Journal of Bioresource Management

Volume 10 | Issue 1 Article 2

Morphological and Physiological Responses of a Halophyte (Atriplex Halimus) to the Effect of Heavy Metal Case of Cadmium

Abderrezzeq Chebout
Bioactive Molecules and Applications Laboratory. Faculty of Exact Sciences and Natural and Life Sciences. Echahid Cheikh Larbi Tebessi University Algeria, abderrezzeqchebout@gmail.com

Hana Souahi
Water and Environment Laboratory. Faculty of Exact Sciences and Natural and Life Sciences, Echahid Cheikh Larbi Tebessi University. Algeria, s.hanauniv@yahoo.fr

Zahia Kadi
Functional Ecology and Environment Laboratory, Faculty of Exact and Natural Sciences and Life Sciences, University of Oum el Bouaghi. Algeria., kadizahia6@yahoo.fr

Rania Gacem
Bioactive Molecules and Applications Laboratory. Faculty of Exact Sciences and Natural and Life Sciences. Echahid Cheikh Larbi Tebessi University Algeria., gcm.rania@hotmail.com

Recommended Citation

Chebout, A., Souahi, H., Kadi, Z., & Gacem, R. (2023). Morphological and Physiological Responses of a Halophyte (Atriplex Halimus) to the Effect of Heavy Metal Case of Cadmium, *Journal of Bioresource Management, 10* (1).
ISSN: 2309-3854 online
(Received: Oct 3, 2022; Accepted: Dec 13, 2022; Published: Mar 30, 2023)

Morphological and Physiological Responses of a Halophyte (Atriplex Halimus) to the Effect of Heavy Metal Case of Cadmium

Chebout et al., (2023). Effects of Cadmium on a Halophyte (*Atriplex halimus*).
J Biores Manag., 10(1):08-23

MORPHOLOGICAL AND PHYSIOLOGICAL RESPONSES OF A HALOPHYTE (*ATRIPLEX HALIMUS*) TO THE EFFECT OF HEAVY METAL CASE OF CADMIUM

ABDERREZZEQ CHEBOUT[1*], HANA SOUAHI[2], ZAHIA KADI[3], AND RANIA GACEM[1]

[1] Bioactive Molecules and Applications Laboratory. Faculty of Exact Sciences and Natural and Life Sciences. Echahid Cheikh Larbi Tebessi University Algeria.
[2]Water and Environment Laboratory. Faculty of Exact Sciences and Natural and Life Sciences, Echahid Cheikh Larbi Tebessi University. Algeria.
[3]Functional Ecology and Environment Laboratory, Faculty of Exact and Natural Sciences and Life Sciences, University of Oum el Bouaghi. Algeria.

Corresponding author's email: abderrezzeq.chebout@univ-tebessa.dz, abderrezzeqchebout@gmail.com

ABSTRACT

Today, cadmium (Cd) contamination challenges the environmental quality and food security. This experiment was realized to study the morphological and physiological response of the halophyte species *Atriplex halimus* L to cadmium toxicity by applying different concentrations of Cd (0, 500, 1000, 1500, 2000 ppm) on the plant *A.halimus* for two weeks after 60 days of seeding. The morphological parameters and physiological wish evaluated the stem length (SL), root length (RL), leaf area (LA), chlorophylls (a, b, t and carotenoids), and the relative water content (RWC). The results show a decrease in stem elongation, (11.333 ± 3.512 cm in Cd treatments of 2000 ppm), roots (9,500 ± 3,775 cm in Cd treatments of 1000 ppm), and leaf area (1,675 ± 0,816 cm2 in Cd treatments of 2000 ppm) compared to the control. As well as a decrease in the quantity of chlorophyll which ranged from 1088,308 to 972,383 µg/g FM. Finally, it is observed that the accumulation of heavy metals affects the physiological and morphological status of plants. The findings suggest that *Atriplex halimus* L is tolerant to heavy metals, and could be used for phytoremediation of soils contaminated by trace elements.

Keywords: *Atriplex halimus* L. cadmium, morphological parameters, physiological parameters, phytoremediation.

INTRODUCTION

Environmental harm caused by Heavy metals can bio-accumulate across biological chains, are persistent, non-biodegradable, and have a lengthy biological half-life. If consumed in excess, they can have adverse health effects on humans. (Haware and Pramod, 2011). The actual cause of rapid HMs pollution of arable soils and the environment is various anthropogenic activities and industrial processes, as well as chemical discharges into freshwaters (Souahi et al., 2021a). Because of its high water solubility, relative mobility, and long biological half-life, one of the most dangerous metals for plants is Cadmium (Wang et al., 2014). When Cadmium is accumulated in the plant tissue, it causes symptoms such as cell death, chlorosis, wilting, and diminished growth (Benavides and Gallego, 2005; Finger-Teixeira et al., 2010). The process of photosynthesis is sensitive to this metal because it harms photosystems I and II (Li et al., 2015; Mesnoua et al., 2016). Recent studies show that *A. halimus* is a hyper tolerant species at high Cd concentrations up to 400 mM (Lefevre et al., 2010; Nedjimi and Daoud, 2009) and Perez-Esteban et al., 2013 indicated that it was a suitable species for phytostabilizing metals in mine soils.

Atriplex halimus L. (Chenopodiaceae) est une xérohalophyte pérenne et native des régions méditerranéennes arides et semi-arides (Lotmani and Mesnoua, 2011). This species has adaptations in its morphology, anatomy, biochemistry, and physiology to extreme conditions (Walker and Lutts, 2014). These plants have adapted to the harsh conditions of semi-arid environments (Souahi et al., 2022). The species of perennial plants exhibit strong resistance to a variety of abiotic stressors, such as salinity (Bajji et al., 2002), drought (Martinez et al., 2004), cold (Walker et al., 2008), and TMEs (Mateos-Naranjo et al., 2013; Bankaji et al., 2014). Their tolerance to heavy metals may, at least partly, rely on common physiological mechanisms (Souahi et al., 2021c). This study aims to examine the tolerance mechanisms of this plant to cadmium toxicity at increasing concentrations (0, 500, 1000, 1500, 2000 ppm) on morpho-physiological parameters of *Atriplex halimus* L. and the phytoremediation potential in contaminated soils.

MATERIALS AND METHODS

Plant Material

Seeds of A. halimus were collected in December 2021 from a wild population growing in the semi-arid Aïn Zitoun area in the province of Oum El Bouaghi, North-East Algeria.

The seeds were placed in Alveolus for one month. Afterward, the seedlings were individually moved to fill pots with soil and placed in a glasshouse. Three times every week, the pots were irrigated (twice with distilled water and once with Hoagland nutrient solution **(**Hoagland and Arnon, 1950). Five Cd treatments were applied to the plants after 60 days of seedling culture: 0, 500, 1000, 1500, and 2000 ppm Cd (supplied as $CdSO_4$), for 15 days.

