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# Phytoextraction Ability of *Amaranthus mangostanus* L. from Contaminated Soils with Cs or Sr

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## Abstract

The uptake, distribution, and accumulation of $^{133}Cs$ and $^{88}Sr$ with its antioxidant responses in *Amaranthus mangostanus* L plants was studied during cultivation in outdoor potted-soil. The results showed that the uptake capacity of *Amaranthus* for $^{133}Cs$ was higher than that for $^{88}Sr$ at the same molarity treatment where the concentration of $^{88}Sr$ or $^{133}Cs$ in the soil was from 0.1 mmol/kg to 5 mmol/kg. The maximum $^{133}Cs$ and $^{88}Sr$ uptake of total plant was 3535.2 mg/kg dw and 639.4 mg/kg, respectively. Amaranth had much stronger capacity for absorbing $^{133}Cs$ than for $^{88}Sr$. The $^{133}Cs$ BCF of amaranth above-ground part and its total plant at the different concentrtion treatments in the soil was higher than for the $^{88}Sr$ BCF except at the 0.1 mmol/kg treatments. The TF was lower in the lower concentration (0.1 and 0.5 mmol/kg) than that in the higher concentration of $^{133}Cs$ and $^{88}Sr$ in the soil (1 and 5 mmol/kg). Amaranth could be used as a potential candidate plant for phytoremediation of $^{137}Cs$ and $^{90}Sr$. The MDA content under $^{88}Sr$ stress was higher than that under $^{133}Cs$ stress, and the activities of CAT under $^{88}Sr$ stress were less than that under $^{133}Cs$ stress.

**Keywords:** Amaranth; Uptake; Accumulation; $^{133}Cs$; $^{88}Sr$; Phytoextraction

## Introduction

The radionuclides comging from nuclear test or nuclear accident are the main potential nuclear pollutants for environment and are widely paid attention to the phytoremediation technology of radioactive pollution can achieve the goal of clearing radionuclides, remediating or controling contaminated soils. It has many merits, such as low investment, low maintenance cost, convenient manipulation, no the second-time contamination, safety and the function of beautifying the environment [1-4]. The phytoextraction and remediation technology of contaminated soils with low-radioactive nuclides is the popular issues now, and it is considered to be cost-effective for cleaning up sites contaminated with low levels of long half-life radionuclides [5-7]. The selection of hyper accumulators for the different nuclides or metals, their uptake ability and accumulation capacity for the radionuclides is the most important factors which influence the remediation efficiency. Problems such as how to screen a series of plants with appropriate biological characteristics that can rapidly accumulate significant quantities of radionuclides, and how to find a way to enhance the bioavailability of radionuclides to the plants, should be addressed [8-11]. The contamination of soil with $^{90}Sr$ and $^{137}Cs$ has long-term radiological and health impacts due to their long half-lives and chemical similarities with two essential elements required for plant growth, $Ca^{2+}$ and $K^{+}$, respectively [12-14]. Some research reported that the $^{88}Sr$ and $^{134}$ Cs uptake ability of plant from the soil was the same with their $^{90}Sr$ and $^{137}Cs$ uptake ability as the stable isotopes of $^{137}Cs$ and $^{90}Sr$. $^{133}Cs$ and $^{88}Sr$ can imitate the migration and distribution of $^{137}Cs$ and $^{90}Sr$ in the plant soil system very well [15,16]. *Amaranthus mangostanus* L. was chosen as the research material in this experiment to investigate its characteristics of uptake, transportation, and accumulation and its physiological mechanism in $^{133}Cs$ and $^{88}Sr$ polluted soils, and also to lay some theoretical foundations for phytoremediation of soil contamination with radionuclides.

## Materials and Methods

### Plant material and treatment

The experiment was carried out with outdoor potted plants in the lab block of life science in Southwest University of Science and Technology(SWUST) in Mianyang, Sichuan (E=104°42', N=31°32', elevation: 462 m). The soil in the experiment was yellow earth, coming from the nursery in the garden center of SWUST. The pH of the soil in $H_2O$ and KCl were measured with a pH meter. The soil organic matter was measured by using the Tyurin's method; each gram of grinded and sieved soil was mixed even with 5 ml deionized water, and the electrical conductivity of the soil was measured with a conductivity meter after it was static. The main physical and chemical characteristics of the soil were: pH in $H_2O$:7.06, pH in KCl: 6.18, Organic matter: 1.35%, Electrical conductivity: 1.25 ms/cm.

