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Phytoremediation of Cesium and Uranium Contaminated Soils by Plants

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ABSTRACT

The main goal of this study was to investigate the accumulation and distribution of Uranium (U) and Cesium (Cs) in 30 cultivars of wheat *(Triticumaestivum L.)*, alfalfa and giant sunflower (Helianthus giganteus) for their possible use in phytoremediation. Soil samples were collected from Saghand and Bandar Abbas which are closed to uranium mining complexes. Also, loam soil was used as a blank sample for comparing results. Among these species, alfalfa samples could not grow in these soils, hence, it was removed from experiments. Moreover, influence of adding citric acid on performance of plants was investigated. Results proved that both wheat and sunflower could be used for phytoremediation, as, they showed the ability of uranium and cesium uptake. Nevertheless, sunflower was more efficient than wheat in removing uranium and cesium from soils. Moreover, outcomes from experiments ascertained that adding citric acid to soils increased bioavailability of uranium and cesium, however, concentration of citric acid should be considered. Among 0.5, 2.5 and 12.5 mM citric acid concentrations, 2.5 mM performed as the best one, since, plants showed the highest uptake at this concentration.

KEYWORDS: Phytoremediation, Radionuclides, Contaminated Soil, Plants.

1. INTRODUCTION

Nuclear power is a significant energy source; nuclear power plants delivered about 5.7% of the world's energy in 2012 [1]. Nuclear power plant disasters, such as the Chernobyl tragedy in the former Soviet Union [2] and the Fukushima Dai-ichi accident in Japan, beside with nuclear power testing [3] and the explosion of nuclear weapons [4] can lead to environmental pollution to water, air and soil, such as crop land [5]. Thus, Environmental contamination caused by radionuclides is a severe global scale problem, which its developed are associated with the growth of various industries over the last few decades. Applications for radionuclides comprise medical, agricultural and energy generation. The presence of these elements, in particular uranium and cesium can cause serious risks to human health as they can simply be incorporated in the food chain [6]. Therefore, proper management of radionuclides-contaminated environments has become an essential necessity. Uranium is the most plentiful of the naturally occurring actinides that is present in most of the continental earth's crust as a natural trace element. It occurs in numerous minerals and is also found in lignite, monazite sands, phosphate rock, and phosphate fertilizers. Furthermore, the long-lived cesium is a critical indicator of radioactive contamination in aquatic environments. Cesium in the environment derives from a variety of sources. The prime single source was result from atmospheric nuclear weapons tests in the 1950s and 1960s, which had dispersed and accumulated cesium worldwide [7].

For treatment of soils contaminated with radionuclides, different approaches are available. Remediation approaches include encapsulation, size separation, soil washing, leaching with chelating agents, electro kinetics, and ion ex- change are often very expensive, and techniques like soil washing leads to generation of liquid wastes and may notably decrease soil quality and destroy the local ecosystem [8]. However, Phytoremediation has been recommended as a promising technique for long-term remediation of uranium-contaminated soils, as this technology is cost-effective, allows for in situ treatment, does not generate liquid wastes and keeps soil properties intact. Moreover, the exposure time for workers is decreased and the contaminated site is covered by plants during treatment stage that reduces wind and water erosion [9]. Phytoremediation of contaminated sites practices plants that have an inclination for different contaminants such as heavy metals, and radionuclides [10]. These plants have genetic makeup that admits them to engage and store, degrade, or transform substances that kill or hurt other plants and animals [11].

Therefore, phytoremediation has been reported in numerous studies [12-22]. Phytoremediation has the highest performance when the contaminants are dispersed in the soil at low concentration. Radionuclides contaminating soils frequently appear at low concentration, which has fortified assessments of the decontamination potential of

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phytoremediation for radionuclides [23-26]. Cesium and uranium are present at several radionuclide-contaminated sites, and it has been proved regularly that plants can take them up from soil [27].
The main objective of this study was to investigate the accumulation and distribution of uranium and cesium in wheat (Triticumaestivum L.), giant sunflower (Helianthus giganteus) and alfalfa. These plants were chosen for their potential use in phytoremediation for radionuclide-polluted sites[17].

