

Toxicity of Heavy Metals on Germination and Seedling Growth of *Salicornia brachiata*

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Summary

Seed is a developmental stage that is highly protective against external stresses in the plant life cycle. In this study, we analyzed toxicity of heavy metals (Cd²⁺, Ni²⁺ and As³⁺) on seed germination and seedling growth in a halophyte *Salicornia brachiata*. Germination percentage for Ni²⁺ is lower than Cd²⁺ and As³⁺ metal at 200 µM concentration. Shoot length and root length decreased significantly upto 400 µM and 100 µM of Ni²⁺ and As³⁺ respectively. While in case of Cd²⁺ seedlings could survive up to 300 µM concentration with a minor reduction in growth. *Salicornia brachiata* can serve as substantially important plant species for phytoremediation of heavy metals at lower concentrations in saline areas.

Key Words: Heavy metals; halophyte; germination percentage; growth parameters

Introduction

Heavy metals and metalloids are an increasing environmental problem worldwide. Agricultural soils are contaminated with heavy metals by human-induced activities and are creating severe problems [1, 2]. The main sources of contamination in agricultural soils are fertilizer impurities (Cd²⁺), use of refuse-derived compost and sewage sludge (Cd²⁺, Ni²⁺) [3]. Cadmium ranks the highest in terms of damage to plant growth and human health. Moreover, its uptake and accumulation in plants poses a serious health threat to humans via the food chain [4]. Arsenic is of great concern due to extensive contamination and carcinogenicity. It is associated with many types of mineral deposits especially those which include sulfide mineralization [5]. Higher concentrations of essential or nonessential metal ions of Cd, Hg, Pb, Ag, As, are deleterious to metal-sensitive enzymes, resulting in growth inhibition and death of the organism [6]. In the past few years, work has started to uncover molecular mechanisms underlying the uptake and transport of some heavy metals [7]. However, it remains to be further investigated how these metal ions affect plant growth at different developmental stages.

Recently, the responses of plants to individual metal were extensively studied [8, 9]. However, in natural soil plant systems, often have to face multiple metal stresses, and the interactive effects of two or more elements should be studied [10]. Interactive effect of toxic heavy metals have been studied for Cd and As in *Solanum nigrum* [11], and Cd and Cr in *Dalbergia sissoo* [12] which adversely affected the growth, biomass and photosynthesis of these plants. Most of these studies have been conducted using adult plants [13, 14, 15, 16]. In a few studies, the seeds have been exposed to heavy metals [17, 18]. Seed is a stage in the plant life cycle that is well protected against various stresses. However, soon after imbibition and subsequent vegetative developmental

processes, they become sensitive to stress. Germinating seeds and developing seedlings are more sensitive to metal elements than mature plants, as their defense mechanisms are not yet fully developed [19].

In highly contaminated coastal saline areas the halophyte plants can be used to phytoremediate heavy metal pollution. Mangroves highly tolerant to heavy metals are restricted to brackish water only and hence serve only a limited purpose [20]. In coastal saline areas heavy metal pollution could only be remediated by using plant species capable of growing in highly saline conditions. It would, therefore, be beneficial to explore the potential of heavy metal tolerance by various halotolerant species. Reports on the concurrent behaviour of salinity and trace elements in the soil-plant system are few. Therefore, in the present study we have selected *Salicornia brachiata* Roxburgh (Amaranthaceae) for studying effect of heavy metals. *Salicornia* is highly salt-tolerant and can accumulate 30-40% NaCl in its dry weight. In this study we have explored the ability of *S. brachiata* to germinate and grow in medium containing Cd²⁺, Ni²⁺ and As³⁺ metal.

Materials and Methods

S. brachiata were collected from the salt marshes of the western coastline of Gujarat. Seeds were harvested from the dried stem of *S. brachiata* plant. During the first 2 weeks, the fresh seeds were tested for germination behavior or stored at 18°C.

Seeds of *S. brachiata* were surface sterilized with 2% sodium hypochloride for 5 min. Seeds were then washed thoroughly 4-5 times with sterilized distilled water. Seeds were then, placed on MS basal medium [21] supplemented with 200 mM NaCl. For metal treatment MS basal media was supplemented with 50-300 µM CdCl₂.H₂O, 50-800 µM

$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ and 50-300 μM NaAsO_2 (Hi-media, India) separately for each heavy metal stress. The plates were incubated for 15 days at $25 \pm 1^\circ\text{C}$ with 16 h light and 8 h dark-light cycles.

