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Potential of *Chromolaena odorata* for phytoremediation of ^{137}Cs from solution and low level nuclear waste

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ABSTRACT

Potential of *Chromolaena odorata* plants for remediation of ^{137}Cs from solutions and low level nuclear waste was evaluated. When plants were exposed to solutions spiked with three different levels of ^{137}Cs, namely 1×10^3 kBq L^{-1}, 5×10^3 kBq L^{-1} and 10×10^3 kBq L^{-1}, 89%, 81% and 51% of ^{137}Cs was found to be remediated in 15 d, respectively. At the lowest Cs activity (1×10^3 kBq L^{-1}), accumulation of Cs was found to be higher in roots compared to shoots, while at higher Cs activities (5×10^3 kBq L^{-1} and 10×10^3 kBq L^{-1}), Cs accumulation was more in shoots than roots. When plants were incubated in low level nuclear waste, 79% of the activity was removed by plants at the end of 15 d. The present study suggests that *C. odorata* could be used as a potential candidate plant for phytoremediation of ^{137}Cs.

1. Introduction

Radioisotope of cesium – ^{137}Cs with a half life of 30 years – is one of the main artificial radionuclides produced by nuclear fission. It is being introduced into the terrestrial environments by nuclear weapon testing, authorized discharge of nuclear waste and nuclear accidents such as the Chernobyl accident in 1986. It is readily transferred from soil to plant and through the food chain it reaches humans [1]. Hence, it is essential to effectively remove the radionuclides like ^{137}Cs from contaminated soils and solutions to reduce the radiation risk to humans.

Phytoremediation, the use of vegetation for in situ treatment of contaminants from soil and solutions is a promising technique that can deal with pollutants [2,3]. It is a cost effective and eco-friendly strategy that can compliment or replace conventional approaches. Cesium has no role in plant nutrition, but has chemical properties similar to potassium and can be taken up by plants. A potential phytoremediation crop should have the ability to accumulate radionuclides in the above ground parts. It is essential to search for plants which can efficiently take up Cs and concentrate in aerial parts.

Chromolaena odorata (L.) King & Robinson (Asteraceae, Eupatorieae), known as Siam weed, is a perennial shrub that forms dense tangled bushes and grows wild as a weed in different geographic locations. Due to its prolific and wind-dispersed seed production, the plants spread very easily in different geographic areas [4]. Earlier workers had used this plant for phytoremediation of metals such as cadmium, lead and zinc [5]. However, there is no report on potential of this plant for phytoremediation of cesium from solution as well as low level nuclear waste (LLNW). The present study was carried out to assess the potential of this plant for ^{137}Cs remediation by exposing hydroponically grown *C. odorata* plants to different activities of Cs under controlled conditions. The behaviour of the plant exposed to LLNW and the pattern of distribution of Cs in different plant parts are also presented.

2. Materials and methods

2.1. Plant material

C. odorata (L.) King & Robinson seeds were collected from BARC campus and germinated in sand and 1-month-old plantlets were grown hydroponically in Hoagland's medium for another 1 month [6]. Uniform plants were selected and used for the experiments.

2.2. Remediation of ^{137}Cs

Hydroponically grown plants were incubated with roots immersed in 50 ml of distilled water spiked with three different concentrations of ^{137}Cs (1×10^3 kBq L^{-1}, 5×10^3 kBq L^{-1} and 10×10^3 kBq L^{-1}) in 100 ml conical flasks along with one set of control under controlled conditions. The level of the solution was made up with distilled water as and when required. pH of the Cs

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solutions was 6. Initial Cs activity and activity after different time intervals were analyzed using γ-spectrometric technique with 8K multi channel analyzer (MCA) and P-type high purity germanium detector (HPGe) having resolution 2 keV with respect to γ energy of ^{60}Co at 1332 keV. Photopeak at γ energy of 661.62 keV was identified peak for ^{137}Cs estimation. MCA unit was standardized and efficiency was determined using known γ energies standard source ^{154}Eu prior to analysis. Samples were drawn out from the solution at different time intervals and analyzed for radioactivity.