2. Materials and Methods

2.1. Plants

In this study, three types of plants were investigated. Alfalfa, wheat and giant sunflower were used and each of these species were bought from a local seed market (TTSA SEED). These seeds were planted at depth of 2 cm at upper layer of soil.

2.2. Soils

Soils were obtained from two different regions of Iran. One batch of soil sample was attained from Saghand and the other batch was gained from Bandar Abbas. These places are closed to uranium mining complexes, hence, it is expected that their soils contain high concentration of radionuclides. Table 1 shows characteristics of these two soils which were examined by doing X-ray fluorescence (XRF) analyzer. It shows that these soils have high concentration of uranium and cesium, therefore, they should be remediated.

Table 1. Concentration of elements in Saghand and Bandar Abbas soil.

Elements	Saghand Soil	Bandar Abbas Soil	Unit
Uranium	402	798	ppm
Cesium	100	150	ppm
Thorium	45	57	ppm
Strontium	120	114	ppm
Barium	116	133	ppm

2.3. Preparing Plants

30 plastic pots were prepared for experiments and their size were 30×30×30 cm and each of them contained 4 kg soil. 12 of them were filled with Saghand soil and 12 of them were filled with Bandar Abbas soil and rest of them were seeded by loam soil. These loam samples were used as an indicator to compare other samples.
In four pots which had Bandar Abbas soil seeds of sunflower, in four pots seeds of wheat and in four pots alfalfa seeds planted in depth of 2cm at the topsoil. This process was applied for Saghand soil, too. For the loam, alfalfa, wheat and sunflower seeds were planted in two pots each one, respectively. All pots were stored in the greenhouse and blue and red lamps were installed in order to simulate sunlight. The samples were in this condition for 18 hours. 150cc water added to each pot twice a day and temperature was controlled (20 to 25°C) with approximately 75% humidity. Soils have a low percentage of organic matter (less than half), thus, NPK fertilizer was added to pots after germination of seeds each 15 days. Characteristics of NPK is illustrated in table 2. Figure 1 elucidates pots after one week.

Figure 1. seeds after one-week planting

Table 2. Characteristics of NPK fertilizer

Components	Percentage of Composition
Nitrogen	20
Phosphor	5.6
Potassium	4
Urea	10.4
Phosphorus in aqueous solution	20
Potassium in aqueous solution	20
Boron in aqueous solution	0.02
Copper	0.005
Iron	0.07
Manganese	0.03
Zink	0.01

Trend of growth were investigated weekly and after one month it was delineated that alfalfa could not grow in these soils, as there was no germination sign and experiments were not applied on it. After one month, 100 cc citric acid 0.5, 2.5 and 12.5 mM were added to 2 pots, twice in one week. No acid was added to other pots as the goal was to evaluate effect of adding citric acid on performance of plants. Figures2and 3 show samples after two and five weeks.

Figure 2. Seeds after two weeks.

Figure 3. Plants after five weeks.

2.3. Experiment Method

After five weeks, plants were removed from pots and stored in the greenhouse for drying. For dry weight calculation, the samples were kept in oven at 70 °C for 24 hours. Then, they were retained at 550 °C for 3 hours and their ashes were collected. Afterwards, 20 cc of solution which contained 3:1 nitric acid to hydrochloric acid and 1 mg ash of each sample were solved in this solution. For enhancing solving process, this experiment implemented on heater for one hour and this method continued till acids were evaporated. Eventually, concentration of radionuclides were measured by plasma atomic emission spectrophotometry (ICP-AES).