Each pot (diameter 25 cm, height 20 cm) was put into 4.5 kg of soil and some calcium superphosphate and clean water was sprayed before sowing. The plants of *Amaranthus mangostanus L* were transplanted into each treatment group when the plant had 5-6 leaves. There were 3 plants for each pot, 3 pots for each treatment, with three replications. Since the radionuclides were set on the soil surface by sedimentation and enters the inside with the time being, $^{133}CsCl$ or $^{88}Sr(NO_3)_2$ solution was sprayed separately and evenly on the soil surface of each pot based on the concentrations in Table 1 in the next day after transplanting. The treatments of $^{133}Cs$ and $^{88}Sr$ were divided into two groups.

The plants were watered regularly during the experiment and maintained a field water capacity of 70%. The management level for each treatment field was the same when maturation the plants were harvested to be measured.

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| Treatment elements | Treatment | | | | |
|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 |
| $^{133}$Cs mmol/kg | 0 | 0.1 | 0.5 | 1 | 5 |
| $^{133}$Cs mg/kg | 0 | 13.29 | 66.45 | 132.91 | 664.50 |
| $^{88}$Sr mmol/kg | 0 | 0.1 | 0.5 | 1 | 5 |
| $^{88}$Sr mg/kg | 0 | 8.762 | 43.81 | 87.62 | 438.10 |

Note: 0 is the control. Each treatment consisted of three replications.

**Table 1:** Concentration of $^{133}$Cs and $^{88}$Sr in the soil.

### Measuring the physiological and biochemical indexes

The leaves from the plants were taken away and each physiological index was measured after harvesting. The MDA content was measured with the TBA colorimetry [17]. The total chlorophyll content was measured at 652 nm with 95% ethanol colorimetry and calculated [17]. The activity of CAT was measured with the ultraviolet absorption method [17]. The activity of the POD and SOD was measured with Li's method [17]. The experiment results were the average values of three repeated tests.

### Measuring the $^{133}$Cs and $^{88}$Sr contents

The plants of *Amaranthus mangostanus L* were harvested after maturation and divided into two parts, viz. roots or above-ground parts. The weeds and stones in the air-dried amaranth plant sample were removed and passed through 2 mm sieve, then rinsed in deionized water. They were dried to a constant weight in an oven and then measured for dry weight. Different parts of plants were pulverized with a stainless steel blade. The sample plants were washed with distilled water, weighed exactly 0.5 g after-sample and placed in the conical flask, in addition, 10 mL acid mixture (volume ratio of nitric acid: perchloric acid was 3:1) was added to it. Having been covered for an overnight, the liquid samples were washed into the Kjeldahl flask and dispelled on the electric stove until it began to give out white smoke. The digestive juice was colorless and transparent. It was kept into the constant volume of 50 ml with 0.5 mol/ L nitric acid. The graphite furnace atomic absorption spectroscopy (AA700, Perkin Elmer Company, USA) was used to measure the content of $^{133}$Cs and $^{88}$Sr.

### Measuring the biomass

The whole plants were used for biomass measurement after harvesting. The plant samples were washed with distilled water and separated into the above-ground parts and the root parts with scissors. Firstly, samples were air-dried in cool and well-ventilated places, then were oven dried (68℃ ± 2℃, 24 h). The dry weight of each part was weighed to calculate the biomass.

### Determination of the TF value and CF

TF (transfer factor) refers to nuclide content in the above-ground parts/nuclide content in the root parts. BCF (concentration factor) refers to nuclide content in the above-ground parts or total plant/ nuclide content in the soil.

### Data analysis

Microsoft Excel 2003 (U.S, Microsoft), DPS3.1 Software (China), and the Origin 6.0 mapping software (U.S., Microcal) were used for data analysis. All detecting data were repeated three times, and results were expressed in the mean ± standard deviation (Mean ± SD) form.

## Results

### The $^{133}$Cs or $^{88}$Sr absorption and distribution in amaranth

The $^{133}$Cs or $^{88}$Sr contents in the plants were measured after harvesting and the results were shown in Table 2.

It can be found from the Table 2 that the content of 133Cs and 88Sr in the control plants was smaller than the minimum detectable amount. The total contents of $^{133}$Cs in the plant rose with the increase of the $^{133}$Cs concentration in the soil and there were very significant differences between all the treatments ($p<0.01$). The highest $^{133}$Cs content of total plant was 3535.2 ± 150.5 $\mu g.g^{-1}$ dw, which was in the 5 mmol/kg treatment. The $^{133}$Cs content in the above-ground parts of the plant was rising with the increase of the $^{133}$Cs concentration in the soil and there were also very significant differences between all the treatment ($p<0.01$), too. The $^{133}$Cs content in the 5 mmol/kg treatment was the highest, which was 1820.1 ± 170.1 $\mu g\ g^{-1}$dw. The variation trend of the $^{133}$Cs content in the root part was the same with as that in the above-ground part. It showed that $^{133}$Cs concentration in the soil was the most important factor which affected the $^{133}$Cs content in the plant of *Amaranthus*. The $^{88}$Sr distribution and transportation were the same trend as they were in the $^{133}$Cs treatment. The highest $^{88}$Sr contents of all the plant was 639.4 ± 21.9 $\mu g.g^{-1}$ dw, which was in the 5 mmol/kg treatment, too.