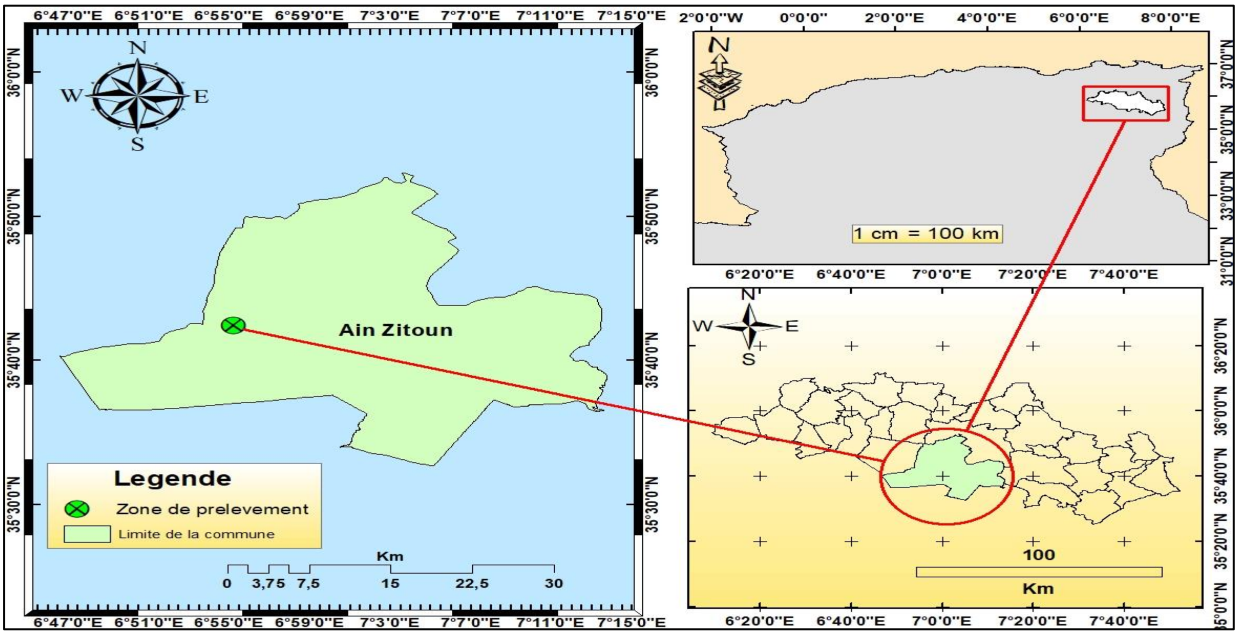

Figure 1: Geographical location of *Atriplex halimus* L. seed collection areas

Morphological Parameters

i. *Growth in Length of the Stems and Roots of the Plant*

The growth in length of the aerial and root part of the plant was measured after the application of metal stress. Stem and root length were measured in centimeters (cm).

ii. Leaf Area

Leaf area (LA) was determined according to the formula of Bezzala, (2005).

LA = ($\boldsymbol{\pi}$ **× a × b) /4**
LA: Leaf area in (cm^2).
a: The length of the limbal in (cm).
b: The width of the limbal in (cm).

Physiological Parameters

Relative Water Content (RWC %)

According to the method of Barrs and Weatherley (1962) and Scippa et al. (2004), the relative water content is determined. The following formula is used to calculate the relative water content RWC %:

RWC (%) = [(Fw- dw) / (ftw- dw)] x 100
Fw: fresh weight (g)
dw: dry weight (g)
ftw: full turgor weight (g)

Determination of the Chlorophyll Content

The extraction of photosynthetic pigments was performed based on the technique of Arnon (1949) in the presence of 80% acetone. In fact 5 ml of 80 % acetone, 100 mg of fresh material was sliced into thin strips. The mixture is kept for 72 hours in total darkness and at 4°C. Chlorophylls "a" and "b" and carotenoids are determined using the extract that was obtained. Using a Jenway spectrophotometer (7035), the level of Chlorophyll (Chl) was determined by measuring the absorbance at wavelengths of 470 nm, 647 nm, and 663 nm. The pigment contents of the leaves were then determined according to the following method Lichtenthaler, (1987), the pigment contents of the leaves were then determined.

Statistical Analysis

Data processing was performed using R Version 4.1.2. Shapiro-Wilk's and Levene's test were applied to test for normality and variance homogeneity across treatments, respectively.

RESULTS

Stems and Roots Length

The results of the length (Stem, Root), Leaf area for the different concentrations of Cd applied to the demonstrated *Atriplex halimus* is shown in Table 1. In general, application of Cd decreases vegetative traits. Cd application decreased stem, root length and leaf area under 500 ppm to 2000 ppm treatments compared with the control.

i. Stems Length

The Boxplots in Fig. 2 shows that treatment with high Cd reduced stem length in the plant *A. halimus*. The maximum stem length in *A. halimus* was shown in control (21.000 ± 2.000 cm). Stem length growth gradually decreased with increasing Cd concentration. Stem length was 13.33 ± 3.786, 12.133 ± 4.500, 14.000 ± 4000, and 11.333 ± 3.512 cm in Cd treatments of 500 ppm, 1000 ppm, 1500 ppm, 2000 ppm, respectively. Our findings are consistent with those from previous results **(**Farooq et al., 2022; Abdal et al., 2021; Abdel Latef et al., 2021; Faiz et al., 2021; Haque et al., 2021; Luyckx et al., 2021; Mitra et al., 2018).

ii. Roots Length

Shapiro Wilk test showed that Cd concentration affected the root length, where it varied from 14.000 to 9.500 cm. The highest root length values were observed in control, Where averaged 14.000 ± 2.646 cm.

Table 1: stem and root length, leaf area in *Atriplex halimus* plants after 15-d growth on a soil with different Cd concentrations

Variable	0 ppm	500 ppm	1000 ppm	1500 ppm	2000 ppm
Stem length	21.000 ± 2.000	13.333 ± 3.786	12.133 ± 4.500	14.000 ± 4.000	11.333 ± 3.512
Root length	14.000 ± 2.646	12.500 ± 1.500	9.500 ± 3.775	10.900 ± 3.651	10.600 ± 4.084
Leaf area	3.794 ± 1.673	1.845 ± 0.981	3.164 ± 1.775	2.549 ± 0.640	1.675 ± 0.816

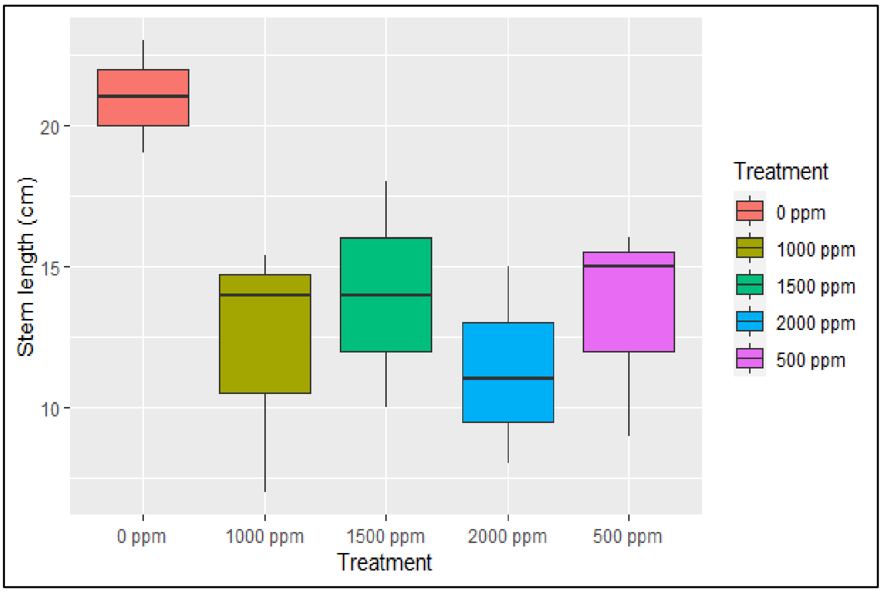

Figure 2: Boxplots displaying the effect of application high treatments of Cd (500 ppm, 1000 ppm,1500 ppm, 2000 ppm) on stems length in the plant *A. halimus* according to Shapiro Wilk test

