Chemosphere 176 (2017) 249–254

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Arsenic uptake by lettuce from As-contaminated soil remediated with *Pteris vittata* and organic amendment

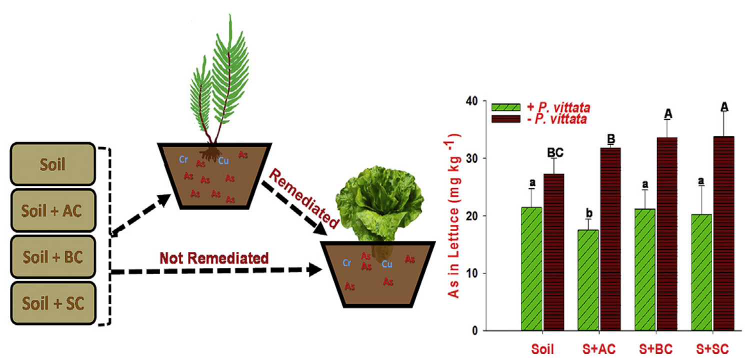
Letuzia M. de Oliveira [a, b], Das Suchismita [c], Julia Gress [a], Bala Rathinasabapathi [d], Yanshan Chen [a, **], Lena Q. Ma [a, b, *]

[a] *State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Jiangsu 210046, China*
[b] *Soil and Water Science Department, University of Florida, Gainesville, FL 32611, USA*
[c] *Life Science and Bioinformatics, Assam University, Silchar, India*
[d] *Horticultural Sciences Department, University of Florida, Gainesville, FL 32611, USA*

HIGHLIGHTS

- Ability of *Pteris vittata* & amendment in reducing As uptake by lettuce was tested.
- Amendment included biochar, activated C and coffee ground.
- Amendment increased lettuce growth due to improved soil fertility.
- Amendment reduced lettuce As uptake by 5.6–18%, activated C being most effective.
- *Pteris vittata* reduced As content in lettuce by 22%.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 December 2016
Received in revised form
17 February 2017
Accepted 24 February 2017
Available online 24 February 2017

Handling Editor: X. Cao

Keywords:
CCA-treated woods
Biochar
Plant uptake
Soil amendments
Phytoremediation

ABSTRACT

Leaching of inorganic arsenic (As) from chromated copper arsenate (CCA)-treated wood may elevate soil As levels. Thus, an environmental concern arises regarding As accumulation in vegetables grown in these soils. In this study, a greenhouse experiment was conducted to investigate the ability of As-hyperaccumulator *P. vittata* and organic amendments in reducing As uptake by lettuce (*Lactuca sativa*) from a soil contaminated from CCA-treated wood (63.9 mg kg^{-1} As). *P. vittata* was grown for 150 d in a CCA-contaminated soil amended with biochar, activated carbon or coffee grounds at 1%, followed by lettuce for another 55 d. After harvest, plant biomass and As concentrations in plant and soil were determined. The presence of *P. vittata* reduced As content in lettuce by 21% from 27.3 to 21.5 mg kg^{-1} while amendment further reduced As in lettuce by 5.6–18%, with activated C being most effective. Our data showed that both *P. vittata* and organic amendments were effective in reducing As concentration in lettuce. Though no health-based standard for As in vegetables exists in USA, care should be taken when growing lettuce in contaminated soils. Our data showed that application of organic amendments with *P. vittata* reduced As hazards in CCA-contaminated soils.

Published by Elsevier Ltd.

* Corresponding author. State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Jiangsu 210046, China.
** Corresponding author.
E-mail addresses: chenyanshan@nju.edu.cn (Y. Chen), lqma@ufl.edu (L.Q. Ma).

http://dx.doi.org/10.1016/j.chemosphere.2017.02.124
0045-6535/Published by Elsevier Ltd.

1. Introduction

Inorganic arsenic (As) is toxic to humans and is considered a carcinogen by the International Agency for Research on Cancer. Elevated As concentrations in soils can adversely impact human health (Tóth et al., 2016). Soil contamination results from several anthropogenic activities including mining, smelting, solid waste disposal and pesticide application. One source of soil As contamination in the US is the use of wood treated with pesticide chromated-copper arsenate (CCA). CCA-wood typically has As concentrations of 1000–5000 mg kg^{-1} and is commonly found around homes and commercial properties throughout the US. CCA-wood leaches As into surrounding soil, causing public health concern (Chirenje et al., 2003; Gress et al., 2015). The soil cleanup target levels for residual use in Florida is 2.1 mg kg^{-1}, however, there are no As standards for garden soils (Teaf et al., 2010).

Arsenic in soils can mobilize and migrate into ground and surface water, entering the food chain through drinking water and contaminated vegetables (Finnegan and Chen, 2012). The guideline by World Health Organization for As in drinking water is 10 μg L^{-1}. Owing to the wide presence of As in soils around homes from CCA-wood used in decks, stairs, fencing and landscape timbers, it is important to reduce the risks associated with As contamination in food chain. Remediation of As-contaminated soil using plant-based technology may reduce its hazard (Garbisu and Alkorta, 2001; Lessl et al., 2014). *Pteris vittata* L. (PV) is an efficient arsenic-hyperaccumulator (Ma et al., 2001). Because it hyperaccumulates large amounts of As (up to 2.3%) into its shoots, it has potential to cleanup As-contaminated sites (Gonzaga et al., 2008; Lessl et al., 2014).

