Current Trends in Natural Sciences Vol. 3, Issue 6, pp. 68-73, 2014

Current Trends in Natural Sciences (on-line)
ISSN: 2284-953X
ISSN-L: 2284-9521

Current Trends in Natural Sciences (CD-Rom)
ISSN: 2284-9521
ISSN-L: 2284-9521

APPLICATIONS OF PTERIDOPHYTES IN PHYTOREMEDIATION

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Abstract
It is considered that ferns could present new adaptations to the action of stress factors as a result of the wide geographical spread and the diversity of the habitats in which they vegetate, adaptations that could allow them, among other things, hyper-accumulation of metals. This article aims at a brief overview of the results obtained in experimental research aimed at using pteridophytes in phytoremediation.

Keywords: pteridophytes, phytoremediation, heavy metals.

1. INTRODUCTION

The class of the heavy metals includes those chemical elements that have an atomic weight greater than 5g/cm^3. They are substances that can be found quite frequently in nature at low concentrations, but humans, through their various activities, modify their weight so that they become harmful both for the environment and human health. An important feature of heavy metals is that they cannot be created or destroyed, so, once released, they remain in the environment for hundreds of years (McGinn, 2002).

The most important source of heavy metal pollution is the industry with all its branches, and the main chemical elements released into the environment as a result of these activities are: As, Cd, Cr, Cu, Zn, Ni, Pb, Hg.

In small amounts, some heavy metals (Zn, Cu, Co) play an essential role in the development of plants, animals and humans, but they become toxic in excess of certain concentrations; numerous heavy metals have been the object of various studies by the International Agency for Research on Cancer (IARC), and some of them were placed into one of the following categories:

- group 1: carcinogenic to humans - arsenic and inorganic arsenic compounds, cadmium and its compounds, compounds of chromium (VI);
- group 2A: probably carcinogenic - cobalt, in combination with tungsten carbide, inorganic lead compounds;
- group 2B: possible carcinogenic - metallic nickel, its compounds and alloys, lead, cobalt sulfate and other soluble compounds of cobalt (II) (Agents Classified by the IARC).

Heavy metals accumulated in medicinal plants could be a potential source of toxicity to humans due to its bioaccumulation along the food chain, especially when concentrations exceed the nominal limit.

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Suruchi and Khanna (2011) evaluated crop production on soils contaminated with heavy metals in urban areas and their surroundings in Agra, India, and observed high concentrations of heavy metals in plant tissues, which indicated a potential risk to human health.

A study was conducted in China on the medicinal species *Blechnum orientale* to determine its ability to accumulate heavy metals. Zhu et al. (2013) analyzed individuals of that species in polluted and unpolluted sites and determined the concentrations of heavy metals (Cu, Zn, Mn, Pb, Cd, Cr, As and Hg) in leaves and roots. The average values for Pb, As, Hg, Cd and Cu in the leaves of the samples of *Blechnum orientale* in the polluted site were 66, 5.6, 0.4, 7.5 and 21.7 mg/kg, which indicated exceeding the limits established for medicinal plants, and thus hazardous potential effects on human health.

2. PTERIDOPHYTES AND PHYTOREMEDIATION

It is considered that ferns could present new adaptations to the action of stress factors as a result of the wide geographical spread and the diversity of the habitats in which they vegetate, adaptations that could allow them, among other things, hyper-accumulation of metals. They are excellent models for experimental research, being used to develop rapid and efficient methods to test, for instance, the toxicity of pollutants affecting the spores and gametophytes.

Since 1980 (Petersen et al., 1980) experiments have been conducted for metal toxicity affecting the germination of spores, and the following findings were reported:

- the percentage of germinated spores in *Onoclea sensibilis* is inversely proportional to the concentration of heavy metals (Hg, Cd, Co) used (Petersen et al., 1980);
- spore germination in the species *Pteris vittata* was not inhibited by high concentrations of As (≤ 2500 ppm) (Barger et al., 2007);
- Cu shows an inhibitory effect on the germination of spores in *Polypodium cambricum* (Muccifora, 2008);
- in the species *Pteris confusa* it was found that the spores germinated in the control sample and the samples of 120 and 140 ppm concentrations of Zn, while in *P. argyraea* the maximum percentage of germinated spores was recorded in the control sample and the 140 ppm Zn variant, and in the 120 ppm Zn variant the spores did not germinate (Irudayaraj et al., 2011).