The root length of treatment 500 ppm was the least affected with a mean of 12.200 ± 1.500 cm. the highest inhibition rate of the root length was observed at 1000 ppm. Compared with the control group with a mean of 9.500 ± 3.775 cm. (Figure 3). Previous studies have shown that Cd exposure reduces root elongation. Cadmium limited root growth, according to prior studies (Ali et al., 2022; Abdel Latef et al., 2021; Han et al., 2021; Luyckx et al., 2021; Gao and Song, 2019; Ronzan et al., 2018; Rui et al., 2016).

iii. Leaf Area

The application of Cd (500, 1000, 1500, 2000 ppm) decreased leaf area, The order of Cd treatments 1000 ppm, 1500 ppm, 500 ppm, 2000 ppm with a mean of 3.164 ± 1.755, 2.549 ± 0.640, 1.845 ± 0.981, 1.675 ± 0.816 respectively, compared to the control (Figure 4). Physiology has reportedly been negatively influenced by cd. Other research has also shown that Cadmium can significantly reduce total leaf area, which confirms our results (Zea et al., 2022; Azizi et al., 2021; Shah et al., 2021; Dai et al., 2020; Shiyu et al., 2020; Ronzan et al., 2018; Jinadasa et al., 2016).

i. Chlorophyll Content

An analysis of Chlorophyll content in *A. halimus* was performed using software R, employing the data that are shown in Table 2. With the Shapiro-Wilk test, Chl content and RWC index decreased in *A. halimus* leaves when exposed to Cd. This decrease differed according to the concentration of Cd. Disruption of photosynthesis under high levels of Cd mainly was attributed to a reduction of growth and biomass. Cd interferes with photosynthesis by damaging chlorophyll biosynthesis (Malec et al., 2010).

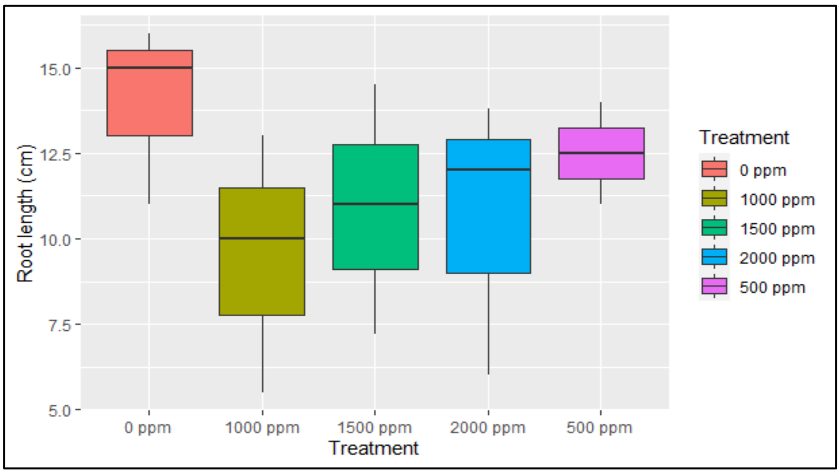

Figure 3: Boxplots displaying the effect of high application treatments of Cd (500 ppm, 1000 ppm, 1500 ppm, 2000 ppm) on roots length in the plant *A.halimus* according to Shapiro Wilk test

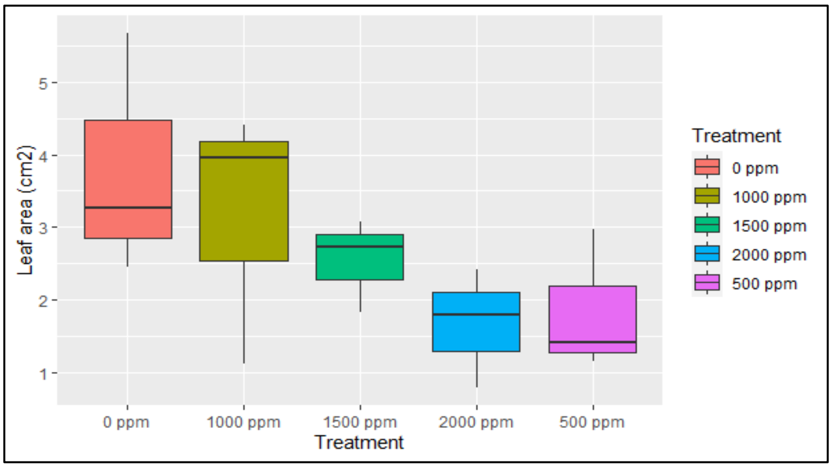

Figure 4: Boxplots displaying the effect of high application treatments of Cd (500 ppm, 1000 ppm, 1500 ppm, 2000 ppm) on leaf area in the plant *A.halimus* according to Shapiro Wilk test.

Table 2: Total chlorophyll (Chl) and relative water content in *Atriplex halimus* plants after 15-d growth on a soil with different Cd concentrations

Variable	0 ppm	500 ppm	1000 ppm	1500 ppm	2000 ppm
Chlorophyll a	712.050± 165.507	753.701 ± 186.675	780.761 ± 228.246	650.501 ± 119.349	524.825 ± 69.555
Chlorophyll b	361.640 ± 88.597	334.607 ± 39.932	354.212 ± 109.340	321.881 ± 62.313	236.741 ± 63.462
Chlorophyll t	1073.690 ± 239.417	1088.308 ± 226.581	1134.973 ± 337.020	972.383 ± 170.003	972.383 ± 170.003
Carotenoids	28.053 ± 7.451	53.455 ± 11.036	52.093 ± 20.257	50.413 ± 17.296	31.130 ± 20.694
RWC	55.423 ± 6.549	53.570 ± 19.424	64.348 ± 8.141	51.230 ± 8.156	52.194 ± 4.189

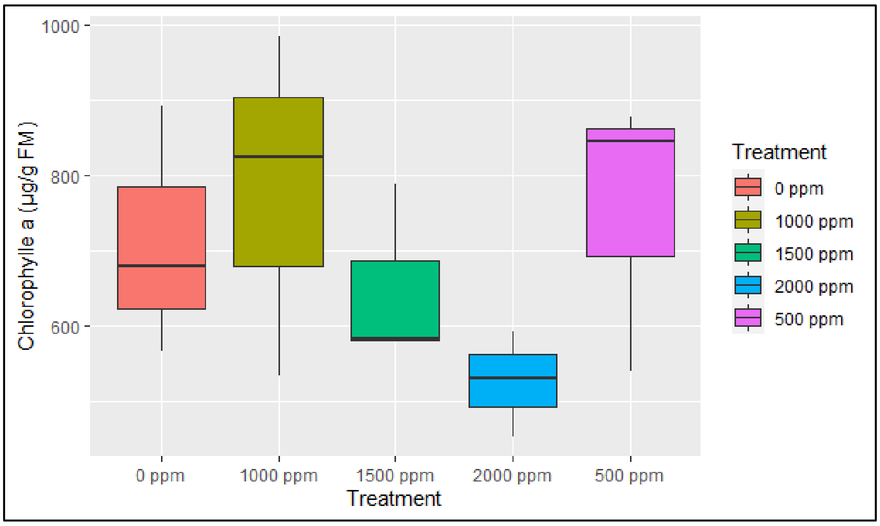

Figure 5: Boxplots graph with Shapiro Wilk test displaying the variation of Chlorophyll a in different treatments of Cd on the plant *A. halimus*

Chlorophyll A

Values of Chl a ranged between 524.825 and 780.761 µg/g FM (Fig. 5). The Shapiro Wilk test showed the variation of Chl a between the different concentrations of Cd on the plant *A.halimus* where Chl a in treatments 500 ppm and 1000 ppm was higher compared to the control 753.701 ± 186.675 µg/g FM and 780.761 ± 228.246 µg/g FM respectively. At the same time, treatments 2000 ppm of Cd indicated Chl a values 524.825 ± 69.555 µg/g FM lower than the control (table2).

