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Salix viminalis L. - A highly effective plant in phytoextraction of elements

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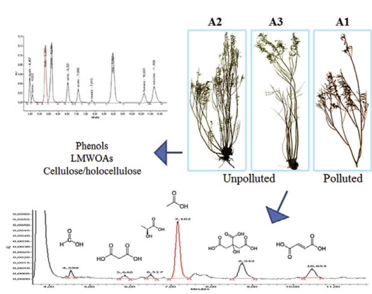
HIGHLIGHTS

- *Salix viminalis* L. was able to growth at extremely polluted mining sludge (A1).
- Effective phytoextraction and lowest biomass in treated willows was observed.
- Content of cellulose and hollocellulose in willows from A1 was lowest.
- Creation of organic acids and phenols was correlated with metal content in plant organs.
- Explanation of the cause of studied plants high survivability is necessary.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of the study was to compare specimens of *Salix viminalis* L. able to grow in polluted mining sludge (A1) with specimens of the same willow clone growing in two unpolluted areas (A2 and A3). Plants from the polluted area were characterized by the highest accumulation of the majority of elements in their organs with a clear limitation of their uptake to roots and effective translocation to aboveground organs. Willows from the unpolluted areas were characterized by significantly higher biomass than the treated plants, as shown in the content of cellulose/holocellulose.

The different chemical characteristics of the substrates influenced tree physiology, including the organic acids and phenolic compounds profile and/or content. The total content of organic acids in lateral roots was higher for *S. viminalis* L. grown in unpolluted areas, while for leaves the opposite situation was observed. However, their creation was significantly correlated with the content of the majority of elements in the organs of *S. viminalis* L. Enhanced synthesis of phenolic compounds in roots (besides quercetin) and in leaves (besides myricetin and quercetin) was confirmed in the polluted area, and correlated with metal content in plant organs. Resilient plants characterized not only by their survivability but also by their effective phytoextraction of toxic metals, have great potential for widespread practical application on highly polluted mining sludge and for reducing the associated threat to human

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health. The obtained results suggest that further investigation of these plants is necessary to determine the mechanism(s) responsible for their high survivability.

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1. Introduction

Using plants for the remediation of areas polluted with heavy metals has been the subject of numerous studies and reviews over the last 15 years (Bi et al., 2011; Sarma, 2011). Plants that are commonly found in the environment such as trees (Sawidis et al., 2011), halophytic plants (Manousaki and Kalogerakis, 2011) and hyper- and nonhyperaccumulators (Benzarti et al., 2008; Krämer, 2010; Milner and Kochian, 2008) have been studied in unpolluted and polluted areas, along with fast-growing species such as willows or poplars (Wahsha et al., 2012; Wang and Jia, 2010). Because of their rapid growth or their facility in adapting to new environmental conditions, the latter group of plants seem to be particularly favorable for remediation of polluted areas (Goliński et al., 2016; Tlustoš et al., 2007). The biomass of such plants as willows is an important parameter of practical use in phytoremediation, but this issue should be viewed more in the light of the possibilities of biomass cropping (Pulford and Watson, 2003). If willow is able to grow with enough biomass for collection, effectively transport highly toxic elements to its aboveground parts and can survive in an extremely polluted area, it is a suitable plant for remediation of polluted soil (Algreen et al., 2014; Máthé-Gáspár and Anton, 2005).