2.3. Remediation of radioactivity from LLNW

Remediation of radioactive elements from LLNW using *C. odorata* plants was also assessed. LLNW was the actual waste taken from low level nuclear waste treatment plant. This waste is generated during cleaning/decontamination operations of intermediate level waste treatment facilities and needs remediation of radioactive elements from it. Initial activity (gross β,γ) in the LLNW was 20×10^4 Bq L^{-1} (200 kBq L^{-1}) with 99% of the activity contribution from ^{137}Cs (198 kBq L^{-1}). ^{90}Sr was the other radionuclide contributing to 1% of the total activity. The pH of the solution was 6.6. Elemental analysis of the waste was carried out and sodium was found to be the major constituent having concentration of 125 mg L^{-1}. The total dissolved salt of the waste solution was found to be less than 0.05% (w/v). Plants were subjected to LLNW for a period of 15 d and the activity was checked in the waste at different time periods.

Analysis of the left over solutions was carried out for radioactivity content by plancheting known volume of the samples, drying under IR lamp, followed by determination of radioactivity using GM counter. GM counter was calibrated with standard source prior to the estimation of samples. In addition, radioactivity of the leftover solutions was also estimated using γ-spectrometry technique using 8K MCA with HPGe detector.

Transfer factor (TF) was calculated for the Cs uptake in plants from Cs solutions and LLNW.

- Transfer factor (TF) = Cp/Cs.
- Cp = ^{137}Cs activity in plants.
- Cs = ^{137}Cs activity in solution/LLNW.

2.4. Distribution of activity

At the end of each experiment, plants were thoroughly washed with distilled water, separated into root and shoot, blotted dry and dried in an oven at 60 °C for 48 h. The dried plant tissues were digested in HNO_3:$HClO_4$ (5:1, v/v) to leach out the activity into the solution and analyzed for radioactivity using MCA. The parameters of the instrument were optimized having liquid standard sources (energy and efficiency correlation). Each experiment was carried out with three replicates and repeated twice. Standard error was calculated for all the data.

3. Results and discussion

3.1. Remediation of ^{137}Cs

In the present study, *C. odorata* plants were exposed to three different activities of ^{137}Cs for a period of 15 d and the plants were found to be efficient in remediating ^{137}Cs from all the concentrations tested. Plants treated with cesium have not shown any visible symptoms of toxicity. When these plantlets were exposed to lowest Cs concentration (1×10^3 kBq L^{-1}), a slow and steady decline in Cs activity in the solution was observed with increase in time period

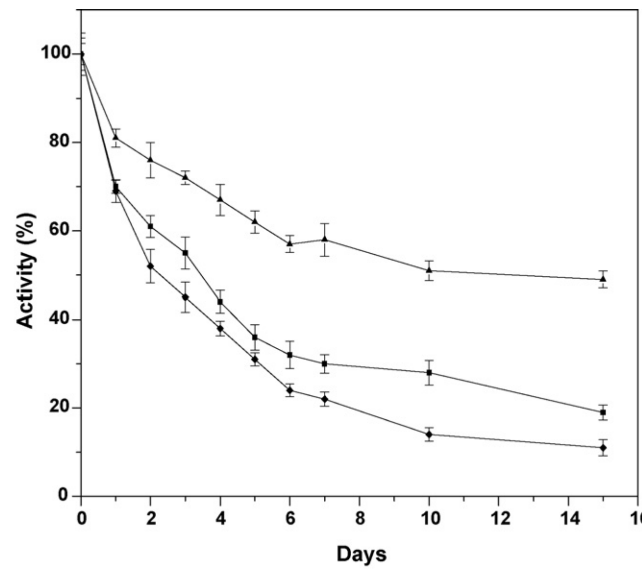

Fig. 1. Activity of ^{137}Cs in solutions after incubation with *C. odorata* plantlets for different time periods. All the values are mean of three replicates ± S.E. Initial activities of ^{137}Cs were 1.1×10^3 kBq L^{-1} (♦), 2.5×10^3 kBq L^{-1} (■) and 3.10×10^3 kBq L^{-1} (▲).