Chlorophyll B

Chl b averaged 354.212 ± 109.340 in the treatments 1500 ppm, where it is ranged from 361.640 to 236.741 µg/g FM (Fig. 6). The highest Chl b values observed in control, where the Chl b averaged 361.640 ± 88.597 µg/g FM. While Chl b values in the treatments 2000 ppm were the lowest 236.741 ± 63.462 µg/g FM.

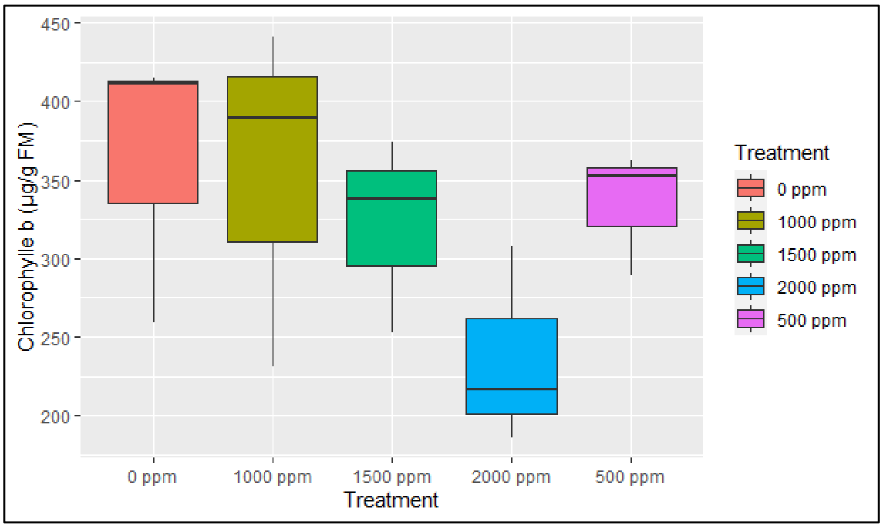

Figure 6: Boxplots graph with Shapiro Wilk test displaying the variation of Chlorophyll b in different treatments of Cd on the plant A.halimus

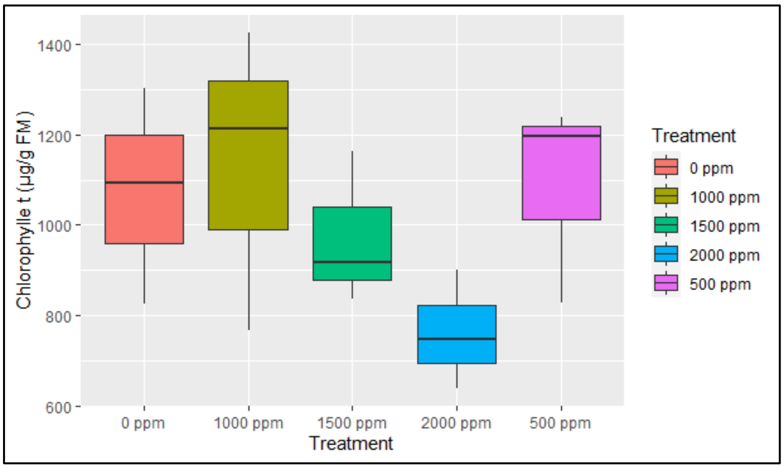

Figure 7: Boxplots graph with Shapiro Wilk test displaying the variation of Chlorophyll t in different treatments of Cd on the plant *A. halimus*

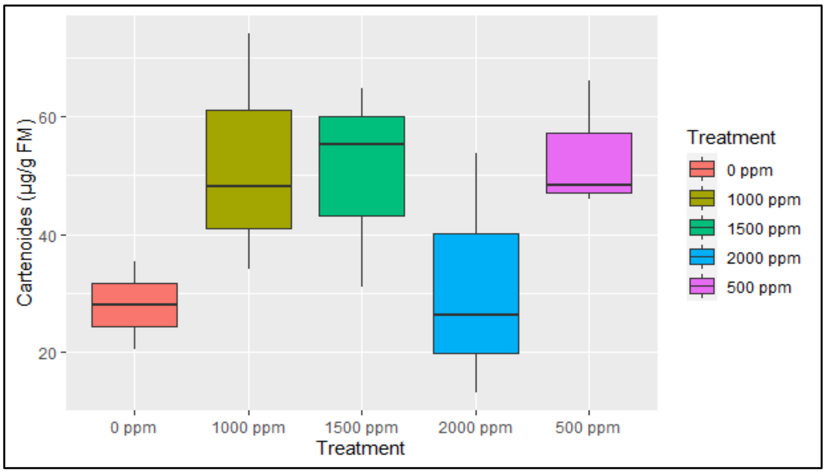

Figure 8: Boxplots graph with Shapiro Wilk test displaying the variation of Carotenoids in different treatments of Cd on the plant *A. halimus*

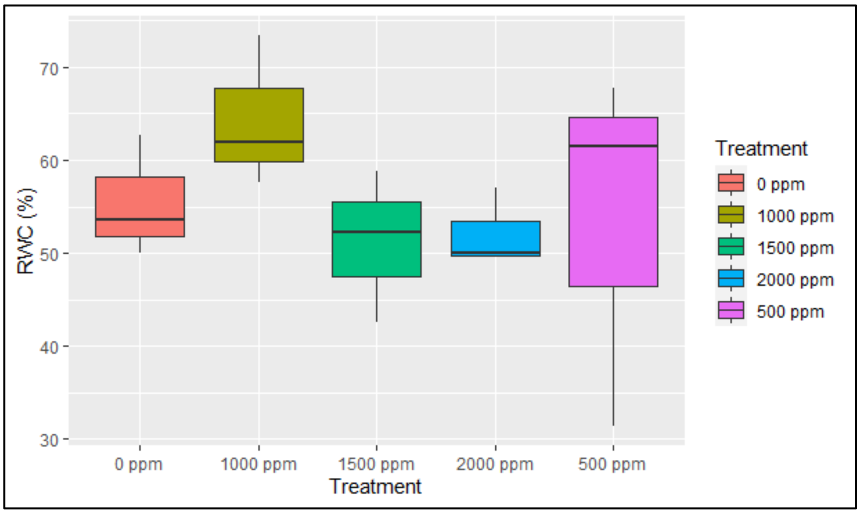

Figure 9: Boxplots graph with Shapiro Wilk test displaying the variation of RWC in different treatments of Cd on the plant *A.halimus*

Chlorophyll T

The maximum level of chl t was recorded in the treatments 1000 ppm 1134.973 ± 337.020 µg/g FM. the control followed with a mean of 1073.690 ± 239.417 µg/g FM, the treatment of 500 ppm (1088.308 ± 226.581) was classified in the third position. In contrast, the lowest was measured in treatments 1000 ppm with 761.566 ± 130.976 µg/g FM (Figure 7).