Starting from phytotoxicity tests, *ex situ* and *in situ* studies were carried out in order to determine the ability of ferns to accumulate heavy metals for use in phytoremediation.

To determine whether a species is suitable for phytoremediation a number of determinations are conducted, calculating the translocation factor (the ratio of metal concentration in above-ground tissues and the root concentration) and bioaccumulation (the ratio of metal concentration in the soil and the concentration in above-ground tissues).

A species belongs to the hyperaccumulating type if it accumulates more than 100 mg/kg Cd, 1,000 mg/kg As/Co/Cu/Pb/Ni, 10,000 mg/kg Mn/Zn in its above-ground parts, and if it has a translocation and bioaccumulation factor higher than 1. Ma et al. (2001) found that, in China, the species *Pteris vittata* can grow in soils contaminated with arsenic and accumulate large amounts of arsenic in its higher (above-ground) biomass: 3,280-20,000 ppm. The plant was also tolerated on soil of 1,500 ppm arsenic concentrations, while most plants cannot survive in 50 ppm concentrations.

Pityrogramma calemelanos (Francesconi et al., 2002) and several species of the genus *Pteris* (Ma et al., 2001; Meharg and Hartley-Whitaker, 2002; Zhao et al. 2002), are reported to be hyperaccumulators of arsenic. However, not all species of *Pteris* are hyperaccumulators, and researches attempt to identify characteristics of species that accumulate arsenic (McGrath et al., 2002).

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Also, for a species to be suitable for phytoremediation it should not show sensitivity to toxicity. *Asplenium australasicum* and *A. bulbiferum* were able to accumulate As up to 1,240 and 2,630 µg As/g dry weight (DW) in the leaves after 7 days, in the variants with a 100 mg/L concentration of As, hence a larger translocation factor. However, being As sensitive species, they showed symptoms of toxicity. For this reason, these species are not recommended for phytoremediation of soils contaminated with As, at least not in those whose concentrations are higher than 50 mg/l (Sridokchan et al., 2005).

Phytoremediation using ferns can be done by: phytovolatilisation, phytostabilization / phytoimmobilization, phytoextraction / phytoaccumulation / phytoabsorbtion / phytocapturing.

1.Phytovolatilisation involves absorption of some metaloids or heavy metals from the soil, conveying them to the leaves and transforming them into volatile compounds in the stomata. As has been successfully volatilized in the leaves of the species *Pteris vittata* as As compounds (Sakakibara et al., 2010).

Phytovolatilisation is the most controversial method of phytoremediation because some authors (Atkinson et al., 1990; Heaton et al., 1998) argue that it cannot be used for phytoremediation of soils contaminated with Se and Hg, and the inorganic forms of these elements are removed, and the gaseous forms are not likely to be redeposited in the affected site or close by, and are less toxic than the inorganic forms in the soil. Other authors believe that this method is limited because the pollutant is not completely eliminated, but only transferred from one living environment (soil) to another (atmosphere), whence it can be redeposited (Padmavathiamma and Li, 2007). There are also inconsistencies as far as the risks to human and environment are concerned, when using this method: some researchers have reported that such volatile compounds released into the atmosphere are dispersed and diluted so that there are no risks (Lin et al., 2000; Meagher et al., 2000), while others (Heaton et al., 1998; Rugh et al., 2000) recommend that this method should not be applied near urban centers or rural areas, or in places with unique weather conditions which can cause rapid deposition of volatile compounds.

