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Research Article
Phytoaccumulation of Toxic Elements by Native Terrestrial Plants Collected from Arid Desert of Chile

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Abstract

Background and Objective: A variety of elements, that are found in the soil might be essential for plants, which can overly the vegetal through stress condition and produce toxic effects. The manuscript is aimed to (1) Show the capacity of four native terrestrial plants species: *Atriplex atacamensis* (*A. atacamensis*), *Atriplex halimus* (*A. halimus*), *Lupinus microcarpus* (*L. microcarpus*) and *Tessaria absinthioides* (*T. absinthioides*) to accumulate arsenic (As) and other toxic elements from agricultural soils of the Antofagasta Region in Chile and (2) Determine the effects of As on the levels of bioindicators of stress. **Materials and Methods:** Surface soil samples (0-20 cm depth) were collected from a plot in the village of Chiu-Chiu (Northern Chile). This soil was used for the different experimental trials. Control soil (0-20 cm depth) was collected from an area located in central Chile. The main physico-chemical characteristic of experimental and control soils were determined. Four native terrestrial plant species: *A. atacamensis*, *A. halimus*, *L. microcarpus* and *T. absinthioides* were selected for its capacity to accumulate As, to assess toxic effects of As in *L. microcarpus* and to determine stress indicators in *Atriplex* genus species. The statistical analysis was based on the mean values concentrations with its standard deviation, variation coefficient and analysis of variance. Duncan test ($p \leq 0.05$) was used to check for statistically significant differences. **Results:** *A. atacamensis* and *A. halimus* resist both the high salinity of the soil and the high levels of As and possibly of other elements, accumulating mainly the metalloid in the roots but not in the case of *L. microcarpus*. Visual As toxicity symptoms such as foliar chlorosis, necrosis of the leaf tips and margins, leaf wilting and stunted were observed in *L. microcarpus*. **Conclusion:** *A. atacamensis* and *A. halimus* by its rapid generation of biomass justify recommending these species as vegetative cover for soils that have been developed for mining activities. At the same time, *A. halimus* and *L. microcarpus* can be recommended to perform phytoremediation programs in agricultural soils with high As levels. In these conditions, these species act like phytostabilizators and phytoextractors of As in agricultural soils, respectively.

Key words: *Atriplex atacamensis*, *Atriplex halimus*, *Lupinus microcarpus*, *Tessaria absinthioides*, arsenic-toxicity

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

A variety of elements that are found in the soil might not be essential for plants. This is the case of arsenic (As), cadmium (Cd), lead (Pb), among others, which can overly the vegetal through stress condition and/or produce diverse toxic effects[1].

Plants vary in their ability to accumulate and tolerate toxic elements from the environment and its mobility is generally low with respect to translocation from roots to aerial parts, except in hyperaccumulator plants[2]. The term hyperaccumulator was first used by Brooks[3], in relation to plants containing more than 1000 mg kg^{-1} (0.1%) of Ni in dry tissue. It was not only the early eighties, that it was noticed that hyperaccumulators might be used to remediate polluted soils by growing a crop of one of these plants and harvesting it to remove the pollutants[4]. The success of any phytoremediation technique depends upon the identification of suitable plant species that hyperaccumulates elements from the soils, especially heavy metals and metalloids and produce a large amount of biomass using established crop production and management practices[4].

The phytotoxicity effects commonly observed toxic element exposure, include growth inhibition, chlorophyll degradation, nutrient depletion and oxidative stress[5,6]. Oxidative stress is reflected by an increase in malondialdehyde (MDA), whereas SH group (thiol), can avoid this oxidative stress by the formation of complex[1,6].

Preliminary results in order to identify metal accumulator species have demonstrated the potential of 4 terrestrial plant species that grow in the contaminated soils of Antofagasta Region in Chile, from which they can remove or accumulate contaminants through its roots, especially highly toxic arsenic metalloid[7]. Such plant species are: *Atriplex atacamensis*, *Atriplex halimus*, *Lupinus microcarpus* and *Tessaria absinthioides*, which are important native plants that constitute part of the desert scrub community of the pre-Andean area of the Antofagasta Region[8,9].

The *Atriplex* genus (Chenopodiaceae), denominated salt-bush, is one of the most important families of plants in the Antofagasta Region[10,11]. These xerohalophyte shrubs are dominant in many arid and semi-arid regions of the world, particularly in saline, arid soils and they are used for the rehabilitation of degraded lands, ornamental plants and revegetating sealed landfills and for animal feed[12-15].

Lupinus microcarpus, var. *microcarpus* (lupine), Fabaceae, is a species of lupine native to Western North America from South Western British Columbia to the Mojabe Desert in California and Baja California, as well as a disjunct population in South America in Central Chile and Western Argentina. It grows from sea level in the North of the range up to 1600 m in Southern California. It is an annual plant grows up 80 cm high. The leaves are palmately compound with 5-11 leaflets, 1-5 cm long and up to 1 cm broad. The flowers are generally pink to purple in color but can also be between white and yellow, they are produced in open whorls on an erect spike[16].

