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Nickel uptake in hydroponics and elemental profile in relation to cultivation reveal variability in three *Hypericum* species

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Highlights

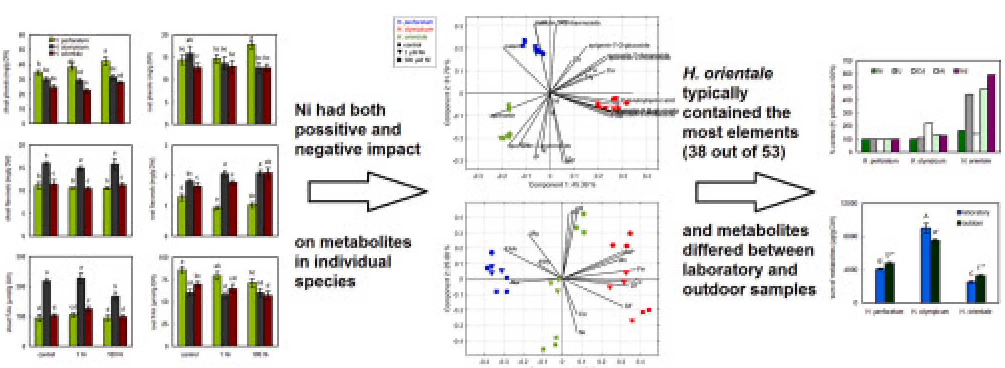
- Uptake of Ni by 3 Hypericum species in hydroponics and 53 elements were monitored.
- The highest Ni amount in *H. olympicum* depleted quercetin glycosides and amino acids.
- Essential elements, but not Co or Na, were typically depleted by Ni excess.
- Outdoor plants had more phenols than laboratory ones, but not *H. olympicum*.

- *H. orientale* control contained the most elements (up to 38) in soil or hydroponics.

Abstract

The Hypericum species (*H. perforatum*, *H. olympicum,* and *H. orientale*) were cultured in hydroponics with excess nickel (Ni, 1 or 100 μM Ni) to compare the metallic and metabolite content. Identical species were collected outdoor to assess the same parameters (including uranium and lanthanides) with total of 53 elements. The results showed that Ni was less accumulated in shoots in hydroponics (translocation factor of 0.01–0.25) and the highest absolute amount was detected in *H. olympicum*. Essential elements were typically depleted by Ni excess, but Co and Na increased. Soluble phenols, sum of flavonols and catechin rather increased in response to Ni but quercetin glycosides and free amino acids decreased in the shoots of *H. olympicum* mainly. Comparison of laboratory and outdoor growing plants showed more phenols in outdoor samples but not in *H. olympicum* and individual metabolites differed too. Plants cultured in hydroponics contained lower amount of non-essential, toxic and rare earth elements (30–100-fold) and shoot bioaccumulation factor in outdoor samples was low for most elements (<0.01) but not for Cd and Pt. Data reveal that *H. olympicum* is a potent source of phenolic metabolites whereas *H. orientale* accumulates many elements (38 out of 53 elements).

Graphical abstract



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Introduction

Nickel (Ni) is an essential "ultramicronutrient" for some plant species and is frequently found in the environment, including urban and agricultural soils, with levels above 200 mg Ni/kg of soil considered to be contaminated soils (Kováčik et al., 2011; Kováčik et al., 2012; Pavlova and Karadjova, 2013). If tested under laboratory conditions and/or in hydroponics, Ni toxicity is typically lower compared to other metals such as Cd but it is not a general rule for all species (Kováčik et al., 2019). Ni uptake differs in relation to plant species and/or experimental setups though various species in the same study were rather rarely compared (Soudek et al., 2009; Antokniewicz et al., 2016).

Plants contain small amounts of about 90 elements, only some of which are essential for them: if we consider Hoagland's solution (with some modifications), it contains 12 nutrients (Supplementary Table S1). Non-essential, toxic and rare elements are commonly present in the soil (Ramos et al., 2016; Modabberi et al., 2018; Cicchella et al., 2020) and taken up in plants but their accumulation in plants has only rarely been complexly studied (Bonanno, 2011; Kováčik et al., 2014; Dołęgowska et al., 2022). These elements are often taken up depending on their availability in the soil, although this is not a general phenomenon (Kováčik et al., 2016), and they can pose a health risk if they accumulate in excessive amounts in crops or medicinal plants (Kováčik et al., 2012; Kováčik et al., 2014; Valivand and Amooaghaie, 2021a). However, mainly the quantification of trace elements including so-called the rare earth elements (REE) is not frequent because it needs sensitive techniques (Dołęgowska et al., 2022).

