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# Effects of cadmium hyperaccumulation on physiological characteristics of *Sedum alfredii* Hance (Crassulaceae)

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**Abstract**

*Sedum alfredii* is a newly found cadmium (Cd)-hyperaccumulator, but there have been no detailed studies on its physiological responses when Cd is hyperaccumulated. Leaf expansion and root growth were inhibited significantly at high Cd concentrations, and Cd was suggested to suppress cell expansion and induce senescence. Chlorophyll fluorescence analysis indicated that its photosynthesis appeared to be unaffected. Decreased $F_v/F_m$ correlated well with decreased water content of leaves. Cd treatments were demonstrated to result in an increase of chlorophyll content. The chlorophyll *a*/*b* ratio showed a reduction with increasing Cd concentrations. The Cd content peaked and reached a maximum of 11,000 mg $kg^{-1}$ in leaves at 600 μM Cd. It was almost saturated at 600 μM Cd in stems and roots, and then was, respectively, up to a maximum of 5300 and 3100 mg $kg^{-1}$ at 800 μM Cd. Fe concentrations in leaves, stems and roots increased significantly in the presence of Cd. Increasing Cd concentration might induce the expression of Fe transporter. This could have important implications both for human nutrition and for phytoremediation of metal contamination. Other elements (K, Ca, Zn and P) were distributed differently. Taking together, these results suggested that *S. alfredii* could be a good new model to investigate the mechanism of metal hyperaccumulation.


*Keywords:* Cadmium; Chlorophyll; Chlorophyll fluorescence; Hyperaccumulator; *Sedum alfredii*; Tolerance

## 1. Introduction

Cd is a non-essential trace element and considered as one of the most phytotoxic heavy metal contaminants [1,2]. Cd accumulation in soil and water owing to industrial contamination or through application of agricultural fertilizers containing high levels of Cd poses a major environmental hazard to human and animal health. Although not essential for plant growth, Cd is readily taken up by roots and translocated into leaves in many plant species. High concentrations of Cd cause toxicity in plants. It has been shown that Cd could decrease carbon assimilation [3], generate oxidative stress [4,5], induce stomatal closure and disturb plant water status [6], inhibit chlorophyll synthesis [7], damage root tips, reduce nutrient uptake, impair photosynthesis and inhibit plant growth [1,2]. However, various plants have different tolerance capacity. In *Brassica napus*, Cd at low concentration (5 μM) reduces its growth, chlorophyll content and photochemical quantum yield of photosynthesis and leads to stomatal closure [8,9]. In *Brassica juncea*, Cd does not affect its photosynthesis but decreases the transpiration rate [10]. Some plants such as *Thlaspi caerulescens* are tolerant to high level of Cd and could accumulate up to 10,000 mg Cd $kg^{-1}$ in the shoot dry matter without suffering phytotoxicity under hydroponic conditions [11]. The hyperaccumulating ability of these species can be used to remove heavy metals from contaminated soils.

Heavy metal hyperaccumulators are those plants that have the ability to uptake heavy metal from soils

*Abbreviations:* ABS, absorption flux; ABS/RC, absorption flux per reaction center; ALA, δ-aminolevulinic acid; CAM, crassulacean acid metabolism; $DI_0$/RC, dissipation flux per reaction center; ET, electron transport flux; $ET_0$/RC, electron transport flux per reaction center; $F_0$, initial fluorescence; $F_m$, maximum fluorescence; $F_v$, variable fluorescence; $F_v/F_m$, potential efficiency of PSII photochemistry; $F_v/F_0$, variable chlorophyll fluorescence ratio; $Q_A$, the primary stable quinone electron acceptor of PSII; RC, reaction center; TR, trapping flux; $TR_0$/RC, trapping flux per reaction center; WC, water content of leaves

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extraordinarily and transport and accumulate them in their shoots. Metal hyperaccumulating plants have been defined as plants that accumulate greater than 1000 $\mu g\ g^{-1}$ (dry weight) Ni, 10,000 $\mu g\ g^{-1}$ Zn or Mn, 1000 $\mu g\ g^{-1}$ Co or Cu, and 100 $\mu g\ g^{-1}$ Cd when grown in native soils [12,13]. To date, only *T. caerulescens* J. & C. Presl [13,14] and *Arabidopsis halleri* (L.) O'Kane & Al-Shehbaz (previously known as *Cardaminopsis halleri*) [15] have been identified as Cd-hyperaccumulators, which both belong to Brassicaceae family. More recently, Yang et al. [16] reported that Zn-hyperaccumulator *Sedum alfredii* Hance can also hyperaccumulate Cd. *S. alfredii* belongs to Crassulaceae family and has been found in an old Zn/Pb mining area in China [17]. It is a perennial and succulent herb with clumped population, growing on moist stones beside the rivulet or under the bamboo grove. It possesses characteristics of fast growth, large biomass and asexual reproduction. It can grow up to 60 cm height and propagate three to four times in a year if the environmental conditions are favorable. The rootstock of *S. alfredii* is stolon, and its leaves are alternate, without petiole, juicy, obovate or spathulate shape with 10–30 mm in length and 5–10 mm in width. Corymbose inflorescence is set in apex of the branches. Yellow flowers are small with four sepals, four petals, eight stamans and four carpels (Fig. 1). According to our observation, it flowers from April to July.

So far, numerous studies focus on the mechanisms of metal tolerance, but the precise mechanisms of metal toxicity is often neglected [18]. The exact physiological mechanisms of Cd toxicity are still debated and phytotoxicity mechanisms in different plant species involve different biochemical pathways. It has recently been shown that *S. alfredii* has an exceptional ability to tolerate and hyperaccumulate Cd [16]. However, little is known about its physiological responses when Cd is hyperaccumulated in *S. alfredii*. In the present study, the responses of root growth, leaf expansion, water content of leaves, chlorophyll content, chlorophyll fluorescence and mineral composition to external Cd levels were investigated in order to have a better understanding of Cd tolerance in the new Cd-hyperaccumulator *S. alfredii*.

## 2. Materials and methods

### 2.1. Plant material and growth conditions

*S. alfredii* Hance was collected from an old Pb/Zn mining area in Quzhou city of Zhejiang province, PR China. Healthy and equal-sized shoots were chosen and grown in 2 l vessels for the initiation of new roots. The compositions of nutrient solution were 2 mM $Ca(NO_3)_2 \cdot 4H_2O$, 0.1 mM

Fig. 1. *Sedum alfredii* Hance.