The $^{133}$Cs or $^{88}$Sr contents in the above-ground part was lower than it in the root in 0.1mmol/kg and 0.5mmol/kg treatment and the number of their transfer factor (TF) were lower than 1. In the high level trearment (1mmol/kg and 5mmol/kg), however, the situations were opposite and the number of their TF was higher than 1. It showed that the $^{133}$Cs or $^{88}$Sr could be transported easily from the root to the above-ground parts when the $^{133}$Cs concentration in the soil was high. The TF of $^{133}$Cs or $^{88}$Sr in amaranth was similar.

BCF (concentration factor) can reflect the nuclide or heavy metal phytoextraction ability of plant from the soil. The Table 2 showed that the amount of $^{133}$Cs or $^{88}$Sr BCF trend of amaranth above-ground and its total plant was similar, which declined with the rise of $^{133}$Cs or $^{88}$Sr concentration in the soil., which indicated that it was more dificulty to extrat $^{133}$Cs or $^{88}$Sr from the soil in the higher concentration treatment by the amaranth than in the lower concentration. Except in the 0.1 mmol/kg treatment, $^{133}$Cs BCFs of above ground and total plant was higher than the BCFs of $^{88}$Sr which means the $^{133}$Cs phytoextraction ability were higher than $^{88}$Sr phytoextraction ability of amaranth in the higher $^{133}$Cs or $^{88}$Sr concentration in the soil. But in the 0.1 mmol/kg $^{133}$Cs or $^{88}$Sr treatment, the $^{133}$Cs or $^{88}$Sr CF of total plants was 21.69 and 28.29, respectively. The $^{133}$Cs phytoextraction ability was lower than $^{88}$Sr phytoextraction ability of amaranth.

### Effects of $^{133}$Cs or $^{88}$Sr on the growth and biomass distribution of amaranth

The biomass of the amaranth plants was measured after harvesting, and the results were showed in Table 3. It can be found from the Table 3 that the difference of total biomass was not significant to the control in the low $^{133}$Cs concentration treatments (0.1 and 0.5 mmol/kg), while in the high concentration treatments (above 1 mmol/kg), it was significantly lower than the control and the low concentration treatments. The treatments of different $^{133}$Cs concentrations had the same trends of effects on the above-ground and root biomass of the amaranth plants.

For different concentrations of $^{88}$Sr treatments, the above-ground,

| | Treatment (mmol) | Treatment mg/kg | Contents of above ground μg/g.dw | Contents of roots μg/g.dw | Contents of total plant μg/g. dw | TF | BCF of aboveground | BCF of total plant |
|---|---|---|---|---|---|---|---|---|
| $^{88}$Sr | 0 | - | - | - | - | - | - | - |
| | 0.1 | 8.76 | 119.2 ± 4.3dD | 128.6 ± 2.1dD | 247.8 ± 3.3dD | 0.93 | 13.61 | 28.29 |
| | 0.5 | 43.81 | 158.4 ± 12.1cC | 161.4 ± 36.3cC | 319.8 ± 24.2cC | 0.98 | 3.62 | 7.30 |
| | 1 | 87.62 | 217.6 ± 13.4bB | 201.4 ± 18.6bB | 419.0 ± 15.5bB | 1.08 | 2.48 | 4.78 |
| | 5 | 438.1 | 382.7 ± 25.2aA | 256.7 ± 16.4aA | 639.4 ± 21.9aA | 1.49 | 0.87 | 1.46 |
| $^{133}$Cs | 0 | 0 | - | - | - | - | - | - |
| | 0.1 | 13.92 | 128.4 ± 24.1dD | 173.5 ± 6.9dD | 301.9 ± 15.0dD | 0.74 | 9.22 | 21.69 |
| | 0.5 | 66.45 | 455.3 ± 22.3cC | 473.2 ± 11.6cC | 928.5 ± 17.6cC | 0.96 | 6.85 | 13.97 |
| | 1 | 132.91 | 913.6 ± 32.7bB | 753.4 ± 29.7bB | 1667.0 ± 31.1bB | 1.21 | 5.67 | 12.54 |
| | 5 | 664.50 | 1820.1 ± 170.1aA | 1715.1 ± 130.8aA | 3535.2 ± 150.5aA | 1.06 | 2.74 | 5.32 |

Note: Results represent means ± SD. Different small letters represents significant difference at p=0.05 level. Different capital letters represents significant difference at p=0.01 level. "-" means the item could not be detected.