Carotenoids

All The treatments of Cd revealed significantly higher carotenoids than the control, except the treatment 2000 ppm (Table 2). The highest value was detected in the treatment 500 ppm 53.455 ± 11.036, the treatment 1000 ppm 52.039 ± 20.257, and the treatment 1500 ppm 50.413 ± 17.296 µg/g FM. Whereas the Carotenoids ratio was 28.0537.451 µg/g FM in control. Values of Carotenoids 31.130 ± 20.694 µg/g FM in the treatments 2000 ppm were not different compared to the control (Figure 8)

Relative Water Content

Boxplots graph for RWC showed high concentrations Cd (500, 1000, 1500, 2000 ppm) decreased RWC by about 53.570 %, 64.348 %, 51.230 %, 52.194 %, respectively compared to the control (Figure 9).

DISCUSSION

Reduction of physiological and biochemical processes of plant growth, usually caused by high concentrations of toxic elements (Souahi et al., 2014; Souahi et al., 2016).

The heavy metal cadmium (Cd) affects the physiological and morphological characteristics and pollutes the environment (Azizi et al., 2021). Seed germination, early seedling development, and plant biomass are all reduced by Cadmium. It affects stomatal conductance, root and shoot length, fresh and dry mass, chlorophyll levels, and gas exchange properties, as well as altering photosynthesis and other physiological processes (Hussain et al., 2021; El Rasafi et al., 2021; Rizwan et al., 2016).

There were plant species that responded to stress conditions among the ones that were researched to varying degrees, as well as plant species that significantly responded to stress conditions. (Souahi, 2021). Halophytes are widely distributed worldwide. Due to their developed morphological and physiological characteristics, such as limiting the penetration of heavy metals, they can also manage the stress related to heavy metals (Caparrós et al., 2022). The high resistance of halophytes to heavy metals, such as Atriplex have very efficient Cd ion exclusion mechanisms (Wang et al., 2013). Recent research on A. halimus L has demonstrated that these plants can accumulate significant amounts of Cd. (Kahli et al., 2021; Pérez-esteban et al., 2013).

As a non-essential mineral, Cd hurts plants. Hence it is necessary to modify the concentration of Cd in cells to support plant growth and development (Qian et al., 2022; Haque et al., 2021) Cd treatment significantly reduced biomass in all tissues (roots, stems, and leaves) (Yu et al., 2022). As the Cd level increased, the inhibition degree of growth gradually increased (Qian et al., 2022; Dai et al., 2020). The root turns into necrotic, decomposing, and mucilaginous after a long time of Cd exposure, decreasing the elongation of roots and shoots of plant life and causing leaf rolling and chlorosis (Abbas et al., 2018). Decreases in root length, dry mass, and enlargement of root diameter are due to cadmium toxicity (Grat˜ao et al., 2009). One of the precocious and apparent signs of Cd toxicity is the inhibition of root elongation (Lux et al., 2011). cadmium provokes the inhibition of root elongation; this inhibition could be attributed to the depolymerization of the cellular cytoskeleton microtubules and the formation of chromosomal aberrations, which result in a decrease of mitotic activities of meristematic cells (Seth et al., 2008). Cd adversely impacts the homeostasis of auxins, inhibiting the cell division inside the apical meristem of roots, resulting in reduced plant increase (Krishnamurthy and Rathinasabapathi, 2013).

Previously, plants' decrease in chlorophyll content was related to metal stress (Souahi et al., 2017; Souahi, 2021b). Cd exposure caused a decrease in the ontent of the total chlorophylls, significantly compromising the growth (Singh et al., 2020; Carfagna et al., 2013). Cadmium is one of the toxic heavy metals that interacts with the photosynthetic components and damage photosystems. (Bashir et al., 2015). Changes in chloroplast ultrastructure with low chlorophyll content result from changes in leaf phenology caused by Cd toxicity, leading to chlorosis and reduced photosynthetic activity (Gallego et al., 2012; Miyadate et al., 2011). The tolerance of plants to different stresses can be evaluated by changes in pigment composition (Rong-hua et al., 2006; Ramirez et al., 2014; Xue et al., 2018; Souahi, 2021). The synthesis and/or accumulation of photosynthetic pigments is negatively affected by heavy metal stress (Parmar et al., 2013; Souahi et al., 2017). For example, in a previous study on peanuts under Cd-stressed conditions, a significant decrease in chlorophyll content was observed (Dong et al., 2019). In the current study, we observed a decrease in chlorophyll a, b chlorophyll contents in *Atriplex halimus* under Cd stress at 8000ppm (Souahi et al., 2022). Our results indicate that the increase of Cd concentration induces a reduction in the process of photosynthesis and it affects the content of photosynthetic pigments in Atriplex halimus. All these changes can be considered as biomarkers of Cadmium toxicity on the plant.

The quantity of reactive oxygen species (ROS) increases in response to Cd stress, which damages structural proteins in chloroplasts (Azizi et al., 2021). Cadmium inhibits photosynthesis in most plants; the high level of Cd reduces Chl contents and inhibits electron transport in the leaves, resulting in reduced photosynthetic activity (Xue et al., 2018; Zhou and Qiu, 2005). Cadmium-responsive reduced Chlorophyll and carotenoid content may be because of the inhibition of enzymes answerable for pigment biosynthesis, and this inhibition triggered a type of senescence (Qian et al., 2009). Different concentrations of Cd significantly affect the total chlorophyll content (Małkowski et al.,2019; Sajeev et al., 2012). As a result of Cd-induced oxidative stress, Chlorophyll and carotenoid levels may fall (Cherif *et al*., 2012). Generally, the ratio of carotenoids to Chlorophyll is more critical in Cd-stressed plants therefore, carotenoids are less affected by Cd than chlorophylls (Dobrikova et al., 2017). At the same time, mature leaves lose their chlorophyll b fast due to the conversion into chlorophyll a. The reason is the interplay with the senescence signaling resulting in the interconversion of chlorophyll b into a before degradation (Ebbs and Uchil, 2008). The Cd affects photosynthesis in higher plants. As a result, in our earlier experiments, the Cd strain significantly decreased the chlorophyll contents (Chl a and b) in Atriplex (Nedjimi, 2018).

Cadmium reduces the leaf water content (Anwar et al., 2019; Mostofa et al., 2019). Due to stomatal closure in the presence of high Cd, low transpiration rate and high stomatal resistance are observed. A decrease in leaf osmotic capacity revealed an adaptive response of the plant to water stress (Rucinska-Sobkowiak, 2016). A water deficit in the leaves is a result of the reluctance of long-distance water shipment, which causes a depletion of water in the leaves (Osakabe et al., 2014). A complicated collection of water-related changes are brought about by cadmium exposure across the entire plant. Due to Cd toxicity, water absorption is reduced, and water transport is inhibited in roots (Kudoyarova et al., 2015). Cd reasons for multifaceted changes in plant life at morphological and physiological stages (Kaur and Hussain, 2020; Bączek-Kwinta, 2019). Therefore, the cultivation of *A. halimus*, which is often recommended for the phytostabilisation of metal-polluted sites, could be started by seeding.

CONCLUSION

Contamination by trace metals (TME) has become a significant environmental issue that limits plant production and poses health risks to humans. in this context that our study was conducted, which led us to analyze the effect of Cadmium on young plantlets of *Atriplex halimus*. In plants, the most directly visible effect of Cadmium is an inhibition of the growth of the aerial and root parts of *Atriplex halimus*.