(Fig. 1). At the end of 7 d, 22% and at 15 d, 11% ^{137}Cs activity remained in the solution showing 78% and 89% remediation of the initial Cs activity on respective durations. 30% and 19% of activity remained in the solution when plants were exposed to 5×10^3 kBq L^{-1} ^{137}Cs for 7 d and 15 d, respectively. When exposed to 10×10^3 kBq L^{-1} Cs, 58% and 49% activity remained in the solution at the end of 7 d and 15 d exposures, respectively (Fig. 1). After 15 d, at 1×10^3 kBq L^{-1}, 5×10^3 kBq L^{-1} and 10×10^3 kBq L^{-1} Cs activities, transfer factor was found as 0.89, 0.81 and 0.51, respectively.

For efficient phytoremediation, screening and selection of effective accumulator plants, especially for important radionuclides like ^{137}Cs is essential. Thus, it is necessary to search for plants with high efficiency for remediation of Cs from contaminated soils and waters effectively. In the present study, *C. odorata* was found to have high potential for remediation of ^{137}Cs from solutions. Plants belonging to Chenopodiaceae such as *Beta vulgaris*, *Chenopodium quinoa*, *Salsola kali* [7–9] and Amaranthaceae such as *Amaranthus retroflexus* [10] were found as effective remediators of ^{137}Cs. In our previous reports, we have studied the pattern of radionuclide uptake in two different plants namely *Calotropis gigantea* [11] and *Vetiveria zizanoides* [12], which were exposed to ^{137}Cs and ^{90}Sr individually as well as in mixed condition (5×10^3 kBq L^{-1}) for 7 d. Both the plants were able to remediate ^{90}Sr as well as ^{137}Cs from the solutions. However, they were found to be more efficient for the remediation of ^{90}Sr than ^{137}Cs. The present studies have shown that *C. odorata* plants belonging to Asteraceae is a good remediator of ^{137}Cs from solutions. Earlier studies [13] had shown that plants belonging to Asteraceae are efficient accumulators of ^{134}Cs compared to plants such as *B. vulgaris* belonging to Chenopodiaceae, which are recognized as candidate plant for ^{137}Cs remediation from contaminated sites [14].

3.2. Distribution of ^{137}Cs in different plant parts

The distribution of Cs showed different pattern when *C. odorata* plants were exposed to different concentrations of Cs. When exposed to low levels of (1×10^3 kBq L^{-1}) Cs, roots of treated plants accumulated more Cs than shoots at the end of 15 d. However, when the plants were exposed to high levels of Cs for 15 d, higher levels of Cs were recorded in shoots than roots (Table 1). In *C. gigantea* and

Table 1
Transfer factor and distribution of ^{137}Cs in roots and shoots of *C. odorata* plantlets exposed to three different Cs activities and LLNW

Initial activity (kBq L^{-1})	Transfer factor	Roots (kBq g^{-1})	Shoots (kBq g^{-1})
Cs solution			
1×10^3	0.89	445 ± 20	356 ± 12
5×10^3	0.81	542 ± 25	702 ± 30
10×10^3	0.51	615 ± 35	962 ± 35
LLNW			
200	0.79	335 ± 18	296 ± 12

The values are mean of three replicates ± S.E.