**Table 2:** The uptake and distribution of $^{133}$Cs or $^{88}$Sr in amaranth.

| Treatment (mmol/kg) | $^{133}$Cs treatment(g dw plant$^{-1}$) | | | $^{88}$Sr treatment(g dw plant$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Above-ground part | Root part | Total biomass | Above-ground part | Root part | Total biomass |
| 0 | 11.28 ± 0.30a | 1.83 ± 0.18a | 13.11 ± 0.22a | 11.28 ± 0.30a | 1.83 ± 0.18a | 13.11 ± 0.24a |
| 0.1 | 11.32 ± 0.38a | 1.89 ± 0.06a | 13.21 ± 0.22a | 11.03 ± 0.09a | 1.57 ± 0.13ba | 12.60 ± 0.11b |
| 0.5 | 11.52 ± 0.48a | 1.83 ± 0.06a | 13.35 ± 0.25a | 9.66 ± 0.40b | 1.32 ± 0.13b | 10.98 ± 0.27c |
| 1 | 9.88 ± 0.41b | 1.73 ± 0.07b | 11.61 ± 0.24b | 8.78 ± 0.23bc | 1.27 ± 0.12bc | 10.05 ± 0.18c |
| 5 | 8.58 ± 0.42b | 1.71 ± 0.06b | 10.29 ± 0.24b | 7.63 ± 0.20c | 1.14 ± 0.05c | 8.77 ± 0.13d |

Note: Different lowercase letters represents significantly different (p<0.05).

**Table 3:** Effects of $^{133}$Cs and $^{88}$Sr stresses on the biomass and the biomass distribution in amaranth.

| Treatment (mmol/kg) | $^{133}$Cs Treatment | | | | | | $^{88}$Sr Treatment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | concentration in the soil(mg/kg) | concentration in the plant (mg.kg$^{-1}$ dw) | Biomass of total plant g/ plant | Contens in the plant (mg)/plant | Contents in a pot (mg)/pot | Ratio of Contens in the plant\ Contents in a pot (%) | concentration in in the soil(mg/kg) | concentration in in the plant (mg.kg$^{-1}$ dw) | Biomass of total plant g/ plant | Contens in the plant (mg)/ plant | Contents in a pot (mg)/pot | Ratio of Contens in the plant\ Contents in a pot (%) |
| 0 | 0 | - | 13.107 | - | - | - | - | - | 13.107 | - | - | - |
| 0.1 | 13.29 | 300.21 | 13.210 | 3.97 | 59.81 | 19.91 | 8.762 | 250.26 | 12.600 | 3.15 | 39.429 | 23.97 |
| 0.5 | 66.45 | 930.34 | 13.347 | 12.42 | 299.02 | 12.46 | 43.81 | 320.13 | 10.983 | 3.51 | 197.145 | 5.35 |
| 1 | 132.91 | 1660.15 | 11.613 | 19.29 | 598.10 | 9.68 | 87.62 | 420.47 | 10.047 | 4.22 | 394.29 | 3.21 |
| 5 | 664.50 | 3540.32 | 10.293 | 36.45 | 2990.25 | 3.66 | 438.10 | 570.35 | 8.770 | 5.00 | 1971.45 | 0.76 |

**Table 4:** The $^{133}$Cs and or $^{88}$Sr extraction efficiency of amaranth.

root and total biomass all decrease with the increase of the $^{133}$Cs concentration in the soil and there were significant difference (p<0.05) except between the 0.5 and 1 mmol/kg treatment. It could be found that high concentrations of $^{88}$Sr had stronger effect on the biomass of amaranth than that of $^{133}$Cs stress.

Table 3 also demonstrates the biomass distribution of the above-ground and root parts of amaranth. The results showed that the $^{133}$Cs or $^{88}$Sr treatment had no significant influence on the proportion of biomass of above-ground parts and root parts to the total biomass. The biomass of above-ground parts took up 82-88% of the total biomass. The biomass of root parts took up 12-18% of the total biomass. It was universal that the biomass of the roots was lower than that of the above-ground parts.