3. RESULTS AND DISCUSSION

3.1. Growth Rate

All samples were examined weekly and the plants size were measured during weeks. Figure 4demonstrates length of stems belonged to wheat specie in various soils. It shows that growth of wheat in Saghand soil was fairly less than Bandar Abass soil. On the other hand, wheat has grown in loam soil much better and it implies that plants growth in radionuclides contaminated soil would decrease.

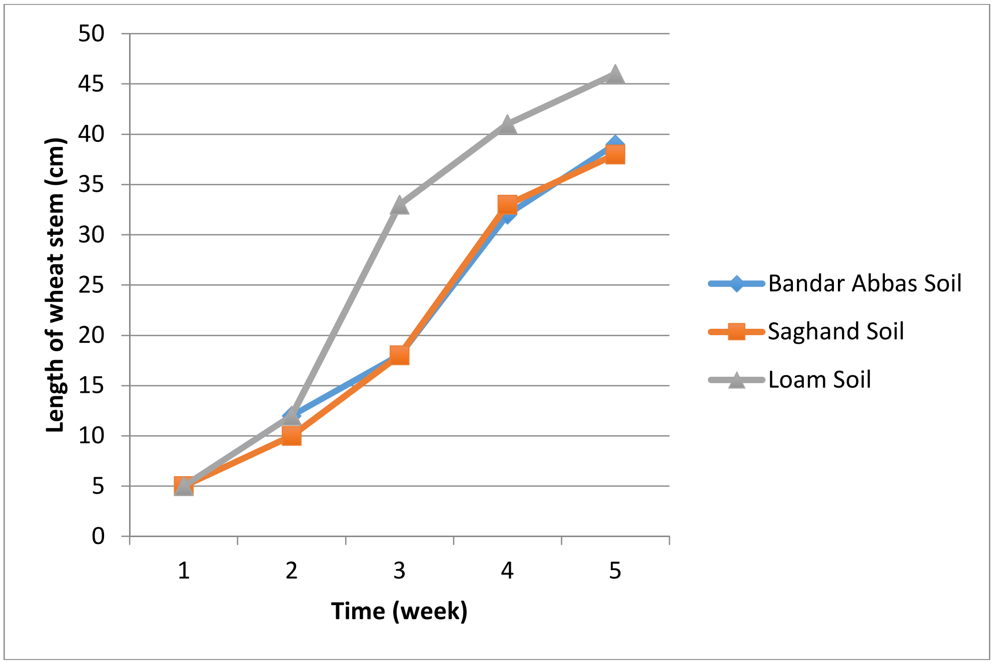

Figure 4. Growth rate of wheat in different soils.

Also, the same method was applied for sunflower and its results are shown in figure 5. It can be inferred that presence of radionuclides did not have a significant influence on growth of sunflowers, since, growth rate in Saghand soil after five weeks even is higher than loam soil.