The increase of Cd concentration induces a reduction of photosynthesis and inhibits chlorophyll synthesis, and all these observed changes could be taken as biomarkers of heavy metal toxicity on the plant. The Cd-induced metal stress effect is reflected in a decrease in the relative water content in *Atriplex halimus*.

Finally, *Atriplex halimus* should be exploited for soil remediation using phytoremediation approaches. These plants could constitute an attractive model for studying metal exclusion mechanisms but could also be used for cultivation on metal-contaminated soils. Our results support the hypothesis that *Atriplex halimus* L could be implicated in projects to rehabilitate Cd-contaminated soils or agro-ecosystems.

AUTHORS CONTRIBUTION

Authors’ contributions CH A designed the study, extracted the data and wrote the study manuscript. S H contributed to data analysis and interpretation the manuscript. K Z and G R read the manuscript and participated in the preparation of the final version of the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

A. CH, H. S, Z. K and R. G declare that they have no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

REFERENCE

Abbas T, Rizwan M, Ali S, Adrees M, Zia-ur-Rehman M, Qayyum MF, Murtaza G (2018). Effect of biochar on alleviation of cadmium toxicity in wheat (Triticum aestivum L.) grown on Cd-contaminated saline soil. Environmental Science and Pollution Research., 25(26):25668-25680.

Abdal N, Abbas G, Asad SA, Ghfar AA, Shah GM, Rizwan M, Shahbaz M (2021). Salinity mitigates cadmium-induced phytotoxicity in quinoa (Chenopodium quinoa Willd.) by limiting the Cd uptake and improved responses to oxidative stress: implications for phytoremediation. Environmental Geochemistry and Health., 1-15.

Abdel Latef AAH, Akter A, Tahjib-Ul-Arif M (2021). Foliar Application of Auxin or Cytokinin Can Confer Salinity Stress Tolerance in Vicia faba L. Agronomy., 11(4):790.

Ali S, Mfarrej MFB, Hussain A, Akram NA, Rizwan M, Wang X, Ali B (2022). Zinc fortification and alleviation of cadmium stress by application of lysine chelated zinc on different varieties of wheat and rice in Cadmium stressed soil. Chemosphere., 295:133829. chemosphere.2022.133829

Anwar S, Khan S, Hussain I, Bashir R, Fahad S (2019). Chelators induced uptake of Cadmium and modulation of water relation, antioxidants, and photosynthetic traits of maize. Environmental Science and Pollution Research., 26(17):17577-17590.

Arnon DI (1949). Copper enzymes in isolated chloroplasts. polyphenoloxidase in beta vulgaris. Plant Physiol. (Rockv.)., 24:1-15.

Azizi I, Esmaielpour B, Fatemi H (2021). Exogenous nitric oxide on morphological, biochemical and antioxidant enzyme activity on savory (Satureja Hortensis L.) plants under cadmium stress. Journal of the Saudi Society of Agricultural Sciences., 20(6), 417-423.

Bączek-Kwinta R (2019). Cadmium (Cd): An Emerging Regulatory Metal with Critical Role in Cell Signalling and Plant Morphogenesis. In Plant-Metal Interactions. Springer, Cham., 61-77.

Bajji M, Kinet JM, Lutts S (2002). Osmotic and ionic effects of NaCl on germination, early seedling growth and ion content of Atriplex halimus (Chenopodiaceae). Canadian Journal of Botany., 80: 297–304.

Bankaji I, Sleimi N, López-Climent, MF, Perez-Clemente, RM, Gomez-Cadenas A (2014). Effects of combined abiotic stresses on growth, trace element accumulation, and phytohormone regulation in two halophytic species. Journal of Plant Growth Regulation., 33(3): 632-643.

Barrs HD, Weatherley PE (1962). A re-examination of the relative turgidity technique for estimating water deficits in leaves. Australian journal of biological sciences, 15(3): 413-428.

Bashir H, Qureshi MI, Ibrahim MM, Iqbal M (2015). Chloroplast and photosystems: Impact of Cadmium and iron deficiency. Photosynthetica., 53(3): 321-335.

Benavides MP, Gallego SM (2005). Cadmium toxicity in plants. Braz. J. Plant Physiol., 17: 21-34. biology and uses, J. Arid Environ. 100-101 (2014) 111-121.

Bezzala A (2005). Essai d'introduction de l'arganier dans la zone de M'doukel et évaluation de quelques paramètres de résistance à la sècheresse (Doctoral dissertation, Thése de Magister en Sciences Agronomiques. Université El Hadj Lakhdar, Batna., 106p.

Caparrós PG, Ozturk M, Gul A, Batool TS, Pirasteh-Anosheh H, Unal BT, Toderich KN (2022). Halophytes have potential as heavy metal phytoremediators: A comprehensive review. Environmental and Experimental Botany., 193: 104666.

Carfagna S, Lanza N, Salbitani G, Basile A, Sorbo S, Vona V (2013). Physiological and morphological responses of Lead or Cadmium exposed Chlorella sorokiniana 211-8KChlorophyceae). SpringerPlus., 2(1): 1-7.

Cherif J, Derbel N, Nakkach M, von Bergmann H, Jemal F, Lakhdar Z B (2012). Spectroscopic studies of photosynthetic responses of tomato plants to the interaction of zinc and cadmium toxicity. Journal of Photochemistry and Photobiology B: Biology., 111:9-16.

Walker, DJ, Lutts S (2014). The tolerance of Atriplex halimus L. to environmental stresses. Emirates Journal of Food and Agriculture., 1081-1090.

Dai F, Luo G, Li Z, Wei X, Wang Z, Lin S, Tang C (2020). Physiological and transcriptomic analyses of mulberry (Morus atropurpurea) response to cadmium stress. Ecotoxicology and Environmental Safety., 205:111298.

Dobrikova AG, Yotsova EK, Börner A, Landjeva SP, Apostolova EL (2017). The wheat mutant DELLA-encoding gene (Rht-B1c) affects plant photosynthetic responses to cadmium stress. Plant Physiology and Biochemistry., 114:10-18.

Ebbs S, Uchil S (2008). Cadmium and zinc induced chlorosis in Indian mustard [Brassica juncea (L.) Czern] involves preferential loss of chlorophyll
b. Photosynthetica., 46(1);49-55.

El Rasafi T, Oukarroum A, Haddioui A, Song H, Kwon EE, Bolan N, Rinklebe J (2021). Cadmium stress in plants: A critical review of the effects, mechanisms, and tolerance strategies. Critical Reviews in Environmental Science and Technology., 1-52.

Faiz S, Shah AA, Naveed NH, Nijabat A, Yasin NA, Batool AI, Ali A (2022). Synergistic application of silver nanoparticles and indole acetic acid alleviate Cadmium induced stress and improve growth of Daucus carota L. Chemosphere., 290:133200.

Farooq MU, Ishaaq I, Barutcular C, Skalicky M, Maqbool R, Rastogi A, Zhu J (2022). Mitigation effects of selenium on accumulation of Cadmium and morpho-physiological properties in rice varieties. Plant Physiology and Biochemistry., 170;113.

Finger-Teixeira Maria de Lourdes LF, Anderson RS (2010). Cadmiu-induced lignification restricts soybean root growth. Ecotoxicol. Environ. Saf., 73:1959-1964.

Gallego SM, Pena LB, Barcia RA, Azpilicueta CE, Iannone MF, Rosales EP, Benavides MP (2012). Unravelling cadmium toxicity and tolerance in plants: insight into regulatory
mechanisms. Environmental and Experimental Botany., 83:33-46.

