na^+ content in different parts of rice and chickpea seedlings. 150 μM Al increased Na^+ accumulation in the root by 2.1- to 2.2-folds from 3 to 96 hrs of treatment. Aluminium at a concentration of 150 μM caused a dramatic 2- and 3.4-folds increase in Cl^- accumulation in the root and shoot of rice, respectively. In chickpea, 150 μM Al increased Cl^- accumulation in the root by 2-folds. On the contrary, Al application decreased NO_3^- accumulation in different parts of rice and chickpea seedlings.

Introduction

Aluminium (Al) is the third most abundant metallic element in soil but becomes available to plants only when the soil pH drops below 5.5. When pH drops below 5.5, aluminosilicate clays and aluminium hydroxide minerals begin to dissolve, releasing aluminium-hydroxy cations Al $(H_2O)_6^{3+}$ or (Al^{3+})[1]. The mononuclear Al^{3+} species is considered as the most toxic forms[2-3]. Al toxicity is a major factor limiting plant production on acid soil[4].

Aluminium toxicity decreased K^+ content in the root but increased in the stem of *Theobahia* and in the leaves of both genotypes of *Cacao*[5]. Al treatment decreased K^+ content in the root, stem and leaves of tomato[6]. On the contrary, Al increased accumulation of K^+ in the root of sorghum[7]. Aluminium reduced NO_3 uptake in soybean[8-9] and in wheat[10]. On the other hand, Al increased absorption of nitrate in *Stylosanthes guianensis* and *S. macrocephala* [11-12].

Reports on the effect of aluminium application on the accumulation of K^+, Na^+, Cl^- and NO_3^- in rice (*Oryza sativa* L.) and chickpea (*Cicer arietinum* L.) are very rare. Therefore, in this paper, the effect of aluminium toxicity on the accumulation and distribution of K^+, Na^+, Cl^- and NO_3^- in rice and chickpea seedlings is reported.

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Material and Methods

Rice (*Oryza sativa* var. BRRI Dhan-53) and chickpea (*Cicer arietinum* var. Bari Chhola-7) were taken as experimental plant material. Seeds of rice were collected from Bangladesh Rice Research Institute (BRRI) and that of chickpea were procured from Bangladesh Agricultural Research Institute (BARI).

The seeds were surface sterilized according to Samad and Karmoker[13]. Then the seeds were spread over cotton gauge placed in a plastic lid having holes and was placed upon the beaker filled with half strength Hoagland solution. After 48 hrs of sowing, the seeds were germinated and then were transferred to light bank. Rice seedlings were grown at a day/night temperature of 30ºC ± 1ºC/25ºC ± 1ºC and day/night length of 14 hrs/10 hrs. Chickpea seedlings were grown at a day/night temperature of 2 ºC ± 1ºC /18ºC ± 1ºC and day/night length of 10 hrs/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. 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.

Shoots, stems and leaves were collected in triplicate after 3, 6, 24, 48, 72 and 96 hrs of aluminium treatment. The K^+, Na^+, Cl^- and NO_3^- were extracted from dry tissue by boiling in water bath with two changes of 10 ml distilled water contained in test tubes. K^+ and Na^+ ions were measured by flame photometer (Jenway, PEP-7, UK) at a wavelength of 767 nm and 589 nm, respectively. Amount of Cl^- was measured by titrimetric method with 0.05 N $AgNO_3$ using 5% $K_2Cr_2O_4$ as an indicator. Nitrate was determined following the method of Cataldo *et al.* [14].

Results and Discussion

Aluminum at concentrations of 10 to 150 μM decreased K^+ accumulation in the root of rice except an initial stimulation. 10 and 150 μM Al caused 8 to 20% and 18 to 39% inhibition of K^+, respectively in the root of rice seedlings (Fig. 1a). 150 μM Al resulted in a 13 to 48% decrease in accumulation of K^+ in the shoot of rice from 6 to 96 hrs of treatment (Fig 1b).

In chickpea seedlings, 10 μM Al decreased K^+ content in the root by 8 to 24% from 3 to 96 hrs of treatment. Al-induced inhibition of K^+ accumulation in the root increased with the increase in Al concentration from 10 to 150 μM (Fig. 2a). In the stem of chickpea, maximum accumulation of K^+ in the stem occurred at 150 μM Al treatment which ranged from 25 to 44% from 3 to 96 hrs of application (Fig. 2b). Similarly, all the concentrations of Al used inhibited accumulation of K^+ in the leaves of chickpea (Fig. 2c). This result is supported by Bhalerao and Probhu[15] who found that Al decreased K^+ accumulation in maize and sorghum. On the contrary, Al increased K^+ content in *Stylosanthes*[16].