Organic amendments have been used to reduce contaminant availability in soils (Kumpiene et al., 2008; Ahmad et al., 2014; Khan et al., 2015). Amendments including biochar and activated C have been tested (McBride et al., 2015; Namgay et al., 2010). They are C-rich materials produced via slow pyrolysis of organic feedstocks in an oxygen-limited atmosphere at temperature <700 °C (Dong et al., 2014). The materials are characterized with high sorption ability for metals (Glaser et al., 2002). For example, Beesley and Marmiroli (2011) reported that biochar effectively retained As from an As-contaminated leachate.

Arsenic is not essential for plant growth and it is phytotoxic at high concentrations. Typical As contents for plant shoots growing in unpolluted soils are 1–1.7 mg kg^{-1} (Kabata Pendias, 2011) while Chaney (1989) suggested potentially phytotoxic effects at 3–10 mg kg^{-1} As. Soil-plant As transfer is a pathway for human exposure to As (Geng et al., 2006). There are no regulatory limit on As content in vegetables in the U.S. However, Poland's standard for fresh vegetables is 0.2 mg kg^{-1}, China's standard for rice, beans, and vegetables is 0.5 mg kg^{-1} (NFHPC, 2012) and Japan's is 1.0 mg kg^{-1} for spinach, tomatoes and cucumbers. Ingestion of vegetables grown in As-contaminated soils poses a potential risk to human health. As a common vegetable in the US, human risks may exist when lettuce is cultivated in CCA-contaminated soil. Due to its efficient As accumulation and high biomass, PV has potential to reduce As concentrations in soils and thereby plant uptake.

Limited information is available regarding the risks of As exposure from homegrown vegetables. In the present study, we investigated the ability of As-hyperaccumulator *P. vittata* coupled with organic amendments in reducing As uptake by lettuce from a CCA-contaminated soil.

2. Materials and methods

Ten soil samples from in-use CCA-treated telephone poles were collected from residential areas in Gainesville, Florida. They were collected from top 0–30 cm at a distance of 10 cm away from a pole and were composited into one sample, totaling 25 kg. The air-dried soil was sieved through a 2-mm sieve.

Hardwood biochar and activated carbon were obtained from Dunnellon, FL, spent coffee organic matter were obtained from a local coffee shop in Gainesville, FL and lettuce (*Lactuca sativa* L.) seeds were bought from Botanical Interest, Inc (Broomfield, CO). The amendments and CCA-soil were stored in polyethylene containers before use. The pH was measured in a 1:5 of solid: water suspension after 24 h of equilibration with a pH meter (Thermo Orion 920A). The amount of organic matter was determined using the loss upon ignition at 400 °C after 16 h. Selected properties of soils and amendments are presented in Table 1.

2.1. Experimental setup

Organic amendment (biochar, activated C or coffee ground) was added to CCA-soil to grow *P. vittata*. Each treatment was replicated four times, and pots without plants were included as controls, resulting in 20 pots. The pots were arranged in a completely randomize design in a greenhouse. The amendment was added to soil at 1%, i.e., 5 g of amendment was mixed with 495 g of soil. They were aged for a month at 50% water holding capacity in plastic bags with partial opening for aeration. This was based on a previous study, showing As availability in soils was stable after one month of aging (Liang et al., 2014). To stimulate field drying-wetting cycles, the soils were stored in a dark room and deionized water was added to soils weekly.

Six months old *P. vittata* sporophytes used in this study were propagated in our laboratory (de Oliveira et al., 2014). The spores stored in a small plastic container were sprinkled onto a moist soil mixture (50% sand, 25% peat and 25% garden soil) in seed trays, which were covered with a plastic film to maintain moisture and humidity. After 2 months when the sporelings attained a height of 3–4 cm with 2–3 leaves, they were transplanted into 2-in plastic pots (one plant per container) containing Miracle-Gro potting soil where they remained for a month (Marysville, Ohio). Ferns with

Table 1
Soil and amendment properties, and changes in soil metal concentrations after growing *P. vittata* for 150 d.

	pH	Organic matter	Sand	Clay + silt	Total As	Total Cr	Total Cu
		(%)			(mg kg^{-1})		
					Before growing *P. vittata*		
Soil	6.2 ± 0.04 b	1.48 ± 0.2 c	88.9	11.5	63.9 ± 5.8	59.4 ± 6.0	91.2 ± 8.2
					After growing *P. vittata*		
Soil					35.2 ± 3.0 b	36.9 ± 3.3 a	47.9 ± 3.8 a
Activated C	7.2 ± 0.03 a	35 ± 0.13 b			43.1 ± 4.1 a	37.9 ± 4.0 a	45.7 ± 2.9 a
Biochar	6.7 ± 0.02 a	39 ± 0.11 a			30.7 ± 3.7 c	32.1 ± 2.1 b	44.6 ± 4.0 a
Spent coffee	6.8 ± 0.09 a	39 ± 0.14 a			36.2 ± 3.1 b	24.4 ± 1.9 c	36.2 ± 3.2 b

Columns with values followed by the same letter are not significantly different ($p < 0.05$). Data are the means of four replicates with bars representing standard error.