Gao M, Song Z (2019). Toxicity of Cadmium to wheat seedling roots in the presence of graphene oxide. Chemosphere., 233, 9-16.

Grant CA, Bailey LD, Selles F, Uckley WT (1995). Cadmium accumulation in crops, Canadian Network of Toxicology Centres National Workshop on Cadmium Transport in to Plants, WorkShop Proceedings, Ottawa.,55-71.

Grat˜ao PL, Monteiro CC, Rossi ML, Martinelli AP, Peres LEP, Medici LO, Lea PJ, Azevedo R A (2009). Differential ultrastructural changes in tomato hormonal mutants exposed to Cadmium. Environ Exp Bot., 67: 387-394.

Han T, Sun M, Zhao J, Dai C, Li Y, Zhang P, Ge S (2021). The roles of Cadmium on growth of seedlings by analysing the composition of metabolites in pumpkin tissues. Ecotoxicology and Environmental Safety., 226:112817.

Haque AM, Tasnim J, El-Shehawi AM, Rahman MA, Parvez MS, Ahmed MB, Kabir AH (2021). The Cd-induced morphological and photosynthetic disruption is related to the reduced Fe status and increased oxidative injuries in sugar beet. Plant Physiology and Biochemistry., 166:448-458.

Haware DJ, Pramod HP (2011). Determination of specific heavy metals in fruit juices using Atomic Absorption Spectrophotometer (AAS), Int. J. Res. Chem. Environ., 4(3):163-168, 2011.

Hoagland DR, Arnon DI (1950). The water-culture method for growing plants without soil. Calif. Agric. Exp. Stn. Circ., 347, 1e 32.

Hussain A, Ali S, Rizwan M, Zia-ur-Rehman M, Yasmeen T, Hayat MT, Hussain SM (2019). Morphological and physiological responses of plants to cadmium toxicity.

In Cadmium Toxicity and Tolerance in Plants. Academic Press., 47-72.

Jinadasa N, Collins D, Holford P, Milham PJ, Conroy JP (2016). Reactions to cadmium stress in a cadmium-tolerant variety of cabbage (Brassica oleracea L.): is cadmium tolerance necessarily desirable in food crops?. Environmental Science and Pollution Research., 23(6):5296-5306.

Kahli H, Sbartai H, Cohen-Bouhacina T, Bourguignon J (2021). Characterization of cadmium accumulation and phytoextraction in three species of the genus Atriplex (canescens, halimus and nummularia) in the presence or absence of salt. Plant Physiology and Biochemistry., 166;902-911.

Kaur H, Hussain SJ (2020). Cadmium: Bioavailability in Soils and Phytotoxicity. In Sustainable Solutions for Elemental Deficiency and Excess in Crop Plants . Springer, Singapore., 351-391.

Krishnamurthy A, Rathinasabapathi B (2013). Auxin and its transport play a role in plant tolerance to arsenite-induced oxidative stress in A rabidopsis thaliana. Plant, cell & environment., 36(10):1838-1849.

Kudoyarova GR, Dodd IC, Veselov DS, Rothwell SA, Yu Veselov S (2015). Common and specific responses to availability of mineral nutrients and water. Journal of Experimental Botany., 66(8):2133-2144.

Lefevre I, Marchal G, Edmond Ghanem M, Correal E, Lutts S (2010). Cadmium has contrasting effects on polyethylene glycol - sensitive and resistant cell lines in the Mediterranean halophyte species Atriplex halimus L. J. Plant Physiol., 167 :365-374.

Li S, Yang W, Yang T, Chen Y, Ni W (2015). Effects of cadmium stress on leaf chlorophyll fluorescence and photosynthesis of Elsholtzia argyi a cadmium accumulating plant. Int. J. Phytoremediation., 17:85-92.

Lichtenthaler HK (1987). Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. In Methods in enzymology. Academic Press.,148:350-382.

Lotmani B, Mesnoua M (2011). Effects of copper stress on antioxidative enzymes, Chlorophyll and protein content in Atriplex halimus. African Journal of Biotechnology., 10:10143-10148.

Lux A, Martinka M, Vacul´ık M, White PJ (2011). Root responses to Cadmium in the rhizosphere: a review. J Exp Bot., 62: 21-37.

Luyckx M, Hausman JF, Isenborghs A, Guerriero G, Lutts S (2021). Impact of Cadmium and zinc on proteins and cell wall-related gene expression in young stems of hemp (Cannabis sativa L.) and influence of exogenous silicon. Environmental and Experimental Botany., 183:104363.

Malec P, Maleva MG, Prasad MNV, Strzałka K (2010). Responses of Lemna trisulca L.(Duckweed) exposed to low doses of Cadmium: thiols, metal binding complexes, and photosynthetic pigments as sensitive biomarkers of ecotoxicity. Protoplasma., 240(1):69-74.

Małkowski E, Sitko K, Zieleźnik-Rusinowska P, Gieroń Ż, Szopiński M (2019). Heavy metal toxicity: Physiological implications of metal toxicity in plants. In Plant metallomics and functional omics. Springer, Cham., 253-301.

Martinez JP, Lutts S, Schank A, Bajji M, Kinet JM (2004). Is osmotic adjustment required forwater stress resistance in themediterranean shrub Atriplex halimus L. Journal of Plant Physiology., 161:1041-1051.

Mateos-Naranjo E, Andrades-Moreno L, Cambrollé J, Perez-Martin A (2013). Assessing the effect of copper on growth, copper accumulation and physiological responses of grazing species Atriplex halimus: ecotoxicological implications. Ecotoxicology and Environmental Safety., 90:136-142.

Mesnoua M, Mateos-Naranjo E, Barcia-Piedras JM, P´erez-Romero JA, Lotmani B, Redondo-G´omez S (2016). Physiological and biochemical mechanisms preventing Cd-toxicity in the hyperaccumulator Atriplex halimus L. Plant Physiology. Biochemestry., 106:30-38.

Mitra S, Pramanik K, Sarkar A, Ghosh PK, Soren T, Maiti TK (2018). Bioaccumulation of Cadmium by Enterobacter sp. and enhancement of rice seedling growth under cadmium stress. Ecotoxicology and environmental safety., 156:183-196.

Miyadate H, Adachi S, Hiraizumi A, Tezuka K, Nakazawa N, Kawamoto T, Akagi H (2011). OsHMA3, a P1B- type of ATPase affects root-to- shoot cadmium translocation in rice by mediating efflux into vacuoles. New phytologist., 189(1):190-199.

Mostofa MG, Rahman M, Ansary M, Uddin M, Fujita M, Tran LSP (2019). Interactive effects of salicylic acid and nitric oxide in enhancing rice tolerance to cadmium stress. International journal of molecular sciences., 20(22):5798.

Nedjimi B (2018). Heavy metal tolerance in two Algerian saltbushes: A review on plant responses to Cadmium and role of calcium in its mitigation. Plant nutrients and abiotic stress tolerance., 205-220.

Nedjimi B, Daoud Y (2009). Cadmium accumulation in Atriplex halimus subsp. schweinfurthii and its influence on growth, proline, root hydraulic conductivity and nutrient uptake. Flora Morphol. Distrib. Funct. Ecol., Plants 204:316-324.

Osakabe Y, Osakabe K, Shinozaki K, Tran LSP (2014). Response of plants to water stress. Frontiers in plant science., 5:86.

