Available online at www.sciencedirect.com
ScienceDirect
Bioresource Technology 99 (2008) 1103–1110
BIORESOURCE TECHNOLOGY

Effects of cadmium and arsenic on growth and metal accumulation of Cd-hyperaccumulator *Solanum nigrum* L.

Yuebing Sun [a,b], Qixing Zhou [a,c,*], Chunyan Diao [c]

[a] *Key Laboratory of Terrestrial Ecological Process, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, PR China*
[b] *The Provincial Key Laboratory of the Conservation and Exploitation of Biological Resources in College of Life Sciences, Anhui Normal University, Wuhu 241000, PR China*
[c] *College of Environmental Science and Engineering, Nankai University, Tianjin 300071, PR China*

Received 22 October 2006; received in revised form 20 February 2007; accepted 20 February 2007
Available online 24 August 2007

Abstract

Remediation of heavy metal contaminated sites using hyperaccumulators presents a promising alternative to current environmental methodologies. In the pot-culture experiment, the effects of Cd, and Cd–As on the growth and its accumulation in the Cd-hyperaccumulator (*Solanum nigrum* L.) were determined. No reduction in plant height and shoot dry biomass was noted when the plants were grown at Cd concentration of $\leqslant$25 mg/kg. The contents of Cd in the stems increased from 122 to 387 mg/kg with increasing Cd, with the Cd transfer factor and bioaccumulation factor being >1.0. The plant can be classified as a Cd-hyperaccumulator. Growing in the presence of 10 mg/kg Cd and 50 mg/kg As, the plant height and shoot dry matter yields did not decrease significantly ($p > 0.05$) compared to that at 10 mg/kg Cd, however the stem Cd content increased by 28%. It was also observed that *S. nigrum* used exclusion strategy to reduce As uptake in the roots and restricted translocation into the shoots, resulting in As contents of the plant being root > leaf > stem > seed. The Cd accumulation capacity coupled with its relatively high As tolerance ability could make it useful for phytoremediation of sites co-contaminated by Cd and As.

Keywords: *Solanum nigrum* L.; Cd-hyperaccumulator; Phytoremediation; Combined pollution

1. Introduction

Arsenic (As) and cadmium (Cd) are of highly bioactive and toxic elements, their presence at elevated levels in soils and drinking water is threatening food safety and human health (Kang and Jin, 2004; Geng et al., 2005). They adversely affect biological activities as a teratogen, carcinogen or mutagen as well as having detrimental effects on the digestive system, respiratory system and immune system (Zhou and Huang, 2000; Zhou and Song, 2004; Liao et al., 2005). Large areas of cultivated land in many countries have been contaminated by As and Cd due to agricultural and industrial practices such as application of pesticides and chemical fertilizers, waste water irrigation, precipitation from heavy coal combustion, and smelter wastes and residues from metalliferous mining (Boisson et al., 1999; Zhou and Huang, 2000; McGrath et al., 2001; Xie et al., 2006; Verma et al., 2007). Recognition of the ecological and human health hazards of some toxic pollutants has led to development of reliable and cost-effective technologies such as bioremediation capable of reducing As and Cd in soils and wastes to environmentally acceptable levels (Zhou and Song, 2004; Kertulis-Tartar et al., 2006; Yoshida et al., 2006).

Phytoremediation can be defined as the use of plants including trees and grasses, to remove, destroy, or sequester hazardous contaminants from media, such as soil, water, and air (Chaney et al., 1997; Salt et al., 1998; Prasad,

* Corresponding author. Address: Key Laboratory of Terrestrial Ecological Process, Institute of Applied Ecology, Chinese Academy of Science, Shenyang 110016, PR China. Tel.: +86 24 8397 0373; fax: +86 24 8397 0436.
E-mail address: Zhouqx@iae.ac.cn (Q. Zhou).

0960-8524/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2007.02.035

2003), is gaining a lot of importance in recent years since it is a cost effective, promising technology, as well as a desire 'green', sustainable process (Wei and Zhou, 2004a; Zhou and Song, 2004). Plants with metal resistance mechanisms based on exclusion can be efficient for phytostabilization technologies (Wei et al., 2005b). Hyperaccumulating plants, in contrast, may become useful for extracting toxic elements from the soil and thus decontaminate and restore fertility in polluted areas (Barceló and Poschenrieder, 2003). Hyperaccumulators are plants that have an innate capacity to absorb metal at levels 100 times greater than average plants (Baker and Brooks, 1989; Yang et al., 2004; Zhou and Song, 2004). They are often found in metal-rich regions where those traits probably give them a competitive advantage (Ma et al., 2001; Sun et al., 2005; Gonzaga et al., 2006).