Unlike animals, plants produce a variety of metabolites, among which phenolic compounds are quantitatively abundant. They can contribute to the antioxidant protection and other physiological processes of plants by several mechanisms and, in terms of human nutrition, they are potent antioxidants with a wide range of health benefits (Franklin and Dias, 2011; Kováčik et al., 2012; Kováčik et al., 2019; Singh et al., 2021).

The *Hypericum* genus includes ca. 500 species of herbs or shrubs with numerous health positive effects (Franklin et al., 2017). Despite the numerous species of this genus, *Hypericum perforatum* in particular has been studied in terms of metal excess and subsequent effect on metabolites under laboratory conditions (Babula et al., 2015; Kováčik et al., 2022). Several reports from the real field conditions also reported the accumulation of metals in *H. perforatum* originated from Czech Republic (Sládková et al., 2015), Italy (Bonari et al., 2019), Bulgaria (Pavlova and Karadjova, 2013) or Turkey (Kadioglu et al., 2005).

Therefore, we selected three *Hypericum* species for this research to assess the effect of excess Ni on its uptake and accumulation of essential elements in hydroponics along with quantification of selected phenolic metabolites by LC-MS. At the same time, these species can survive the winter period in real soil conditions in Slovakia (*H. perforatum* is a native species), so we can compare the accumulation of non-essential, toxic and rare elements in plants growing outdoors and in hydroponics. Although the accumulation of toxic or rare elements in hydroponics may arise from pre-cultivation in sand or from distilled water used for cultivation, differences between species can still be expected. Analyses of plants and respective soil samples were precisely done with ICP-MS device, and to our knowledge, no such data are available for the genus *Hypericum*. Phenolic metabolites quantified as a function of cultivation method is another original aspect of this work, and correlations between elements or between metals and metabolites were also evaluated.

Section snippets

Cultivation of plants and experimental design

Fourteen-day old seedlings of *Hypericum perforatum*, *Hypericum olympicum* and *Hypericum orientale* (seeds originated from the Centre of Medicinal Plants, Masaryk University in Brno) pre-cultured in sand were placed to 1/4 strength of Hoagland solution (i.e. macronutrients reduced to 1/4) containing 1.01 mM $Ca(NO_3)_2.4H_2O$, 0.13 mM $(NH_4)H_2PO_4$, 1.51 mM KNO_3, 0.4975 mM $MgSO_4.7H_2O$ and standard dose of micronutrients (μM): 125 NaOH, 288 KOH, 89.2 EDTA, 89.6 $FeSO_4.7H_2O$, 9.68 H_3BO_3, 2.03 $MnCl_2.4H_2O$, 0.314…

General responses of plants

No growth retardation was observed in response to Ni excess (probably due to the use of older seedlings and subsequent longer cultivation of plants in hydroponics). In addition, no chlorotic symptoms were visible as evidence of mineral nutrient depletion.…

Accumulation of Ni and essential elements in hydroponically-grown plants

Ni accumulation increased with increasing external dose from 1 to 100 μM Ni in both shoots and roots, but the intensity varied: an approximately 10–30-fold increase was observed in shoots and an approximately 100–240-fold increase in roots (…

Conclusions

This study revealed that Ni accumulated most in *H. olympicum* growing in hydroponics (67.9 and 2433.9 μg/g DW in shoots and roots, respectively, when treated with 100 μM Ni) and that essential elements were rather suppressed by excess Ni in all species (except Co and Na). High Ni accumulation in *H. olympicum* could be a reason for depletion of free amino acids and some individual phenolic metabolites (quercetin glycosides mainly) in the shoots (and significant negative correlations were…

Author contribution

Experimental design, plant cultivation and spectrophotometry (JK and MV), assay of elements (LH and JP), LC-MS analyses (GG and YR), statistics (JK and LH), manuscript preparation (JK) and manuscript revision (LH and YR).…

Role of the funding sources

Sponsor had no involvement in the present study.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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