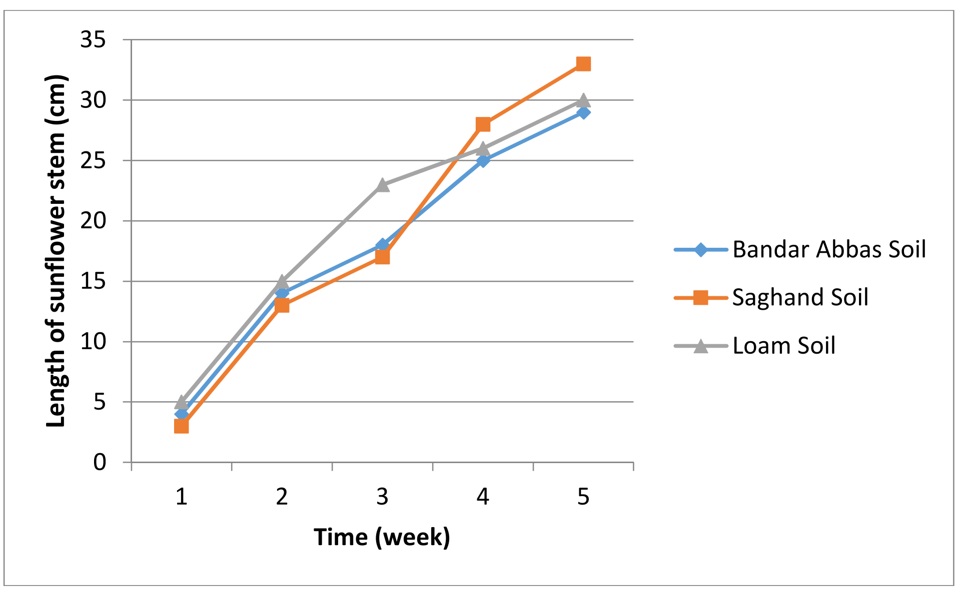

Figure 5. Growth rate of sunflower in different soils.

3.2. Plasma Atomic Emission Spectrophotometry

For evaluating concentration of radionuclides in plants, plasma atomic emission spectrophotometry model Optima 7300 DV was used. Figure 6 shows cesium uptake by wheat in Saghand soil in different concentration of citric acid. By comparing results, it can be deduced that highest uptake has occurred in 2.5 mM citric acid concentration and increasing content of the acid had a significant negative influence on affecting cesium by wheat, since, it decreased less than a sample without having citric acid. Uranium uptake by wheat in Saghand soil is illustrated in figure 7. It shows that increasing concentration of citric acid would intensify uranium wheat uptake. Furthermore, figures 8 and 9 display cesium and uranium uptake by wheat in Bandar Abbas soil. For wheat, rising concentration of citric acid till 2.5 mM had a proper affect on cesium uptake efficiency, however, increasing from 2.5 to 12.5 mM had a negative influence. In contrast, rising the acid concentration in the soil had a positive affect on wheat uptake of uranium.