Parmar P, Kumari N, Sharma V (2013) Structural and functional alterations in photosynthetic apparatus of plants under cadmium stress. Bot Stud., 54:45.

Pérez-Esteban J, Escolástico C, Ruiz-Fernández J, Masaguer A, Moliner A (2013). Bioavailability and extraction of heavy metals from contaminated soil by Atriplex halimus. Environmental and Experimental Botany., 88:53-59.

Perez-Sirvent C, Martínez-Sanchez MJ, García-Lorenzo ML, Bech J (2008). Uptake of Cd and Pb by natural vegetation in soils polluted by mining activities. In: Fresenius Environmental Bulletin., 1666-1671.

Qian H, Li J, Sun L, Chen W, Sheng GD, Liu W, Fu Z (2009). Combined effect of copper and Cadmium on Chlorella vulgaris growth and photosynthesis-related gene transcription. Aquatic Toxicology., 94(1):56-61.

Ramirez DA, Yactayo W, Guterrez R, Mares V, De Mendiburu F, Posadas A, Roberto QA (2014). Chlorophyll concentration in leaves is an indicator of potato tuber yield in water-shortage conditions. Sci Hortic., 168:202–209.

Rizwan M, Ali S, Abbas T, Zia-ur-Rehman M, Hannan F, Keller C, Ok YS (2016). Cadmium minimization in wheat: a critical review. Ecotoxicology and environmental safety., 130:43-53.

Rong-hua L, Pei-guo G, Baum M, Grando S, Ceccarelli S (2006). Evaluation of chlorophyll content and fluorescence parameters as indicators of drought tolerance in barley. Agric Sci China., 5 :751–757.

Ronzan M, Piacentini D, Fattorini L, Della Rovere F, Eiche E, Riemann M, Falasca G (2018). Cadmium and arsenic affect root development in Oryza sativa L. negatively interacting with auxin. Environmental and Experimental Botany., 151:64-75.

Rucińska-Sobkowiak R (2016). Water relations in plants subjected to heavy metal stresses. Acta Physiologiae Plantarum., 38(11):1-13.

Rui H, Chen C, Zhang X, Shen Z, Zhang F (2016). Cd-induced oxidative stress and lignification in the roots of two Vicia sativa L. varieties with different Cd tolerances. Journal of Hazardous Materials., 301:304-313.

Sajeev S, Ramya PV, Sunitha BC, Melo JS, Hegde S (2012). Phytoremediation of Cadmium Using Pteris sp. In Prospects in Bioscience: Addressing the Issues Springer,India., 131-139.

Scippa GS, Di Michele M, Onelli, Patrignani G, Chiatante D, Bray EA (2004). The histone-like protein H1-S and the response of tomato leaves to water deficit. Journal of Experimental Botany, 55(394) : 99-109.

Seth CS, Misra V, Chauhan LKS, Singh RR (2008). Genotoxicity of Cadmium on root meristem cells of Allium cepa: cytogenetic and Comet assay approach. Ecotoxicol Environ Safe., 71:711-716.

Shah AA, Aslam S, Akbar M, Ahmad A, Khan WU, Yasin NA, Ali S (2021). Combined effect of Bacillus fortis IAGS 223 and zinc oxide nanoparticles to alleviate cadmium phytotoxicity in Cucumis melo. Plant Physiology and Biochemistry., 158:1-12.

Shiyu QIN, Hongen LIU, Zhaojun NIE, Rengel Z, Wei GAO, Chang L I, Peng ZHAO (2020). Toxicity of Cadmium and its competition with mineral nutrients for uptake by plants: A review. Pedosphere., 30(2):168-180.

Singh P, Siddiqui H, Sami F, Arif Y, Bajguz A, Hayat S (2020). Cadmium: A threatening agent for plants. In Plant Responses to Soil Pollution. Springer, Singapore.,59-88.

Souahi H (2021). Impact of lead on the amount of chlorophyll and carotenoids in the leaves of Triticum durum and T. aestivum, Hordeum vulgare and Avena sativa. Biosyst Divers., 29(3):207-210.

Souahi H, Chebout A, Akrout K, Massaoud N, Gacem R (2021a). Physiological responses to lead exposure in wheat, barley and oat. Environmental Challenges., 4 :100079.

Souahi H (2021b). Impact of lead on the amount of Chlorophyll and carotenoids in the leaves of Triticum durum and T. aestivum, Hordeum vulgare and Avena sativa. Biosystems Diversity., 29(3):207-210.

Souahi H, Chebout A, Assal N (2021c). Effects of heavy metals on the germination and radicle growth of halophytes species (Atriplex halimus l.). Studia Univ Vasile Goldis Ser Stiintele Vietii (Life Sci Ser)., 31(4):178–186

Souahi H, Gacem R, Chenchouni H (2022). Variation in plant diversity along a watershed in the semi-arid lands of North Africa. Diversity., 14(6):450.

Souahi H, Chebout A, Fares R, Sédairia L (2022). Remediation of Agricultural Soil by the Use of Halophytic Crops Under Heavy Metals Conditions in Semi-Arid Environments. Gesunde Pflanzen.

Souahi H, Gharbi A, Gassarellil Z (2017). Growth and physiological responses of cereals species under lead stress. International Journal of Biosciences., 11(1):266-273.

Souahi H, Meksem Amara L, Djebar MR (2016). Effects of sulfonylurea herbicides on protein content and antioxidants activity in wheat in semi-arid region. International Journal of Advanced Engineering, Management and Science., 2(9):1471-1476.

Souahi H, Meksem Amara L, Grara N, Djebar MR (2014). Physiology and biochemistry effects of herbicides sekator and zoom on two varieties of wheat (Waha and HD) in semi-arid region. Annual Research and Review in Biology., 5(5):449-459.

Walker DJ, Romero P, Hoyos A, Correal E (2008). Seasonal changes in cold tolerance, water relations and accumulation of cations and compatible solutes in Atriplex halimus L. Environmental and Experimental Botany., 64:217-224.

Wang Y, Jiang X, Li K, Wu M, Zhang R, Zhang L, Chen G (2014). Photosynthetic responses of Oryza sativa L. seedlings to cadmium stress: physiological, biochemical and ultrastructural analyses. Biometals., 27:389-401.

Wang Y, Qiu Q, Xin G, Yang Z, Zheng J, Ye Z, Li S (2013). Heavy metal contamination in a vulnerable mangrove swamp in South China. Environmental monitoring and assessment., 185(7):5775-5787.

Xue ZC, Li JH, Li DS, Li SZ, Jiang CD, Liu LA, Kang WJ (2018). Bioaccumulation and photosynthetic activity response of sweet sorghum seedling (Sorghum bicolor L. Moench) to cadmium stress. Photosynthetica., 56(4):1422-1428.

Yu F, Yi L, Mao X, Song Q, Korpelainen H, Liu M (2022). Nitrogen addition alleviated sexual differences in responses to cadmium toxicity by regulating the antioxidant system and root characteristics, and inhibiting Cd translocation in mulberry seedlings. Ecotoxicology and Environmental Safety., 232:113288.

Zea M, Souza A, Yang Y, Lee L, Nemali K, Hoagland L (2022). Leveraging high-throughput hyperspectral imaging technology to detect cadmium stress in two leafy green crops and accelete soil remediation efforts. Environmental Pollution., 292 :118405.

Zhou WB, Qiu BS (2005). Effects of cadmium hyperaccumulation on physiological characteristics of Sedum alfredii Hance (Crassulaceae). Plant Sci., 169: 737-745.