Tessaria absinthioides (Asteraceae) is an evergreen shrub that can reach up to 1.5 m of height. Its foliage has green and some gray color. The leaves are long with serrated edge. The pink flowers are grouped in clusters. Its flowering is abundant during the summer, since December until March. In Chile, this shrub grows from Arica and Parinacota Region until Biobio Region. Traditionally its roots and leaves have medicinal, balsamic, anti-inflammatory and skin properties[17].

This manuscript aimed to report (1) The capacity of 4 native terrestrial plant species to accumulate arsenic and other toxic elements from agricultural soils of Antofagasta Region in Chile and therefore, can be used in phytoremediation and/or revegetation for the recovery of contaminated soils and (2) The effects of arsenic in *L. microcarpus*, *A. halimus* and *A. atacamensis* on the levels of bioindicators of stress.

MATERIALS AND METHODS

Study area: Study area includes agricultural zones located near the village of Chiu-Chiu (22° 20′ S; 68° 39′ W), Lasana (22°16′ S; 68°38′ W) and Ayquina (22°16′ S; 68°19′ W). The zone of pre-Andean Antofagasta Region is influenced by the Loa River and is located prior the confluence with Salado River (Fig. 1). This zone was characterized by scarce/poor plant cover, saline properties of soils and high concentrations of arsenic, boron and other elements of natural origin[1].

Zone of soil collection and determination of the main physicochemical properties: Surface soil samples (0-20 cm depth) were collected from a plot in the village of Chiu-Chiu, located 35 km from the city of Calama (Northern Chile), which were classified as arid soil, show high salinity, it is the result of the lack of rain and high temperatures during the day (Fig. 1). Agriculture is the main economic activity of its inhabitants. Vegetables such as carrots and beetroot are produced in the selected smallholding[18]. This soil was used for the different experimental trials.

Control soil (0-20 cm depth) was collected from an area located in central Chile (33° 26′ S, 68° 39′ W), which was classified as molli soils. The main physico-chemical

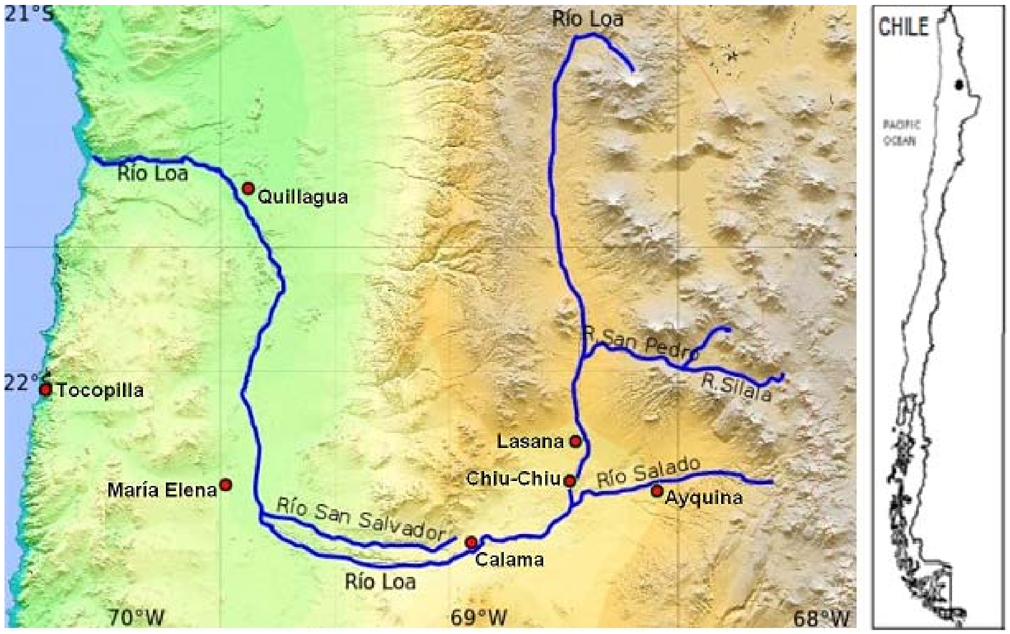

Fig. 1: Study area in the Loa River zone (Antofagasta Region, Chile)

Table 1: Physico-chemical properties of control soil and experimental soil

Soil characteristics	Experimental soil	Control soil
pH[a]	8.40±0.10	7.80±0.10
EC[a] (dS m^{-1} 25°C)	2.60±0.40	1.70±0.20
CCE (cmol kg^{-1})	35.00±6.50	19.00±4.50
Organic matter (%)	0.81±0.10	6.34±0.10
N Kjeldahl (%)	0.21±0.01	0.27±0.02
P total (%)	0.06±0.01	0.21±0.00
As (mg kg^{-1})	111.00±19.0	12.70±1.10
B (mg kg^{-1})	79.60±0.98	1.13±0.06
Cd (mg kg^{-1})	<DL	<DL
Cu (mg kg^{-1})	33.20±1.0	431.00±21
Na (mg kg^{-1})	1263.00±72	784.00±20
Pb (mg kg^{-1})	<DL	302.00±109
Zn (mg kg^{-1})	43.20±4.1	1700.00±52
Clay (%)	13	16
Sand (%)	64	50
Silt (%)	23	34