2.Phytostabilization/phytoimmobilization involves reducing the mobility and bioavailability of heavy metals in the soil. *Nephrolepis cordifolia* and *Hypolepis muelleri* were identified as possible candidates in the phytostabilization of Cu, Pb, Zn and Ni in contaminated soils. Similarly, *Dennstaedtia davallioides* is favourable for use in phytostabilization of soils contaminated with Cu and Zn. These species had higher survival rates and accumulated high amounts of the metals mentioned above (Kachenko et al., 2007). *Polypodium cambricum* is more resistant to Zn, while *Pteris vittat* suffered due to unrestricted absorption, which resulted in macroscopic and microscopic injury and death of plants. The results suggest that *Polypodium cambricum* may be appropriate for phytostabilization of Zn contaminated soils in temperate regions. (Roccotiello et al., 2010)

Species *Adiantum capillus-veneris* had the highest concentration of As in the roots (up to 1,190 µg As/g DW), and only up to 370 µg As/g DW in the leaves), resulting in a decreased translocation factor (0 31), which suggests that there exist some mechanisms of As exclusion (Sridokchan et al., 2005).

Phytostabilization cannot be applied to heavily contaminated soils because plants will not grow, and the heavy metals in the soil are not removed, which requires constant monitoring (Berti and Cunningham, 2000).

3.Phytoextraction / phytoaccumulation / phytoabsorbtion / phytocapturing is performed using hyperaccumulating species that absorb heavy metals in the roots and carry them into the biomass above the ground.

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Athyrium yokoscense accumulates Pb in its tissues (Nishizono et al., 1987), and its gametophyte also shows tolerance to Pb, which it also accumulates (Kamachi et al., 2005).
Pteris cretica and *P. umbrosa* accumulated most As in the leaves (up to 3,090 μg As/g DW), and in the rhizomes only up to 760 μg As/g DW. They can be used for phytoremediation of sites contaminated with As, due to their ability to tolerate high concentrations of As, and also the hyperaccumulation of that metal (Sridokchan et al., 2005).
Three species of ferns were able to accumulate more Se in their leaves than in their roots: *Davallia griffithiana* – treated with selenats, *Pteris vittata* treated with selenate, and *Actiniopteris radiata* regardless of its forms. *Actiniopteris radiata* was the species that had the best results in terms of accumulating Se (Srivastava et al., 2005). *Pteris cretica* can accumulate large amounts of As and Sb; the highest concentration recorded was 1,677.2 mg/kg, and 1,516.5 mg/kg in the leaves. The results show that this fern can hyperaccumulate As and Sb simultaneously, consequently it is used in the phytoremediation of soils contaminated with these metals (Feng et al., 2009). The species *Adiantum philippense* recorded the most significant level of Pb and Ni concentration in the leaves, and *Adiantum caudatum* had the best absorption coefficient for Pb, Ni and Co (Pongthornpruek et al., 2008). Phytoextraction is the most common method of phytoremediation. Its efficiency depends on there being hyperaccumulating plants, which need to grow rapidly and produce large amounts of biomass, on climatic factors, and on soil characteristics: pH, soil texture, soil moisture and soil temperature, the activity of microorganisms, organic compounds, etc.
Most species of the genus *Pteris* are of the As hyperaccumulating type, and can be used in different countries for phytoremediation of soils contaminated with that metal:

- *P. vittata* has met all criteria to be used as a hyperaccumulator in phytoremediation of soils contaminated with As in Nigeria (Oloyede et al., 2013);
- *P. umbrosa* is the most suitable for phytoremediation in Northern Iran due to its increased resistance to the environmental conditions in the area (Saffari et al., 2008);
- *P. cretica* and *P. vittata* are able to accumulate As in the field conditions to be met with in the Chinese Southern province of Hunan (Wei and Chen, 2006).

3. CONCLUSIONS

Pteridophytes include species in which the potential was proven to be used in phytoremediation by phytovolatilisation, phytostabilization / phytoimmobilization, phytoextraction / phytoaccumulation / phytoabsorbtion / phytocapturing. Selecting the phytoremediation method is done taking into account, on the one hand, the mechanisms involved in phytoremediation processes, and on the other hand, the type of soil, the type of metal, the extent and level of contamination, as well as the environmental impact.

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ISSN: 2284-9521
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