The abilities of different willow taxa to adapt, grow and accumulate heavy metals has been analyzed for significantly diverse substrates. Jensen et al. (2009) showed that *Salix viminalis* could grow in soil strongly polluted with copper (Cu), lead (Pb) and zinc (Zn), (1.4, 0.5 and 3.3 g kg^{-1}, respectively), while Roselli et al. (2003) were able to confirm that growth occurred in an area polluted with 555, 620 and 1.8 mg kg^{-1} of Cu, Zn and cadmium (Cd), respectively. In the case of As, numerous studies have investigated the response of willow grown on a substrate with a wide range of As concentration in both hydroponic experiments and the natural environment (Purdy and Smart, 2008; Tlustoš et al., 2007; Zimmer et al., 2011). Plants can react in diverse ways to concentrations of highly toxic elements, which is particularly important with respect to their growth and development. The chemical composition of woody plants depends on numerous factors, e.g. plant species, age or genetic characteristics (Doğu, 2002; Waliszewska, 2002). Environmental pollution plays a significant role in cellulose, lignin and hemicellulose content, as found during studies of relationships between plant growth conditions and the amount and content of wood components. An example can be found in Kiaeil et al. (2015), who described the relationships between chemical properties (cellulose, lignin and extractive) and Cd, Cu, Fe, Ni, Pb and Zn content in some parts of *Parrotia persica*. What is more, environmental pollution significantly influences the content of extractive substances in oak wood (Krutul et al., 2014) and the content of 1% NaOH soluble substances and lignin in birch wood (Krutul et al., 2011). It is important to study the interaction between wood and metal ions and the behavior and chemical reactions of certain components because of the complicated and varied nature of these processes.

As a consequence of soil pollution from high quantities of metals resulting from mining, plants excrete low-molecular-weight organic acids (LMWOAs) into the rhizosphere as one effective extracellular metal detoxification mechanism (Dresler et al., 2014). LMWOAs reduce soil pH which enhances metal mobility in soil profiles and forms complexes with metals by the chelation oxidation-reduction reaction in the rhizosphere (Renella et al., 2004; Adeleke et al., 2017). LMWOAs released by plant roots into the root zone reduce sorption, enhance bioavailability and mobilize metals in soil (Liao and Xie, 2004; Ding et al., 2014). However, organic acids also have another role; they participate in an intercellular detoxification mechanism. Similarly to phytochelatins (PCs) and amino acids (Ma, 2000; Ryan et al., 2001), LMWOAs chelate and sequestrate metals in the vacuole (Chaffai et al., 2006; Dresler et al., 2014). Chelators such as the LMWOAs: citric, malic, acetic or oxalic acids, contribute to metal detoxification, but what should be particularly mentioned is their role in the acquisition and transport of metals to the aerial parts of plants, and subsequent metal accumulation in shoots or/and leaves. It has been found that the metal cation in apoplastic and xylem transport is limited by the high cation-exchange capacity of cell walls, which means that metal–chelate complexes may be more efficiently transported than metal ions in the transpiration stream, as Cd-citrate (Senden et al., 1992; Wei et al., 2007).

In many plants, metal-stress can affect phenolic metabolism because they act as protective molecules (López z et al., 2015; Quideau et al., 2011). They can function as structural components of the cell wall because enhanced lignification is observed during metal stress. However, their main role is an antioxidant function implemented by the scavenging of reactive oxygen species (ROS) and by metal chelating (Michalak, 2006).

The aim of the study was to show the chemical characteristics of *S. viminalis* L., able to survive and grow in extremely polluted mining sludge and to compare collected plants with specimens of the same *Salix* clone of the same age growing in two different unpolluted experimental areas. The content of 53 elements, chemical composition of wood, LMWOAs and phenolic compounds were analyzed in selected organs to investigate the structure and response of *S. viminalis* L. growing in substrate comprised of different chemical characteristics.

2. Materials and methods

2.1. Experimental material

3 specimens of 2 year old *S. viminalis* L., growing in extremely polluted mining sludge (A1), containing dangerous substances of origin other than biological cleaning of industrial waste (19 08 11*) – (samples acquired from non-ferrous metal industry without permission to name the company name) (RME, 2015), were the main object of the studies. These plants were compared to specimens of the same willow clone of the same age growing in two unpolluted areas: one from Gaj Mały (A2), where the willows grew on Haplic Cambisol (52°39'24.62''N, 16°31'15.23''E), and the second from Zielonka village (A3), where the soil is Brunic Arenosol (52°33 '4''N 17 °06'20''E). Three specimens of *S. viminalis* L. from each location were carefully dug up with their root systems intact during the vegetation season of 2017 and immediately transported to the laboratories of the Poznan University of Life Sciences.

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