Hyperaccumulators are defined based on the following characteristics: (1) shoots metal concentrations (threshold values) are >10,000 mg/kg dry weight of shoots for Zn and Mn, 1000 mg/kg for Co, Cu, Ni, As and Se, and 100 mg/kg for Cd (Baker and Brooks, 1989; Ma et al., 2001; Zhou and Song, 2004); (2) bioconcentration factor (ratio of metal concentration in plant to soil) is greater than 1.0, sometimes reaching 50–100 (Brooks, 1998; Cluis, 2004); (3) translocation factor (ratio of metal concentration in shoots to roots) is greater than 1.0 (Wei and Zhou, 2004a,b).

So far, more than 400 species of natural metal hyperaccumulators belonging to 45 families have been documented in the world, but hyperaccumulation of Cd and As are a rare phenomenon in the plant kingdom (Zhou and Song, 2004). Compared with crops, weed plants display their characteristics of strong endurance to adverse environmental conditions, and high capacity to absorb water and fertilizers (Gardea-Torresdey et al., 2004; Wei et al., 2005a; Wei and Zhou, 2006). In this sense, weed is an important type of ideal natural resources for the remediation of contaminated soils. Black Nightshade herb is a very common species in a field in north China. It is tolerant to adverse environment, fast growing and with high biomass, under feasible environmental conditions, its biomass could increase rapidly (Wei et al., 2005a). So it could fill a gap of known hyperaccumulating plants and it has the potential for phytoremediation of metal contaminated soils (Zhou and Song, 2004). The objectives of this study was to examine the growth response and uptake, distribution, and accumulation of As and Cd by *Solanum nigrum* in response to As–Cd combined pollution.

2. Methods

2.1. Field site and soil characterization

The field pot-culture experiment was located at the Shenyang Ecological Experimental Station (41°31′N and 123°41′E). It belongs to the temperate zone with a semi-moist continental climate, 5–9 °C average annual temperature, 520–544 kJ/cm^2 total annual radiation, 650–700 mm average annual precipitation, and 127–164 days frostless duration per year. The coldest month (average −14 °C) is in January and the warmest month (average 24 °C) is in July. Burozem soil located in the station is a relatively clean soil based on the National Soil-Environmental Quality Standards of China (NSEQSC, GB 15618, 1995). Soil samples were collected from the surface (0–20 cm) from a field without pollution of heavy metals (Wei and Zhou, 2006). The main soil parameters were listed as follows: soil pH was 6.56; CEC was 12.26 g/kg; Total N, P, and K were 0.91, 0.40, and 183.00 g/kg, respectively; the concentrations of Cd, Cu, Zn, Pb and As were 0.17, 32.9, 28.1, 11.1 and 10.4 mg/kg, respectively.

2.2. Experimental procedure

Plastic pots of 15 cm in height and 20 cm in diameter were used. Air-dried soil of 2.5 kg was sieved through a 4 mm sieve, and then placed into each pot after mixed with Cd and As.

According to Liao et al. (2005), the concentration of As in the areas near the industrial districts of Chenzhou City, Southern China was 11.0–1217 mg/kg. According to Wei and Chen (2002), high arsenic levels in the Shimeng area was up to 129–3831 mg/kg. The concentration of soil Cd in the Zhangshi sewage irrigation area in the west Shenyang suburb was 7–25 mg/kg (Wen and Shi, 2005). In particular, the concentration of soil Cd in an old smeltery, northeast China was up to 11.19–197.28 mg/kg (Cui et al., 2007). Thus, three levels of Cd (10, 25, and 50 mg/kg) and As (0, 50, and 250 mg/kg) were used in this experiment, resulting in a total of nine treatments. The three Cd treatments will be referred to as 10, 25, and 50 mg/kg, and six Cd/As treatments will be referred to as Cd-10As-50, Cd-10As-250, Cd-25As-50, Cd-25As-250, Cd-50As-50, and Cd-50As-250. One control that had no Cd and As was included. Cadmium and arsenic were applied as $CdCl_2 \cdot 2.5H_2O$ and $Na_2HAsO_4 \cdot 7H_2O$, and then incubated for four weeks. A petri dish was placed under each pot to collect potential leachate during the experiment.

Three seedlings of *S. nigrum* of similar size, which were about three weeks old, 3–4 cm height with 2–3 leaves were transplanted into each pot. To simulate field conditions, the plants were grown under open field conditions and no fertilizer was added. Loss of water was made up using tap water (no Cd and As detected) to sustain 75% of the field water holding capacity. The plants were harvested after 70 days when they reached their physiological maturity. They were washed thoroughly first with running tap water followed by distilled water, and dried at 100 °C for 10 min, then at 70 °C in an oven until completely dry.

2.3. Plant and soil analysis

The plant and soil samples were digested with a solution of 3:1 HNO_3:$HClO_4$ (v/v). The concentrations of heavy