## The $^{133}$Cs or $^{88}$Sr extraction efficiency of the amaranth

The $^{133}$Cs or $^{88}$Sr extraction efficiency of amaranth in $^{133}$Cs or $^{88}$Sr treatments was calculated and the results are showed in Table 4. The Table 4 shows that the $^{133}$Cs or $^{88}$Sr concentration in the soil, concentration in the plant, contents in the plant and contents in a pot were rising gradually with the increasing concentration in the soil, but the biomass of total plant and the ratio of contents in the plant with the contents in a pot were fall gradually. The ratio of $^{133}$Cs or $^{88}$Sr contents in the plant with the contents in a pot was the highest in the 0.1 (mmol/kg) treatments, which was 19.91% and 23.97%, respectively. When in 5(mmol/kg) treatment, the ratio was lowest, which was 3.66% or 0.76%, respectively. That means it was more difficult to uptake $^{133}$Cs or $^{88}$Sr from the soil when $^{133}$Cs or $^{88}$Sr concentration in the soil was high and it would take more time to apply amaranth to remediate high $^{133}$Cs or $^{88}$Sr concentration contaminated soil. In this test, when the $^{133}$Cs concentration in the soil was 0.1mmol/kg or 13.29 mg/kg and the ratio of content in the plant with contents in a pot was the same every time, it needed to grow amaranth plants approximately 5 times (if to grow amaranth plants 2 seasons in a year, it needed 2.5 years) theoretically to uptake all the $^{133}$Cs from the soil. But when the $^{133}$Cs concentration in the soil is 5 mmol/kg or 664.5 mg/kg, it needed to grow amaranth plants approximately 28 times (if to grow amaranth plants 2 seasons in a year, it needed 14 years). When the $^{88}$Sr concentration in the soil is 5mmol/kg or 438.10mg/kg it needed to grow amaranth plants approximately 132 times (if to grow amaranth plants 2 seasons in a year, it needed 66 years).

## Physiological response of amaranth to $^{133}$Cs or $^{88}$Sr stress

**The effect of $^{133}$Cs or $^{88}$Sr on the chlorophyll and MDA content of amaranth:** The chlorophyll and MDA content of amaranth under

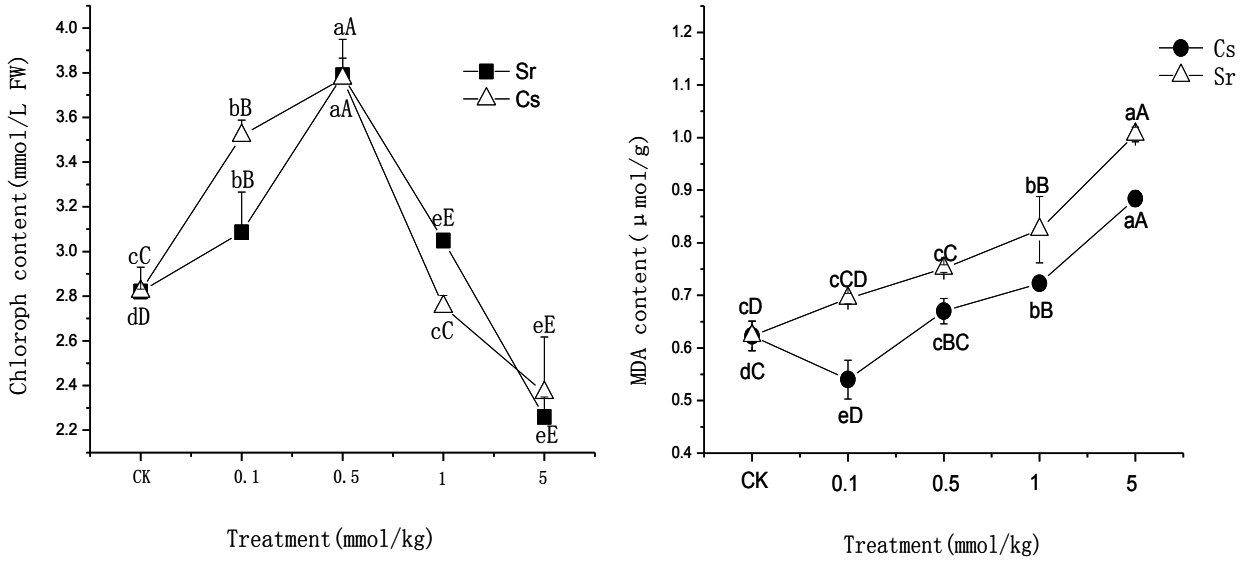


**Figure 1:** The effect of $^{133}$Cs or $^{88}$Sr on the chlorophyll and MDA content of amaranth.

the stress of $^{133}$Cs and $^{88}$Sr was shown in Figure 1. It can be found from the Figure 1 that the effects of $^{133}$Cs and $^{88}$Sr stress were similar, i.e. the chlorophyll content rose at first and then fell with the increasing of $^{133}$Cs and $^{88}$Sr content, it was the highest at the 0.5 mmol/kg treatment with the $^{133}$Cs and $^{88}$Sr treatment and the chlorophyll content decreased at the 1 mmol/kg treatment and it was the lowest at the 1 mmol/kg treatment. Moreover, the chlorophyll contents of all the treatments under the stress were significant difference ($p<0.05$) comparing to the control under the stress of $^{133}$Cs and $^{88}$Sr.

