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Introduction

Environmental pollution by heavy metals represents a major threat to human, animal and plant health [1,2]. Nowadays, land contamination with heavy metals has become a serious problem in the world. In Tunisia, saline depressions with low population levels, o en represent a sink of industrials and urban waste and many of them are contaminated by Cd^{2+}, $Pb^{2+}$and Ni^{2+} [3]. Heavy metals are released into environment by natural and anthropogenic sources. e most signi cant anthropogenic sources are Human activities, particularly industry, urbanism and agricultural practices [4]. Among heavy metals, Nickel (Ni) is recognized as a dangerous environmental pollutant [5]. It has adverse e ects on human health such

phytoremediation, has emerged as a promising technology contributing to reduce the concentrations of Ni in contaminated soils to acceptable levels within a reasonable time frame. is approach based on the capability of selected plants to grow and accumulate metals is an environmental-friendly and relatively cheap technique comparatively to physicochemical methods [16,17]. Phytoremediation includes phytoextraction, phytostabilization, phytovolatization and rhizo ltration [18]. As far as heavy metals are concerned, phytoextraction is especially suitable since those p n,uitane depth from Borj-Cedria region (30 km north of Tunis). The following soil properties were determined: pH (in water) 7.6; K^+ (0.38 µequiv. g^{-1}soil); Na^+ (1.31 µequiv. g^{-1}soil); Ca^{2+} (255.59 µequiv. g^{-1}soil); electric conductivity EC (86.66 µs cm^{-1}); organic matter content (0.47%). The sandy-loam soil was distributed into 24 large plastic pots, each containing 5 kg of air-dried soil. For Ni treatments, the soil was artificially contaminated with 25, 50 and 100 µg Ni g^{-1}soil. Ni was added as aqueous solution of $NiCl_2$ in one dose at the beginning of the experiment. After adding Ni^{2+}, the soil was equilibrated for 21 days during three cycles of saturation with tap water and was thereafter air dried.

Culture condition

Seeds of *Mesembryanthemum crystallinum* and *Brassica juncea* were sown directly in soil, in order to obtain uniform seedlings. Four weeks-old seedlings were selected and transplanted into each pot (3 plants per pot). The experiment was conducted for a period of three-months and it carried out in an open-air area under natural light and ambient temperature, in order as to keep all plants under conditions as similar as possible to those in the field.

Plant growth

At harvest, shoots were harvested and successively rinsed three times with cold water and blotted between two layers of filter paper. Roots were carefully removed from the substrate and dipped in a cold solution of HCl (0.01 M) during 5 min to eliminate heavy metals adsorbed at the root surface, and then washed three times with cold distilled water and blotted dry with filter paper. The fresh weight was immediately estimated, and the dry weight was measured after 48 h of desiccation in an oven at 60°C.

Nutrient concentrations and nickel accumulation

Dried samples (*c.a.* 300 mg) were ground to a fine powder using a stain-less mill and digested by concentrated HNO_3 (10 ml) in a microwave digester (ETHOS D, milestone, Italy) at 100°C. Thereafter, Ni and nutrients concentrations were measured by inductively coupled plasma mass spectrometry (ICP-MS; Perkin Elmer, Sciex-Elan 5000).

Bioconcentration factor: The Ni^{2+} uptake, was depicted by a bioconcentration factor (BCF), provides an index of the ability of the plant to accumulate Ni^{2+} with respect to the concentration of this pollutant in the soil [28]. It is calculated as follows:

e photosynthetic pigments of Ni-treated *B. juncea* plants was adversely impacted as re ected by the signi cant decrease of Chl a, Chl b, and total Chl concentrations (Table 2). For instance, compared to the control, the reductions recorded at 100 µM $NiCl_2$ in Chl a, Chl b and total Chl were 39%, 55%, 44%, respectively. In contrast, for *M. crystallinum* plants, Ni^{2+} led to a slight decrease of Chl a, Chl b and total Chl concentrations, excepting in the 100 µM $NiCl_2$ dose, Ni-treated *M. crystallinum* plants showed a signi cantly higher Chl concentration as compared to the control (Table 2). For both species, the carotenoid concentration was generally constant following Ni exposure, whereas it decreased signi cantly in *B. juncea* at the highest $NiCl_2$ concentration (Table 2).

Ni^{2+} accumulation and translocation

In treated plants, Ni^{2+} concentrations increased markedly in both under- and above-ground organs following Ni exposure (Table 3). It is noteworthy that roots of both *B. juncea* and *M. crystallinum* accumulated much more Ni^{2+} than did shoots. *M. crystallinum* shoot Ni^{2+} concentrations were signi cantly higher than *B. juncea* (for instance 78 µg g^{-1} DW and 57 µg g^{-1} DW at 100 µM $NiCl_2$ respectively), the same trend was also observed in roots (for instance 371 µg g^{-1} DW and 152 µg g^{-1} DW at 100 µM $NiCl_2$ respectively). e phytoextraction potential of a given species depends not only on metal shoot concentration but also on shoot biomass production. In terms of shoot Ni^{2+} content (calculated as the product of the shoot metal concentration by its biomass), *M. crystallinum* translocated more Ni^{2+} toward shoots as compared to *B. juncea* irrespective of $NiCl_2$ concentration (Figure 3). For instance, at 100 µM $NiCl_2$, shoot Ni^{2+} contents were 141 µg $plant^{-1}$ and 66 µg plant *crystallinum* seedlings, such toxicity symptoms were not observed even at a shoot tissue concentration higher than 78 µg g^{-1} dry mass. In both species, Ni negatively affected the plant growth (Figure 1). Biomass productivity of shoots and roots were significantly reduced in response to Ni stress, with root being more impacted than shoot (Figure 2a and 2b). The analysis of total chlorophyll concentrations in apical leaves (Table 2) confirmed that *B. juncea* was more sensitive to nickel than *M. crystallinum*. The severe Ni-induced leaf chlorosis observed in *B. juncea* was associated with lower pigment concentrations in leaves as previously reported in Ni-treated *Hordeum vulgare* and *Triticum aestivum* seedlings [33,34]. The abovementioned Ni-related impact on the plant phenotype and/or biomass production may result from direct (toxicity of Ni^{2+} accumulated in tissues) and/or indirect factors, including the

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