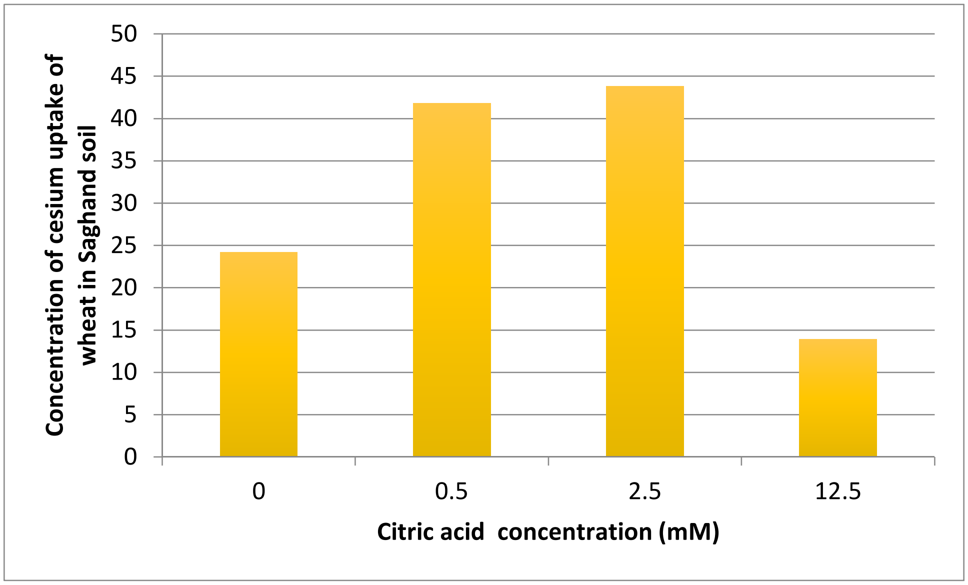

Figure 6. Concentration of cesium uptake of wheat in Saghand soil

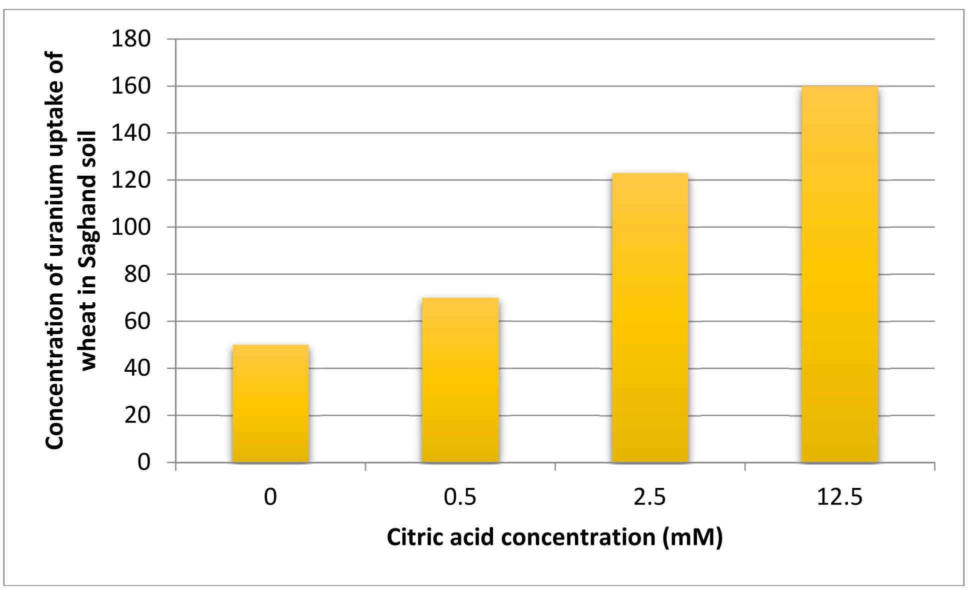

Figure 7. Concentration of uranium uptake of wheat in Saghand soil

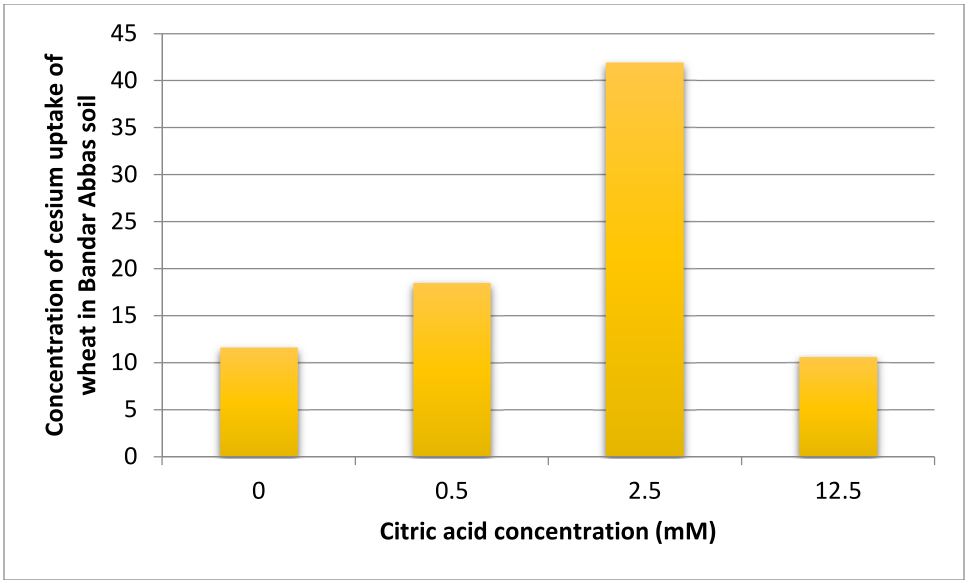

Figure 8. Concentration of cesium uptake of wheat in Bandar Abbas soil

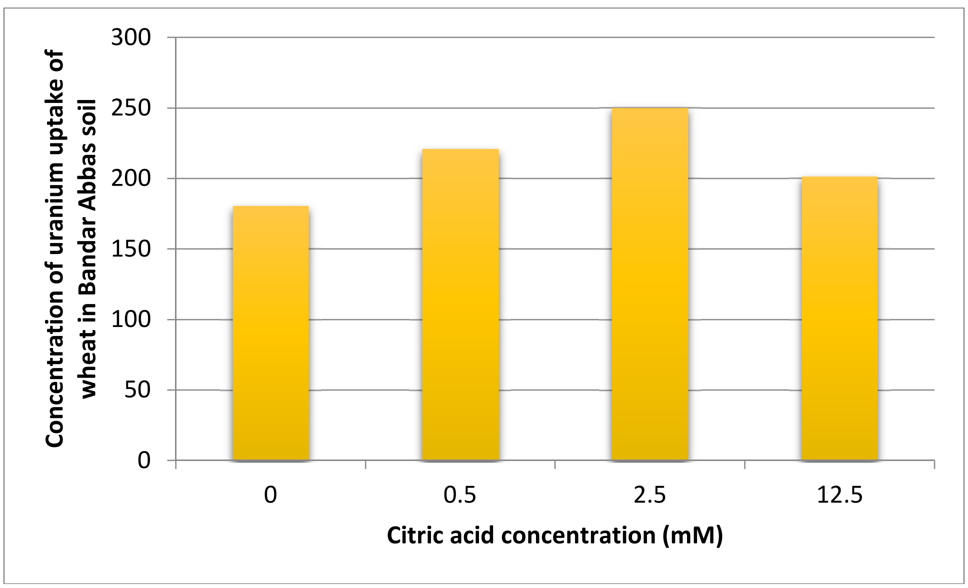

Figure 9. Concentration of uranium uptake of wheat in Bandar Abbas soil

Now, results of sunflower uptake in Saghand and Bandar Abbas soils are presented. Figure 10 presents concentration of cesium in sunflower which planted in Saghand soil. The highest uptake at 2.5 mM concentration took place. Results of uranium uptake by sunflower in Saghand soil is demonstrated in figure 11. Similar to uptake of cesium, highest uranium concentration is detected in a sample which had 2.5 mM citric acid. At 0.5 mM citric acid, uranium uptake was 136.71 ppm and it increased till 147.9 ppm at 2.5 mM citric acid, then, it decreased to 141.01 ppm at 12.5 mM citric acid concentration. Figure 12 reflects results of cesium uptake by sunflower in Bandar Abbas soil. The best result was detected at 2.5 mM citric acid again. Outcomes of uranium uptake by sunflower in Bandar Abbas soil is presented in figure 13. Uranium uptake at 2.5 mM citric acid is 251.01 which is much higher than samples without or 0.5 mM citric acid. It shows that adding citric acid to samples would have a great effect on bioavailability of uranium and plant uptake would increase significantly.

