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Decapitation improves the efficiency of Cd phytoextraction by *Celosia argentea* Linn

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HIGHLIGHTS

- Effects of decapitation on *C. argentea* growth and Cd accumulation were evaluated.
- Decapitation significantly increased branch number, leaf area and plant biomass.
- Leaf Cd increased due to the increase of transpiration in decapitated plants.
- Decapitation is a novel method to improve the efficiency of Cd phytoextraction.

GRAPHICAL ABSTRACT

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ABSTRACT

The effect of decapitation on enhancing plant growth and Cd accumulation in *Celosia argentea* Linn. was evaluated using a pot experiment. Decapitation significantly enhanced the growth of *C. argentea*. The numbers of branch and leaf in the decapitated plants (DP) were significantly higher than those in undecapitated plants (UDP, $p < 0.05$). Decapitation increased the biomass by 75%–105% for roots, 108%–152% for stems, and 80%–107% for leaves. Although the transpiration and photosynthesis rates were not significantly different between DP and UPD, decapitation significantly increased the total leaf area and total transpiration per plant ($p < 0.05$). The higher total transpiration per plant resulted in a higher leaf Cd concentration in DP. DP accumulated Cd in shoots (197, 275, and 425 μg plant^{-1}) that were 2.5–2.8 times higher than UDP (78, 108, and 152 μg plant^{-1}), with the soils containing 1, 5, and 10 mg kg^{-1} Cd. Results suggested that decapitation is a novel and convenient method to improve the phytoextraction efficiency of *C. argentea* in Cd contaminated soils.

1. Introduction

Cadmium is a major soil contaminant that emanates from weathering of rocks, mining, smelting, use of agro-chemicals, and wastewater irrigation (Zhao et al., 2012; Chandra et al., 2009; Robson et al., 2014). In China, a national soil quality and pollution survey showed that 7% of survey sites exceed the maximum allowed concentration of Cd (Ministry of Environmental Protection

Abbreviations: DP, decapitated plants; UDP, undecapitated plants; PR, photosynthesis rate; TR, transpiration rate; LA, leaf area; TTR, total transpiration per plant; LSD, least significant difference test.

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and Ministry of Land and Resources, 2014). Cd is also one of the most toxic heavy metals to plants and has severe bio-toxicity to microbes, animals, and human beings (Dias et al., 2013; Sylwia et al., 2010; Bernhoft, 2013; Gobe and Crane, 2010). The bioavailability of Cd in soils is generally higher than that of other metals because of its higher solubility and the predominance of low-energy bounds to soil solid phase (Gérard et al., 2000). Therefore, the excessive Cd in soil must be cleaned.

Phytoextraction using various hyperaccumulators is a promising and useful technique to remove Cd and other contaminants from the soil (Ali et al., 2013). Although much research is conducted to reveal the success of phytoextraction to be used on many contaminated sites, the method still lacks wide application (Grispen et al., 2006; Doty, 2008; Bauddh and Singh, 2012). The primary disadvantage of phytoextraction is slow compared with other engineering methods. Phytoextraction often takes years to decades to remediate slightly to moderately contaminated soils (Lessl and Ma, 2013; Liu et al., 2011). Therefore, attention is recently focused on the enhancement of phytoextraction.

A direct method for enhancing the effectiveness of phytoextraction is to overexpress the genes in transgenic plants that are involved in the metabolism, uptake, or transport of specific pollutants. Some papers reported that genetic engineering increased the removal rates of Cd, Pb, Zn, and Ni (Shim et al., 2013; Martinez et al., 2006). However, the use of transgenics for phytoextraction may pose potential risks for ecological systems (Linacre et al., 2003). The application of transgenic plants is strictly limited in many countries. Therefore, other approaches for enhancing phytoextraction of heavy metals should be explored.

Decapitation is an agronomic practice that helps to increase the number of branches through the release of apical dominance. Previous studies reported that the decapitation of apical buds significantly enhanced the shoot growth in different plants (Turnbull et al., 1997; Kalia et al., 2007; Pal et al., 2013). Considering that the shoot is the predominant part of Cd accumulation in hyperaccumulators, we hypothesized that decapitation will lead to higher shoot biomass and thus increase phytoextraction efficiency of Cd. In the present study, the effect of decapitation was investigated on branch growth, biomass production, Cd accumulation, transpiration, and photosynthetic rate in *Celosia argentea* Linn., a novel Cd-hyperaccumulator (Shen et al., 2017). The plants were exposed to 0, 1, 5, and 10 mg Cd kg^{-1} soil for up to 50 days. The objectives were to reveal the effectiveness of decapitation in improving Cd phytoextraction of *C. argentea* and to evaluate the applicability of decapitation for enhancing phytoextraction.