Figure 1 also showed the changes of the MDA content in amaranth leaves after different $^{133}$Cs and $^{88}$Sr treatments. It can be found from the Figure 1 that the after harvesting, the MDA content rose continually with the increasing $^{133}$Cs and $^{88}$Sr treatment concentration and all was higher than the control except at the 0.1 mmol/kg $^{133}$Cs treatment. For both $^{133}$Cs and $^{88}$Sr treatments, the highest values of their MDA content appeared at the 5 mmol/kg treatment. The MDA content of amaranth in $^{88}$Sr treatments was higher than in $^{133}$Cs treatments in different concentration$^{133}$Cs and $^{88}$Sr treatments. The MDA content of all the treatments was significant difference ($p<0.05$) with the control under stress of $^{133}$Cs and $^{88}$Sr. It can be found that high concentrations of $^{133}$Cs and $^{88}$Sr strengthened the peroxidization of the membranes of amaranth.

**The effect of $^{133}$Cs or $^{88}$Sr on the activity of CAT, POD, SOD of amaranth:** Figure 2 showed the changes of CAT, POD, SOD activity of amaranth leaves in different $^{133}$Cs and $^{88}$Sr treatments. It can be found from the Figure 2 that after the harvest, the CAT activity rose continually with the increasing $^{133}$Cs and $^{88}$Sr concentration. While the CAT activity declined firstly in $^{88}$Sr 0.1 mmol/kg, then rose with the increasing $^{88}$Sr concentration. Both of the highest values appeared at the 5 mmol/kg treatments, the CAT activity was 102 and 86.33 U/g min in $^{133}$Cs and $^{88}$Sr treatments, respectively, the CAT activity of the control was 35 U/g min. Except the control, the CAT activity of amaranth in $^{88}$Sr treatments was lower than that in $^{133}$Cs treatments among different concentration of $^{133}$Cs or $^{88}$Sr t treatments. The result indicated that high concentrations of $^{133}$Cs and $^{88}$Sr strengthened the the CAT activity of amaranth.

As Figure 2 showed, the effects of $^{133}$Cs and $^{88}$Sr stress on POD activity were different. After the $^{133}$Cs treatment, the POD activities first declined then rose and decline again. It was the highest at the 0.5 mmol/kg treatments, which was 45.1 u/g.min and the lowest at the 5 mmol/kg treatments, which was 17.2 u/g.min. For the $^{88}$Sr treatments, the POD activities of all treatments were lower than the control, and declined continually with the increasing $^{88}$Sr treatments concentration. Besides, the 5 mmol/kg treatment was the lowest.

Figure 2 also showed that the effects of $^{133}$Cs and $^{88}$Sr stress on POD activity were different. After the $^{133}$Cs treatment, the POD activities first rose and then declined. It was the highest at the 0.5 mmol/kg treatments, which was 175.9 u/g.min and the lowest at the 5 mmol/kg treatments, it was 57.6 u/g.min and lower than the control. For the $^{88}$Sr treatments, the POD activities of all treatments were not significantly different ($p<0.05$) from the control, except at the 5 mmol/kg treatment, when it was the lowest.

## Analysis of the correlation between the $^{133}$Cs and $^{88}$Sr contents and each physiological index

Table 5 were acquired after analyzing the correlation of the indexes including the total element content in the plant, MDA content, chlorophyll content, POD-CAT and SOD activity tested after the harvest for $^{133}$Cs and $^{88}$Sr treatments. In Table 5, the $^{133}$Cs content was positively correlated with the CAT activity ($r=0.9240$, $p<0.05$). This means the increase of the 133Cs content in the plant activated CAT activity increasing and alleviated the degree of 133Cs stress to the plant. The chlorophyll content was also positively correlated to the SOD activity ($r=0.9617$, $p<0.01$), too. Which means the increase of SOD activity accelerate chlorophyll synthesis. The correlation between other indexes was not significant. In Table 5, the $^{88}$Sr content was positively correlated to the MDA content ($r=0.9697$, $p<0.01$) and negatively correlated to the POD activity. ($r=-0.8966$, $p<0.05$) It means the increase of the $^{88}$Sr content in the plant activated MDA content increase and reduced the POD activity. The chlorophyll content was positively correlated to the SOD activity. ($r=-0.9094$, $p<0.05$) and the MDA content was positively correlated with the CAT activity.