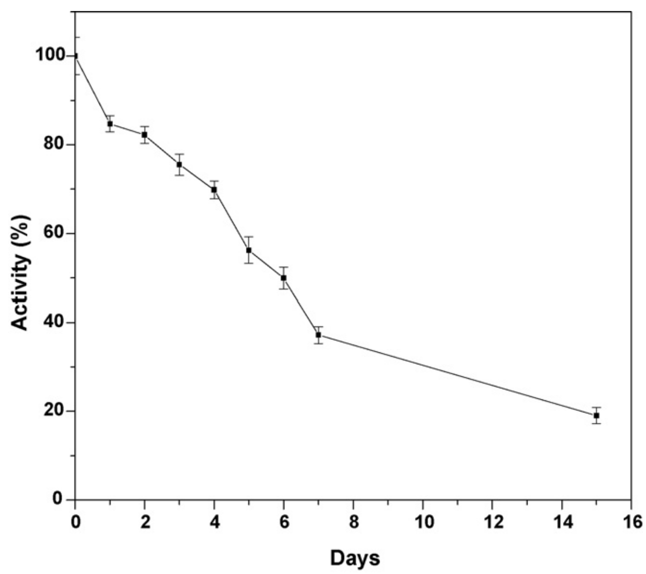

Fig. 2. Activity level in LLNW at different time intervals exposed to plants of *C. odorata*. The values are the mean of three replicates ± S.E. Initial activity (gross β,γ) in the LLNW was 20×10^4 Bq L^{-1}.

V. zizanoides exposed to 5×10^3 kBq L^{-1} ^{137}Cs [11,12], accumulation was reported to be higher in roots than shoots, while in the present study using *C. odorata*, shoots accumulated higher amounts of Cs compared to roots at this concentration. The translocation of ^{137}Cs from roots to shoots depended on the cultivation time and growth condition of the plants [15]. Few plants have shown the capability to translocate ^{137}Cs to aerial parts of the plant [10,16]. The potential *C. odorata* to translocate Cs to shoots when exposed to high concentration of cesium may make it possible to cut off the shoots contaminated with Cs, thus allowing new shoots to develop and the process to continue.

3.3. Remediation studies from LLNW

When *C. odorata* plants were exposed to LLNW, only 37% activity remained after 7 d and 21% activity at the end of 15 d showing 63% and 79% activity remediation after 7 d and 15 d, respectively from LLNW (Fig. 2). Specific radioactivity was recorded more in the roots of the plant than the shoots (Table 1). In the present study, *C. odorata* plants accumulated ^{137}Cs in roots, when plants were exposed to low levels of ^{137}Cs in solution (1×10^3 kBq L^{-1}). The LLNW used in the present study had low levels of ^{137}Cs (198 kBq L^{-1}) and at this concentration, cesium accumulated in roots. Earlier studies with *C. gigantea* exposed to LLNW (6.6×10^4 Bq L^{-1}) showed that the plant could remove all the radioactivity at the end of 15 d [11], but the levels of radioactivity was much higher in the LLNW in the present study. Similarly *V. zizanoides* plants exposed to LLNW (7.5×10^4 Bq L^{-1}) could take up almost all the activity at the end of 360 h (15 d) [12]. Since the radioactivity was higher in the present study (LLNW) using *C. odorata*, the plant could remediate only 79% of the activity at the end of 15 d. In both *C. gigantea* [11] and *V. zizanoides* [12], more activity was located in roots, which is in agreement with the present study using *C. odorata*.

4. Conclusion

A potential phytoremediation crop should have the ability to accumulate radionuclides in the above ground part and should not be eaten by herbivores. In the present study using *C. odorata* exposed to high level of ^{137}Cs, the radionuclide got translocated and accumulated in shoots, but not at lower levels. *C. odorata* grows as a weed and colonises wide geographical locations. It has extremely fast growth (upto 20 mm per day) and is toxic to livestock. The ability of *C. odorata* plants to translocate ^{137}Cs to aerial parts when exposed to high levels of ^{137}Cs in solutions along with its toxicity to livestock may make it a potential plant for remediation of this important radionuclide from solutions.

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