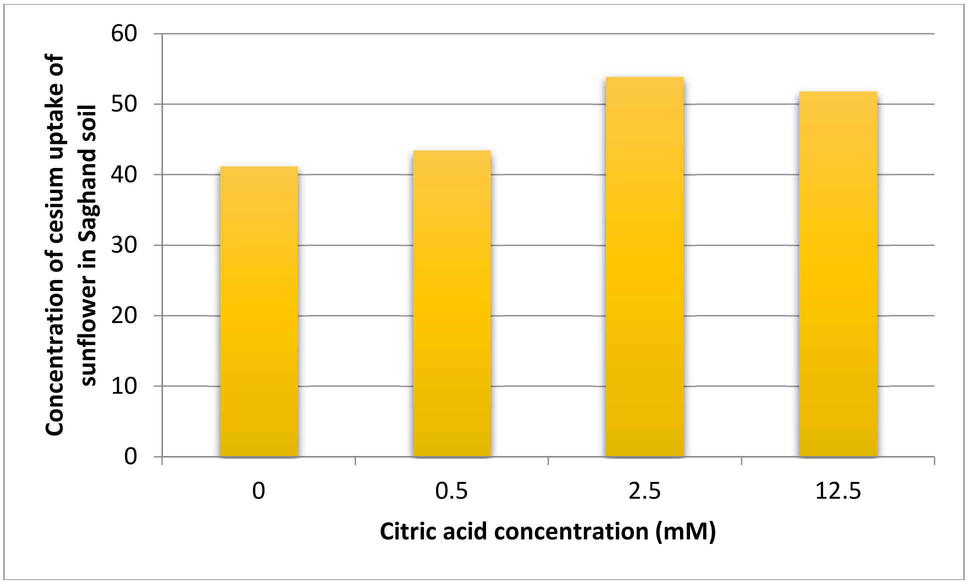

Figure 10. Concentration of cesium uptake of sunflower in Saghand soil

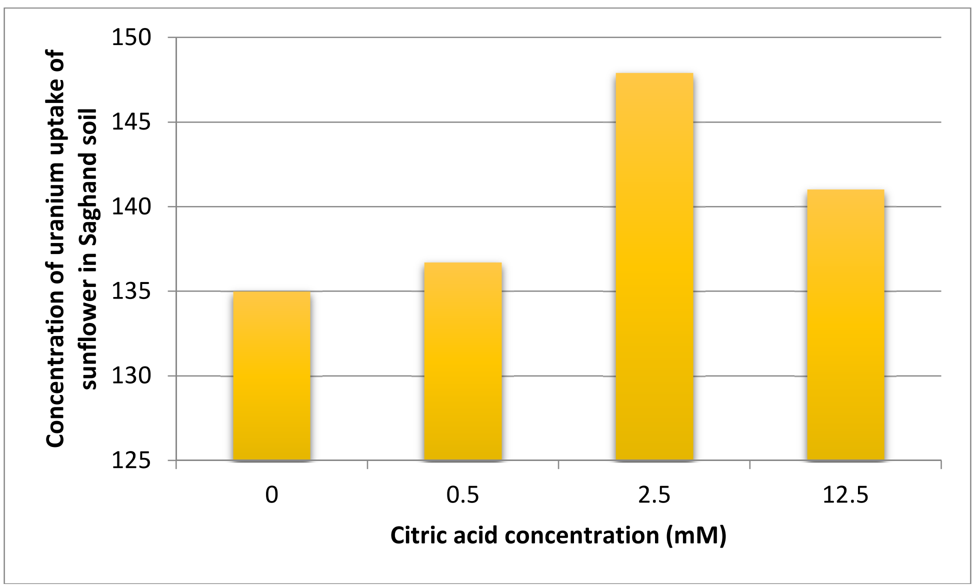

Figure 11. Concentration of uranium uptake of sunflower in Saghand soil

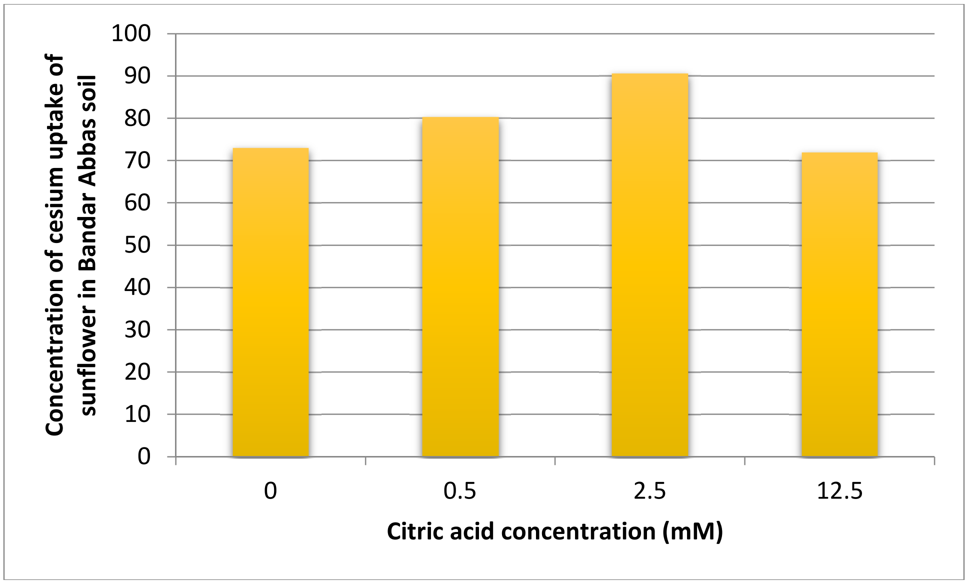

Figure 12. Concentration of cesium uptake of sunflower in Bandar Abbas soil

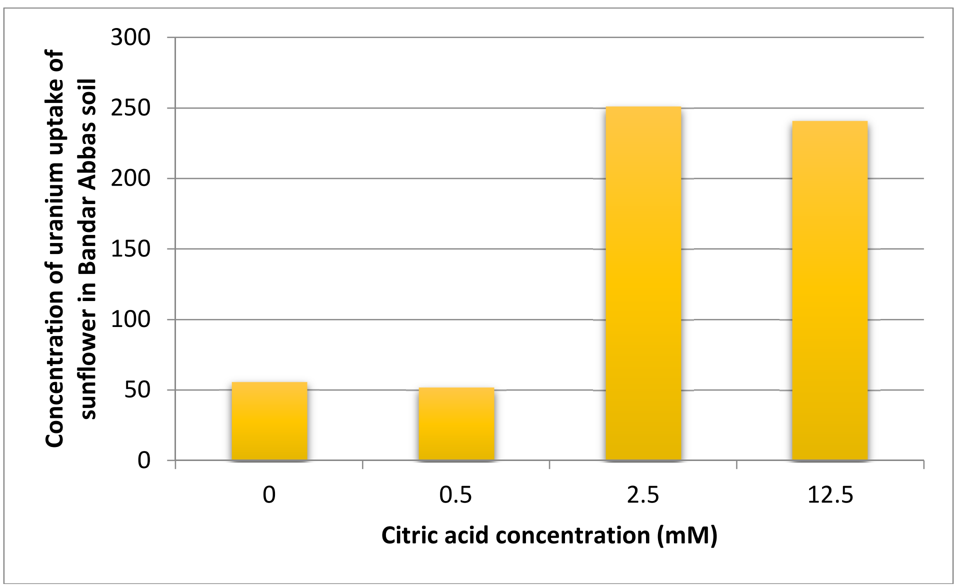

Figure 13. Concentration of uranium uptake of sunflower in Bandar Abbas soil

4. **Conclusion**

In this study, potential effect of phytoremediation on uranium and cesium was investigated. In this regard, alfalfa, wheat (Triticumaestivum L.) andgiant sunflower (Helianthus giganteus) seeds were planted in Bandar Abbas and Saghand soils. These soils have a high concentration of radionuclides, as they were located near uranium mining complexes. According to literature, adding citric acid could increase bioavailability of uranium uptake. Therefore, citric acid in different concentrations were added to some samples and in this way, consequence of adding citric acid was explored. It can be concluded that wheat and sunflower have an ability to remediate uranium and cesium, as they could uptake uranium and cesium. However, alfalfa samples could not grow in these soils so they were removed from experiments. In addition, results proved that adding citric acid has a significant effect on uranium and cesium uptake, nevertheless, it should be considered that excessive citric acid had a negative influence on radionuclides. Among citric acid concentrations, 2.5 mM had the optimist effect on wheat and sunflower. Between these two species, sunflower showed a better performance than wheat for uranium and cesium uptake in Saghand and Bandar Abbas soils. Therefore, sunflower can be used as an apt plant for remediating uranium and cesium.

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