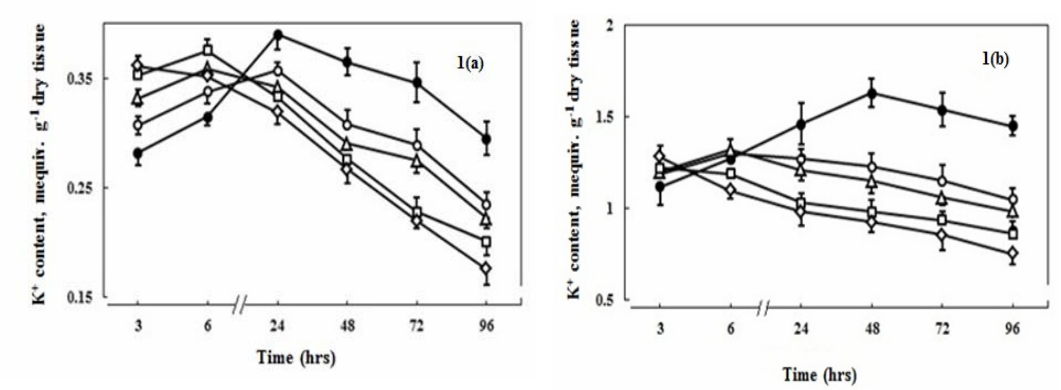

Fig. 1. The effect of different concentrations of aluminium (Al) on the accumulation of K^+ in (a) root and (b) shoot of rice seedlings. ● represents control; ○ 10 μM Al; Δ 50 μM Al; □ 100 μM Al; ◊ 150 μM Al. Each value is the mean of three replicates. Bars represent ± standard error of the mean value.

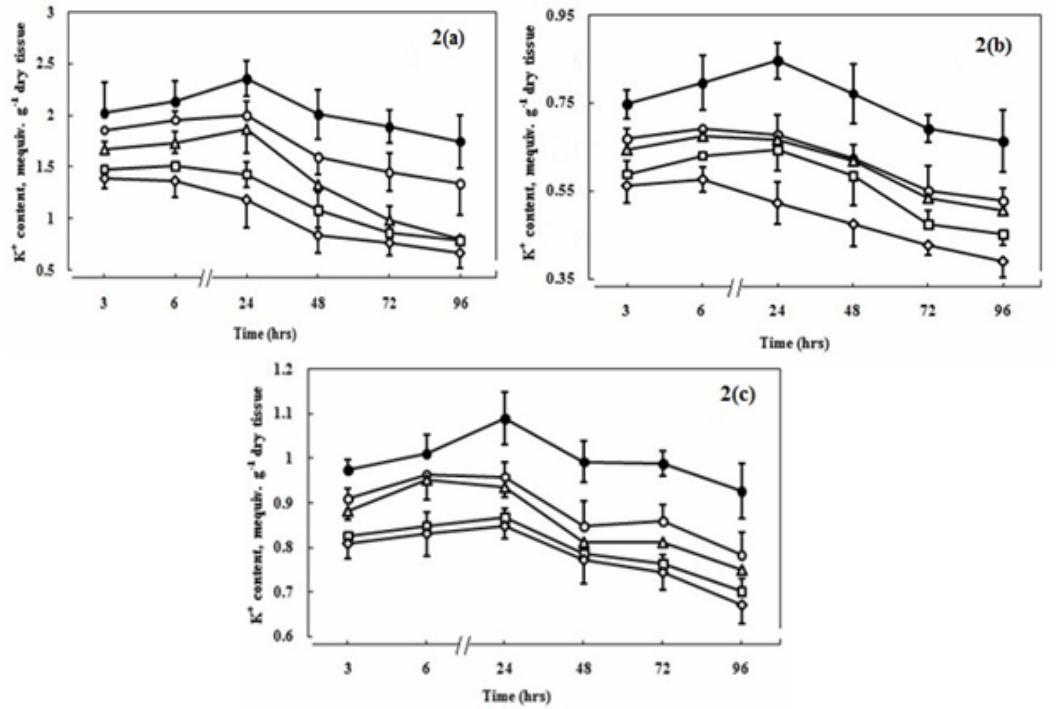

Fig. 2. The effect of different concentrations of aluminium on the accumulation of K^+ in (a) root, (b) stem and (c) leaf of chickpea seedlings. Otherwise as Fig. 1.