Germination was recorded every alternate day for 15 days. Germinated seeds were counted, and germination percentage, germination index and vigour index were then calculated. Each treatment consisted of 50 seeds per petri dish. Seeds with emerged radical were considered germinated. Germination percentage was calculated as germinated seeds/total seeds \times 100. Germination index was calculated as GI/Dt , where GI is the germination index, Gt and Dt are the amount of the germinated seeds and the germination time, respectively. Vigour index was determined as $\text{VI} = (\text{Mean of shoot length} + \text{Mean of root length})/\text{Germination Percentage}$. Growth traits were measured in terms of number of healthy plantlet, shoot length (cm), root length (cm) and fresh weight after 15 d of treatment.

Chlorophyll was estimated using the standard protocol [22]. Tissue for chlorophyll estimation was washed three times with deionized water and blotted on tissue paper. Plant tissue (0.1 g) was homogenized in 80% acetone and incubated in the dark for 6 h. The homogenate was centrifuged at 10,000 rpm for 10 min. The supernatant obtained was read at 645 nm, 665 nm in Spectra Max plus (Molecular Device, USA).

Each experiment was repeated three times and the mean values and standard deviations were then calculated. For all treatments, single factor ANOVA was carried out using Microsoft Excel followed by Dunnett's test. Dunnett's test was conducted by computing the t-test between the mean value of treatment and the control. Mean values higher than the Dunnett table value were considered significant in comparison to the control and marked accordingly.

Result and Discussion

Seed germination percentage, germination index and vigour index of *S. brachiata* seeds treated with heavy metals viz. Cd^{2+} , Ni^{2+} and As^{3+} are listed in Table 1. Increasing concentrations of Cd^{2+} , Ni^{2+} and As^{3+} gradually decreased germination percentage, germination index and vigour index as compared to control seeds. When seed germination is compared for Cd^{2+} , Ni^{2+} and As^{3+} at 200 μM concentrations, germination percentage for Ni^{2+} is lower than other two metals at same concentration. Further at highest concentrations of Ni^{2+} resulted in as low as 16% of seed germinated, which was significantly lower than germination percentage at highest concentration of other metals in the study. Hence, it is evident that Ni^{2+} showed great toxicity among the all metal treatments at the time of seed germination.

Total fresh weight, shoot length and root length of the *S. brachiata* seedling were recorded for Cd^{2+} (50-300 μM), Ni^{2+} (50-800 μM) and As^{3+} (50-300 μM) metals after 15 days of treatments as shown in Table 2. Seedlings could survive up to 300 μM concentration of Cd^{2+} with a minor reduction in overall growth. The fresh weight, shoot length and root length was affected significantly at all concentrations of Cd^{2+} as compared with control. For Ni^{2+} and As^{3+} treatments, plants could tolerate 400 μM and 100 μM concentrations, respectively; however, higher concentrations these metals proven to be detrimental. Ni^{2+} shown toxic effect on seedling as the concentration of Ni^{2+} increases, seedling growth were drastically reduced. Shoot length and root length were decreased significantly upto 400 μM and 100 μM of Ni^{2+} and As^{3+} respectively. There was significant change in fresh weight for both Ni^{2+} and As^{3+} treatments. Apparently, *S. brachiata* seedling showed no symptoms of chlorosis in the 50 μM concentration of Cd^{2+} treatment. However, the chlorophyll content was decreased gradually with the increasing concentrations of all three metals treatments in comparison to control seedlings.

Table 1 Effect of heavy metals on seed germination of *Salicornia brachiata*

Metal treatment	Mean \pm SE	% Germination	Germination Index	Vigour Index
Control	46.6 \pm 1.52	93.2%	3.11	304.45
Cd ₅₀	28.0 \pm 1.00*	56.0%	1.86	136.26
Cd ₁₀₀	22.3 \pm 1.52*	44.6%	1.48	81.91
Cd ₂₀₀	21.6 \pm 0.57*	43.2%	1.44	73.87
Cd ₃₀₀	15.0 \pm 1.00*	30.0%	1.00	50.1
Ni ₅₀	23.6 \pm 1.15*	47.2%	1.57	97.54
Ni ₂₀₀	16.3 \pm 0.57*	32.6%	1.08	72.48
Ni ₄₀₀	15.6 \pm 1.15*	31.2%	1.04	35.36
Ni ₈₀₀	8.0 \pm 1.00*	16.0%	0.53	0
AS ₅₀	30.6 \pm 1.52*	61.2%	2.04	78.54
AS ₁₀₀	24.3 \pm 0.57*	48.6%	1.60	43.15
AS ₂₀₀	20.6 \pm 0.57*	41.2%	1.37	0
AS ₃₀₀	13.0 \pm 1.00*	26.0%	0.86	0