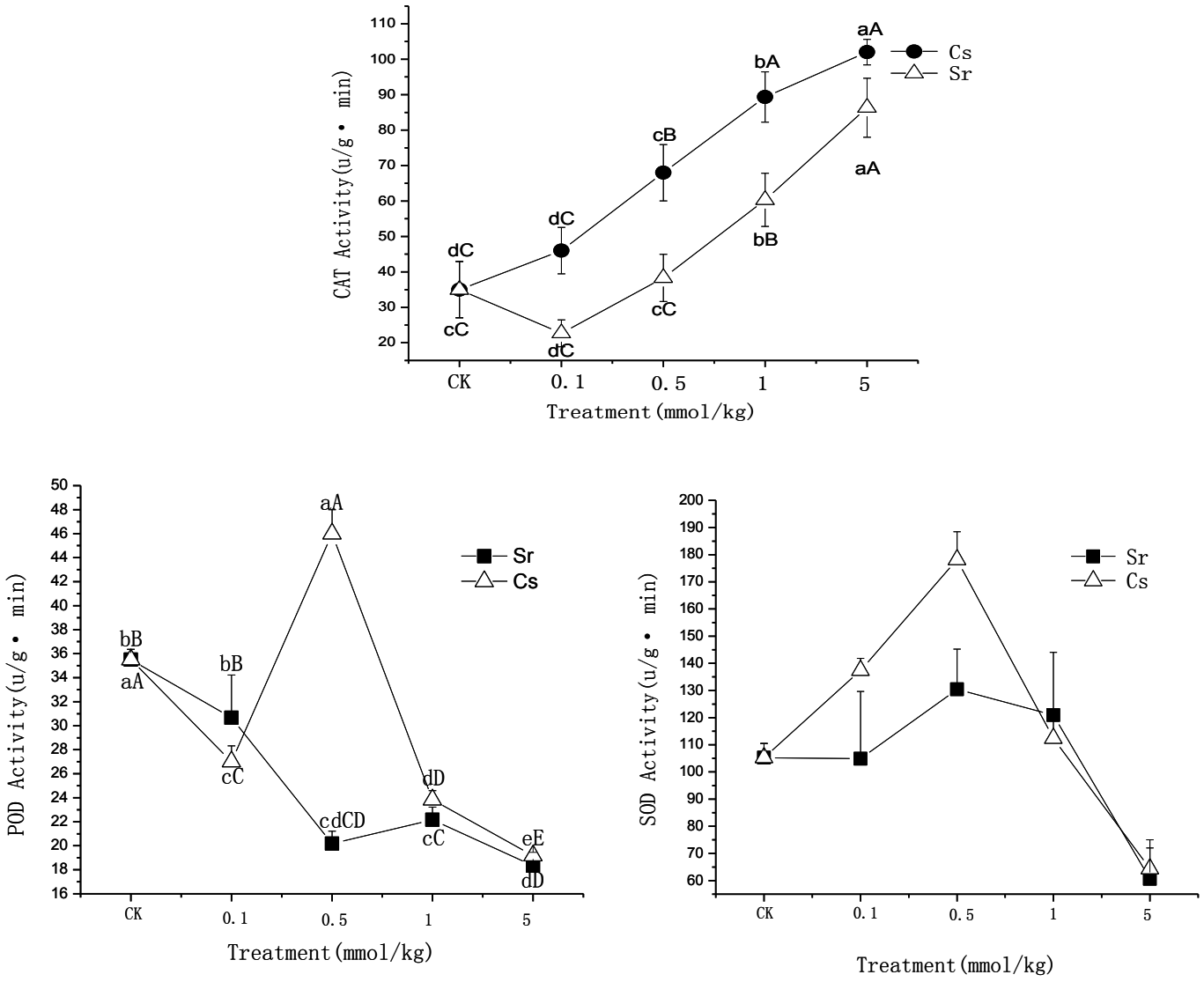


**Figure 2:** The effect of $^{133}Cs$ or $^{88}Sr$ on the activity of CAT ,POD,SOD of amaranth.

| Correlation Coefficient | **$^{88}Sr(^{133}Cs$** ) content in the plant | Chlorophyll content | MDA content | POD activity | CAT activity | SOD activity |
|---|---|---|---|---|---|---|
| **$^{88}Sr(^{133}Cs$** ) content in the plant | | 0.3503(-0.6369) | 0.9697**(0.1440) | -0.8966*(-0.8298) | 0.8275(0.9240*) | -0.5047(-0.6313) |
| Chlorophyll content | | | 0.5178(0.1242) | -0.0253(0.7362) | -0.6372(-0.4914) | 0.9094*(0.9617**) |
| MDA content | | | | -0.8394(0.1293) | 0.9312*(0.4998) | -0.6418(0.2792) |
| POD activity | | | | | -0.7084(-0.5140) | 0.1660(0.8125) |
| CAT activity | | | | | | -0.6499(-0.4114) |
| SOD activity | | | | | | |

Note: The symbol "*", "**" represents significant relativity at p<0. 05 and p<0.01 betwwen the indexes ,respectively;.The figures in the brackets were the correlation coefficient of the indexes of amaranth with **$^{133}Cs$** treatment.