Aluminium at a concentration of 10 μM, increased the accumulation of Na^+ from 28 to 37% in the root of rice from 3 to 96 hrs of treatment. Highest stimulation of Na^+ accumulation in the root occurred at 150 μM Al application which ranged from 2.1- to

2.2-folds (Fig. 3a). A 53 to 55% increase in Na^+ accumulation in the shoot of rice was observed following 150 μM Al treatment from 3 to 96 hrs of treatment (Fig. 3b).

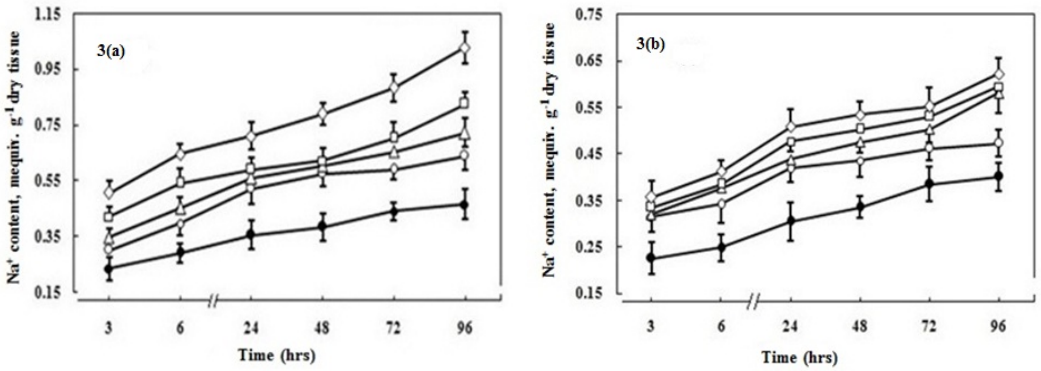

Fig. 3. The effect of different concentrations of aluminium on the accumulation of Na^+ in (a) root and (b) shoot of rice seedlings. Otherwise as Fig. 1.

In chickpea seedlings, 10, 100 and 150 μM Al increased Na^+ accumulation in the root by 9 to 16, 30 to 41 and 40 to 50%, respectively from 3 to 46 hrs of treatment (Fig. 4a). In the stem, 100 and 150 μM Al caused a 23 to 29 and 37 to 43% increase in Na^+ accumulation, respectively from 3 to 96 hrs of application (Fig. 4b). In the leaves, 100 and 150 μM Al increased accumulation of Na^+ by 36 to 52 and 53 to 72%, respectively from 3 to 96 hrs of treatment (Fig. 3c). This result is in agreement with the work of Lidon *et al.*[17] who found that 0.33 mM Al increased Na^+ content in the root of maize.

Uptake of K^+ was decreased by aluminum toxicity (Figs 1 and 2) but that of Na^+ was increased (Figs 3 and 4) in rice and chickpea seedlings. Therefore, it appears that Al alters the K^+/Na^+ selectivity.

In rice, 10 μM Al increased Cl^- accumulation in the root by 19 to 58% from 3 to 96 hrs of treatment. Chloride accumulation increased with the increase in concentration of aluminium. The highest accumulation occurred at 150 μM Al where a 61% to 2.2-folds increase in Cl^- accumulation in the root was recorded (Fig. 5a). In the shoot, 100 and 150 μM Al caused a 2- to 2.5-folds and 2.7- to 3.4-folds increase in Cl^- accumulation, respectively from 3 to 96 hrs of application (Fig. 5b).

In chickpea seedlings, 150 μM Al caused the maximum stimulation of Cl^- in the root ranging from 85% to 2-fold from 3 to 96 hrs of application (Fig. 6a). In the stem, 50 and 150 μM Al increased Cl^- accumulation by 23 to 28 and 36 to 49%, respectively from 3 to 96 hrs of treatment (Fig. 6b). In leaves 150 μM Al caused the maximum (74 to 81%) increase in Cl^- accumulation (Fig. 6c). On the contrary, Al decreased accumulation of Cl^- in maize [18].