*Represents the values are significantly higher/lower than control plants according to Dunnett's table

Table 2 Effect of heavy metals on growth parameters and chlorophyll content of *Salicornia brachiata*

Treatment	No. of healthy plantlet	Health	Shoot length (cm) (Mean \pm S.D.)	Root length (cm) (Mean \pm S.D.)	Fresh weight (g) (Mean \pm S.D.)	Chlorophyll ($\mu\text{g}\cdot\text{g}^{-1}$ tissue)
Control	6/6	+++	1.93 \pm 0.05	1.33 \pm 0.15	0.258 \pm 0.009	246.33 \pm 7.02
Cd ₅₀	6/6	+++	1.26 \pm 0.05*	1.16 \pm 0.05*	0.231 \pm 0.003*	238.33 \pm 3.05
Cd ₁₀₀	6/6	+++	1.00 \pm 0.22*	0.93 \pm 0.14*	0.215 \pm 0.004*	211.66 \pm 3.05*
Cd ₂₀₀	6/6	++	0.88 \pm 0.10*	0.87 \pm 0.14*	0.206 \pm 0.009*	168.00 \pm 4.00*
Cd ₃₀₀	6/6	++	0.80 \pm 0.05*	0.78 \pm 0.11*	0.199 \pm 0.009*	153.66 \pm 4.04*
Ni ₅₀	5/6	++	1.03 \pm 0.05*	1.03 \pm 0.05*	0.223 \pm 0.004*	219.09 \pm 4.00*
Ni ₂₀₀	4/6	++	1.05 \pm 0.17*	1.16 \pm 0.07*	0.181 \pm 0.004*	198.09 \pm 5.15*
Ni ₄₀₀	3/6	+	0.54 \pm 0.00*	0.63 \pm 0.12*	0.154 \pm 0.005*	152.00 \pm 4.35*
As ₅₀	3/6	++	0.53 \pm 0.05*	0.75 \pm 0.25*	0.214 \pm 0.009*	223.33 \pm 6.11*
As ₁₀₀	3/6	+	0.58 \pm 0.08*	0.96 \pm 0.05*	0.178 \pm 0.006*	175.66 \pm 11.50*

Data represent mean value of three replicates and standard deviation; *represents the values are significantly higher/lower than control plants according to Dunnett's table. +++ = Good, ++ = Average, + = Poor

It is well known that germination percentage is an important indicator used to evaluate seed quality [23]. Germination index and vigour index can reflect the germination status. Here, germination percentage, germination index and vigour index were selected to evaluate the effect of Cd²⁺, Ni²⁺ and As³⁺ on the seed germination. The study presented here showed a significant Ni-induced reduction in germination rate, fresh weight, and length of root and shoot of *S. brachiata* seedling. The results are consistent with earlier studies of various crops which have shown that higher levels of trace elements including Ni cause a significant reduction in growth parameters and other essential metabolites [24, 25]. Decrease in chlorophyll is one of the common symptoms of heavy metal toxicity in plants [26]. The reduced chlorophyll accumulation during heavy metal treatment is due to the interference of different chlorophyll biosynthesis stages.

Cd is not an essential element to plants but the contamination therewith could lead to anatomical and physiological changes [19, 27]. In this experiment seedlings could survive up to 300 μM concentration of Cd²⁺ with a minor reduction in overall growth. The fresh weight, shoot length and root length were affected significantly at all concentrations of Cd²⁺ as compared to control. Similar, results for reduction of plant fresh weight under Cd treatment was noted in *Vigna radiata* [28]. The growth inhibition produced by Cd is partially due to the effect of this heavy metal on the photosynthesis rate [29].

For As treatment, *Salicornia* seedlings could tolerate upto 100 μM concentration and higher concentrations of As³⁺ were detrimental for the seedlings. Shoot length and root length were decreased significantly upto 100 μM concentration of As³⁺. It has been reported that plants can develop toxicity symptoms while they are exposed to excess arsenic in soil such as: inhibition of seed germination [30], decrease in plant height [31, 32], reduction in root growth and decrease in shoot growth [33, 34].

Conclusion

Our findings suggest that *Salicornia* seedlings showed a similar trend of sensitivity with increasing concentrations of Cd²⁺, As³⁺ and Ni²⁺. It was also noted that Ni²⁺ showed highest toxicity among the all the metal treatments at the time of seed

germination. It is evident from this study that *Salicornia brachiata* can serve as an important plant species for phytoremediation of heavy metal at lower concentrations in saline areas.

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