**Table 5:** Correlation coefficient of the indexes of amaranth with $^{88}Sr$ and **$^{133}Cs$** treatment.

## Discussion and Conclusion

Plants vary in their abilities to uptake, translocate and sequester radionuclides [7,18,19]. The uptakes of $^{133}Cs$ and $^{88}Sr$ by the plants of amaranth were different when the treatment concentrations were the same in the soil. Generally, the amaranth absorbed more $^{133}Cs$ than $^{88}Sr$ at the same molarity treatment in the soil. The maximum $^{133}Cs$ uptake of the total plant was 3535.2 mg $kg^{-1}$ dw when the $^{133}Cs$ concentration was 5 mmol/kg (664.5 mg/kg) in the soil, and the minimum was 301.9 mg/kg.dw when the $^{133}Cs$ concentration was 0.1 mmol/kg (13.92 mg/kg) in the soil. The maximum $^{88}Sr$ uptake of total plant was only 639.4 mg/kg. dw when the $^{88}Sr$ concentration was 5 mmol/kg (438.7 mg/kg)in the soil, and the minimum was only 247.8 mg/kg. dw when the $^{88}Sr$ concentration was 0.1 mmol/kg (8.76 mg/kg) in the soil. The

result in this study was opposite to Dan Wang's previews reported that accumulation of $^{88}Sr$ was recorded higher than $^{134}Cs$ in radish plantlets [20]. It showed that amaranth had much stronger capacity of absorbing $^{133}Cs$ than $^{88}Sr$. Based on the effects of the $^{133}Cs$ and $^{88}Sr$ stress on the biomass of the plants, the maximum uptake of $^{133}Cs$ or $^{88}Sr$ by amaranth reached 36.437 mg and 5.00 mg per plant, respectively. The $^{133}Cs$ BCF of the above-ground parts and the total plant of amaranth in different concentration treatments in the soil were higher than the $^{88}Sr$ BCF except in the 0.1 mmol/kg treatment. The TF trend of amaranth for $^{133}Cs$ and $^{88}Sr$ were the same and at the lower $^{133}Cs$ and $^{88}Sr$ concentration (0.1and 0.5 mmol/kg), the accumulation of $^{133}Cs$ and $^{88}Sr$ was found higher in roots compared with when it was above –ground parts, while at higher $^{133}Cs$ and $^{88}Sr$ concentration (1 and 5 mmol/kg), $^{133}Cs$ and $^{88}Sr$ accumulation was more when it was in above -ground parts than it was in roots. The result was the same as Shraddha Singh' result [6], which means the transfer capacity of $^{133}Cs$ and $^{88}Sr$ to the above-ground parts, was similar. Some researchers reported many plant species uptake more Sr than Cs when the concentration of Cs or Sr is same in the soil or hydroponic medium [6,16,20]. Which means it is more difficult to remediate Cs pollution than Sr with phytoremediation technology. The stronger uptake capacity of amaranth for $^{133}Cs$ in low concentration was favorable for the restoration of the soils of low level Cs pollution. The present study suggests that amaranth can be used as a potential candidate plant for phytoremediation of $^{137}Cs$.

The biomass of the amaranth plants gradually decreased with the increase of $^{133}Cs$ and $^{88}Sr$ content in the soil. But it was not more obvious in the $^{133}Cs$ treatment than in the $^{88}Sr$ treatment.

The chlorophyll content in leaves is a most important physiology index in the growth and metabolism of plants. Under $^{133}Cs$ and $^{88}Sr$ stress, the chlorophyll content in amaranth firstly increase and then decreases with the increasing of $^{133}Cs$ and $^{88}Sr$ content in the soil. This means lower $^{133}Cs$ and $^{88}Sr$ contents in the soil activate the chlorophyll content and higher $^{133}Cs$ and $^{88}Sr$ content stress can decrease chlorophyll content. This can lead to lower photosynthesis ability and decrease the biomass of plants.

Malondialdehyde (MDA), one of the decomposition products of polyunsaturated fatty acids of membrane is considered as a reliable indicator of oxidative stress [13]. In this experiment, the MDA content under $^{88}Sr$ stress was higher than that under $^{133}Cs$ stress, and the activities of CAT under $^{88}Sr$ stress was lower than that under $^{133}Cs$ stress. It is the important physiological reason why amaranth has better tolerance to $^{133}Cs$ stress and uptake more $^{133}Cs$ than $^{88}Sr$.

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