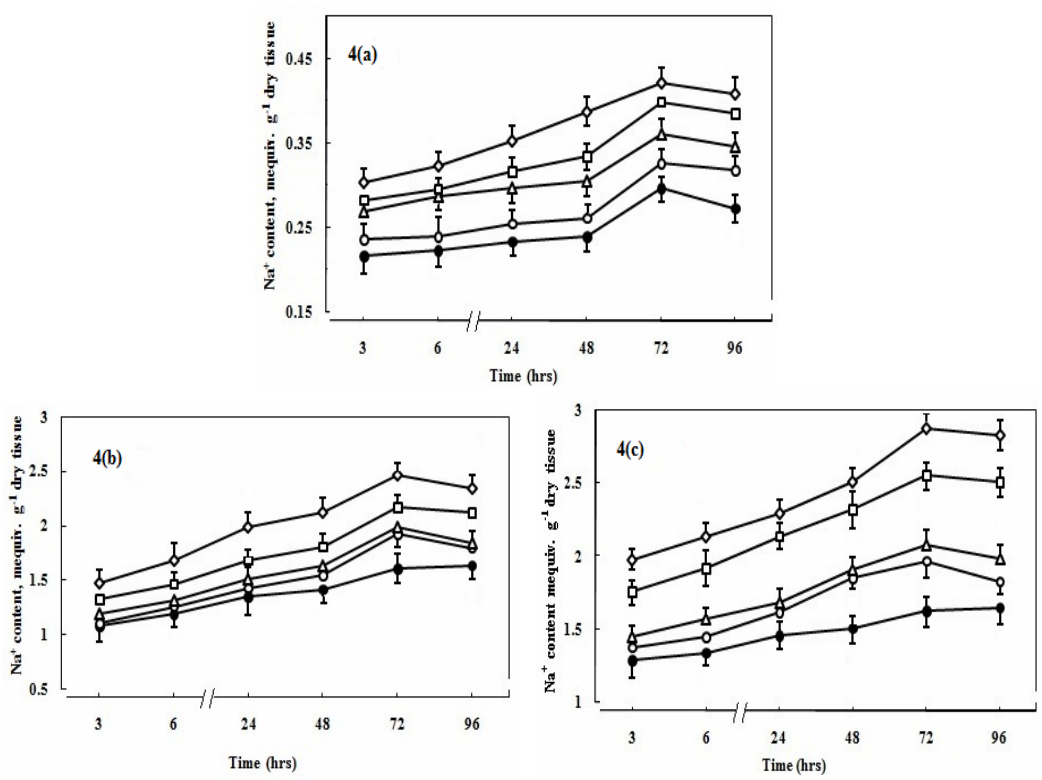

Fig. 4. The effect of different concentrations of aluminium on the accumulation of Na^+ in (a) root, (b) stem and (c) leaf of chickpea seedlings. Otherwise as Fig. 1.

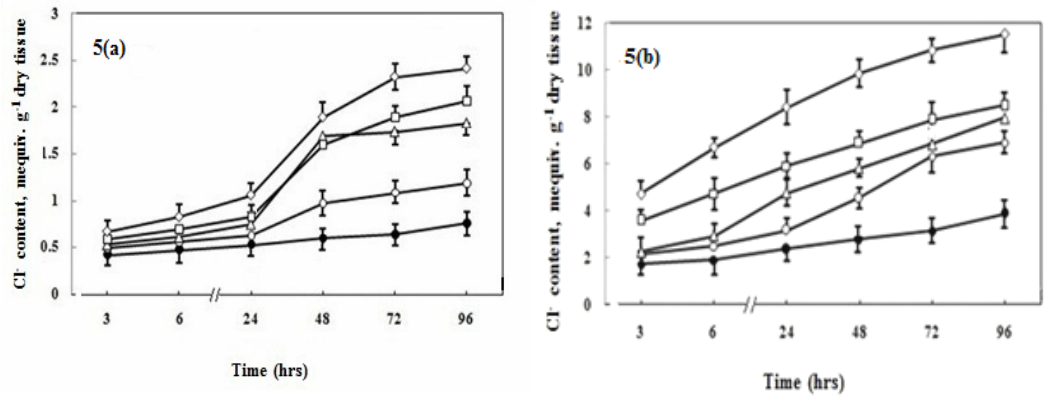

Fig. 5. The effect of different concentrations of aluminium on the accumulation of Cl^- in (a) root and (b) shoot of rice seedlings. Otherwise as Fig. 1.