2. Materials and methods

2.1. Plant and soil materials

Seeds of *C. argentea* were collected from Pingle Mn mine (110°47′39″ E, 24°40′43″ N), Guilin, China. The collected seeds were surface sterilized with 10% H_2O_2 for 10 min, rinsed with sterile distilled water, and then sown in sand. Germinated seedlings were transplanted into a seedbed filled with sand. The seedlings were allowed to grow until four true leaves developed, during which Hoagland's solution was supplied every 5 days.

The soil used for the pot experiment was collected from 0 to 30 cm surface layer of a garden in the campus of Guilin University of Technology. Major physicochemical properties of experimental soil were analyzed and are shown in Table 1. Soil pH was measured with a pH electrode in a suspension of 1:5 (v/v) soil to 0.01 M $CaCl_2$ solution after 1 h shaking. Soil organic matter was determined by the Walkley–Black method (Nelson and Sommers, 1982), and cation exchange capacity was quantified using barium acetate method (Jackson et al., 1986). Total N, available P, total K, and soil texture were measured using the methods proposed by Soil Science Society of China (1983). Total soil Cd concentration was analyzed using inductively coupled plasma atomic emission spectrometer (ICP-OES, Perkin Elmer OPTIMA 7000DV, USA) after the digestion using EPA method 3050B. Available Cd was extracted using DPTA (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M triethanolamine, pH = 7.3) and determined by ICP-OES (Yu et al., 2014).

Table 1
Soil properties.

pH		5.79 ± 0.02
Cation exchange capacity	cmol kg^{-1}	11.6 ± 0.31
Soil organic matter	%	3.61 ± 0.12
Total N	g kg^{-1}	1.37 ± 0.01
Available P	mg kg^{-1}	7.42 ± 0.03
Total K	mg kg^{-1}	43.1 ± 0.11
Total Cd	mg kg^{-1}	0.19 ± 0.01
Available Cd	mg kg^{-1}	0.02 ± 0.00
Texture		Sandy clay loam

Results are means ± SD ($n = 3$).

2.2. Pot experiment

The collected soils were air dried at room temperature and sieved through 2 mm sieves for the pot experiment. The sieved soils (2.5 kg) were placed in a plastic pot (30 cm height and 20 cm diameter) and thoroughly mixed with Cd ($CdCl_2$ solution) at levels of 0, 1, 5, and 10 mg kg^{-1}. Six replications of each treatment were set in a complete randomized block design. The treated soils were set at approximately 50% field capacity for 2 weeks before the transplanting. The concentrations of DTPA-extractable Cd in soils were 0.02, 0.63, 3.15 and 6.86 mg kg^{-1}, respectively. Seedlings with similar sizes were individually transplanted in each pot. The apical buds (about 1 cm) were manually removed from the three plants of each treatment after a week of transplanting. The decapitated and undecapitated plants were grown in a greenhouse under a controlled environment (25 °C day/18 °C night, 70%–75% relative humidity, and 14 h photoperiod). Deionized water was added as required to maintain soil moisture. Numbers of leaf and branch were counted after 50 days of transplanting.

2.3. Transpiration and photosynthetic rate measurement

After 40 days of decapitation, the photosynthesis rate (PR) and transpiration rate (TR) were measured on a mature leaf (the fourth leaf from the top) using a portable photosynthesis system (Li-6400; Li-Cor Inc, Lincoln, NE, USA). The measurements were conducted from 9:30 a.m. to 10:30 a.m. in the greenhouse. The photosynthetic active radiation was 1300–1600 μmol $m^{-2}s^{-1}$, and the temperature of leaf chamber was 25–28 °C. At each measurement, the average of five measurements recorded at 10 s interval was used for analysis.

2.4. Leaf area and total transpiration estimation

Leaf area (LA) was measured with a portable meter (LI-3000C, Li-Cor Inc, Lincoln, NE, USA) after 40 days of decapitation. TR is expressed as water loss per unit time and leaf area (mmol H_2O m^{-2} s^{-1}). The total transpiration per plant (TTR) can be defined as the water loss by transpiration for a whole plant. Therefore, TTR can be calculated using the following equation: $TTR = TR \times LA \times 10^{-4} \times 60$. The TTR is expressed as mmol H_2O min^{-1} per plant.