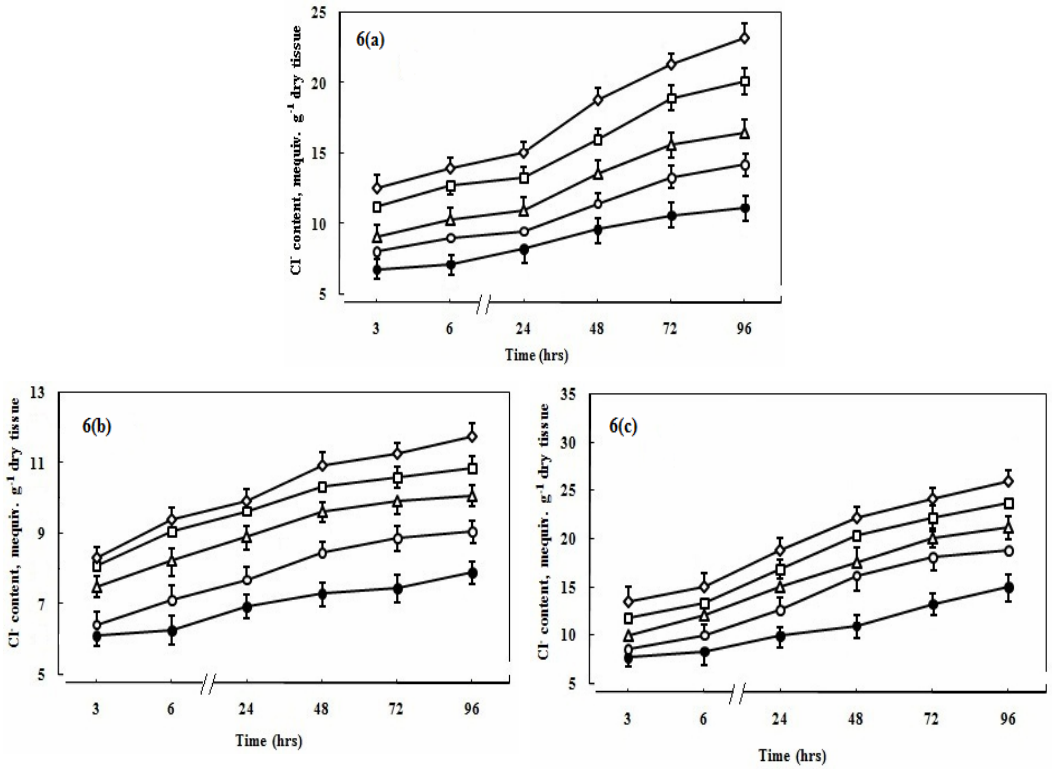

Fig. 6. The effect of different concentrations of aluminium on the accumulation of Cl^- in (a) root, (b) stem and (c) leaf of chickpea seedlings. Otherwise as Fig. 1.

In rice, the maximum inhibition of 34 to 82.8% in NO_3^- accumulation in the root was caused by 150 μM Al treatment (Fig. 7a). In shoot 50 and 100 μM Al decreased NO_3^- accumulation by 17 to 53.7 and 11.7 to 79.8%, respectively from 6 to 96 hrs of treatment (Fig. 7b).

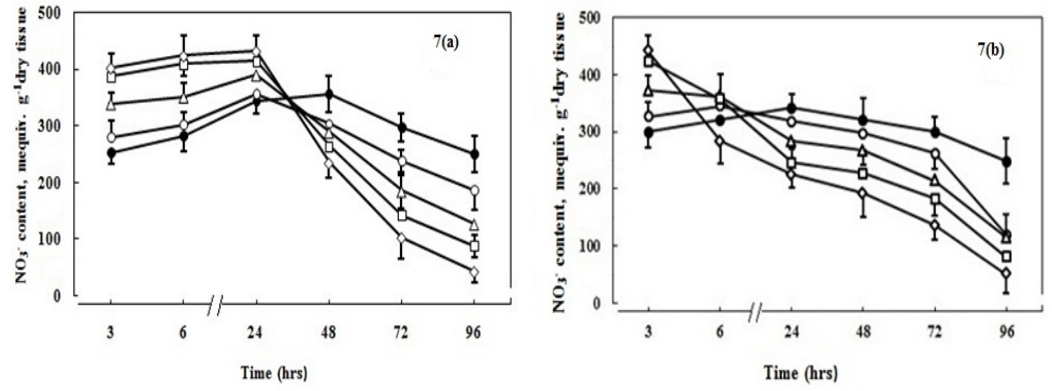

Fig. 7. The effect of different concentrations of aluminium on the accumulation of NO_3^- in (a) root and (b) shoot of rice seedlings. Otherwise as Fig. 1.

In chickpea seedlings, 10 and 100 μM Al inhibited NO_3^- accumulation in the root by 21.7 to 50 and 27 to 61%, respectively from 48 to 96 hrs of treatment (Fig. 8a). In the stem, 10, 100 and 150 μM Al decreased NO_3^- accumulation by 7.5 to 57, 26.6 to 69 and 28.8 to 76.5%, respectively from 3 to 96 hrs of application (Fig. 8b). In the leaves, all the concentration of Al (10-150 μM) decreased NO_3^- accumulation. The highest inhibition of NO_3^- in the leaves was exerted by 150 μM Al where a 37 to 77.9% reduction was recorded from 3 to 96 hrs of treatment (Fig. 8c). Similar Al-induced inhibition of NO_3^- was found in sorghum[19-20].

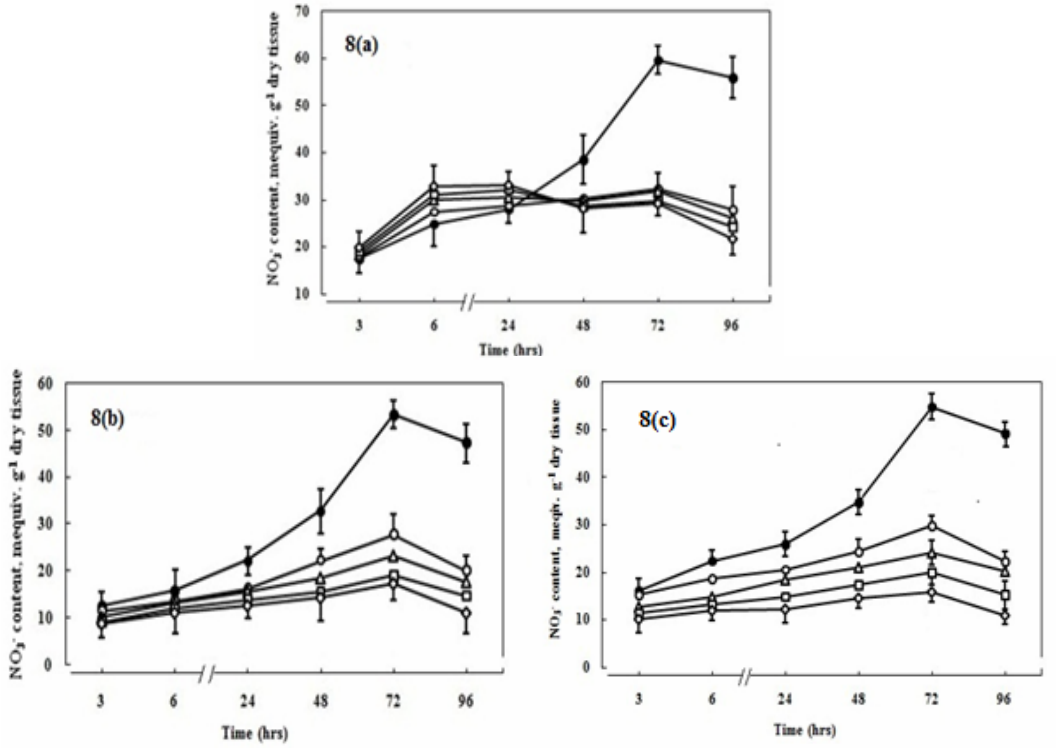

Fig. 8. The effect of different concentrations of aluminium on the accumulation of NO_3^- in (a) root, (b) stem and (c) leaf of chickpea seedlings. Otherwise as Fig. 1.

Al-induced changes in K^+/Na^+ selectivity and low level of K^+ might disrupt metabolic functions of plants. On the otherhand, Al-induced dramatic stimulation of Cl^- in rice and chickpea might be toxic for the plants.

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