[a]1:5 w/v extract in water, DL: Detection limit, EC: Electric conductivity, CCE: Capacity of cationic exchange[1], (values are mean±standard deviation, n = 3)

characteristic of experimental and control soils were determined (Table 1). Electrical conductivity (EC) and pH were determined in water extracts (1:5 w/v) using an electrode (WTW multi 340i). The cation exchange capacity (CEC) was determined with sodium and ammonium acetate[19]. The organic matter content was determined by calcination at 550°C. Nitrogen was determined by the Kjeldahl method. In the digest extracts, total phosphorus was determined using colorimetric method with ammonium molybdate[20]. Arsenic was quantified by Flow Injection Hydride Generation Atomic Absorption Spectrophotometry (FI-HG-AAS) using a Perkin Elmer FIA 100 apparatus (detection limit: 0.01 As µg L^{-1}). Boron was extracted with $CaCl_2$ and determined by colorimetric method with azomethine-H[21]. Cadmium, Cu, Na, Pb and Zn in the digest extracts, were measured using flame Atomic Absorption Spectrophotometry (AAS) with a Thermo Electronic Corporation AA Series apparatus (detection limit: 0.005 Cd mg L^{-1}, 0.004 Cu mg L^{-1}, 0.002 Na mg L^{-1}, 0.005 Pb mg L^{-1}, 0.001 Zn mg L^{-1}). The soil texture was determined using a hydrometer (Bouyoucos method).

Collection of vegetal samples

Cuttings of *A. atacamensis* and *A. halimus*: Cuttings of *A. atacamensis* (29.7±2.5 cm) and *A. halimus* (25.3±2.5 cm), were obtained from the center for Studies of Arid Zones (CEZA, in Spanish) that belongs to the University of Chile. Both species were transplanted in As-soil and control soil treatments (10 plants per treatment) distributed in random blocks using plastic containers of 4 L (19.5 cm diameter×22.0 cm height) in late March of 2011 and maintained for 90 days. This assay was performed in the research greenhouse of the University of Santiago of Chile under ambient conditions and protected from the rain. The plants were irrigated twice per week with 200 mL of tap water per container. During the assay, the average minimum temperature was 7.9±2.8°C, maximum temperature was 23.4±4.6°C and relative humidity was 60.3±26.5%. Leaves, stem and roots, were removed from each plant, lyophilized separately, ground in a hand mill and then cold-stored until analysis[1].

Seeds of *L. microcarpus:* *Lupinus microcarpus* seeds were obtained from a Culture Center of Chilean Native Plant Species, located in Talca city, Maule Region, Chile. Seed samples were sterilized and germinated on moistened filter paper at ambient temperature in the dark for 3 days. Seedlings were placed on perlite in plastic containers for 15 days and then transplanted in experimental soil and control soil treatments. The plants were irrigated once a week with 200 mL of distilled water per container[18,22]. This study was conducted for 180 days in the research greenhouse of the University of Santiago of Chile under ambient conditions and protected of the rain. Toxicity symptoms such as foliar chlorosis, leaf wilting, necrosis of the leaf tips and margins, height (cm), stunted and number of leaves were observed and counted every month[18]. During the assay the average minimum temperature was 7.9±2.8°C, maximum temperature was 23.4±4.6°C and relative humidity was 60.3±26.5%[1,22].

Vegetal samples *in situ* collected: Three plant species were collected from their natural habitat: *Atriplex atacamensis* collected in Lasana, *Tessaria absinthioides* collected in Chiu-Chiu and *Lupinus microcarpus* collected in Ayquina. Then the root, stem and leaves tissues of each plant species were removed and treated as described earlier. Bioconcentration factor (BCF) and transport index (TI) of As were calculated according to the following Eq.[8,23]:

$$\mathrm{BCF} = \frac{\text{As concentrations in leaves } (\mathrm{mg\,kg^{-1}})}{\text{As concentrations in soil } (\mathrm{mg\,kg^{-1}})}$$

$$\mathrm{TI} = \frac{\text{As concentrations in leaves } (\mathrm{mg\,kg^{-1}})}{\text{As concentrations in roots } (\mathrm{mg\,kg^{-1}})}$$

Analysis of vegetal samples

Stress indicators in *Atriplex* genus species: Arsenic concentrations were determined at the beginning of the assay (0 day) and after 30 and 90 days. Plants were separated into leaves and stems (aerial part) and roots and the soil particles were manually removed. Plant material was rinsed under tap water for 5 min and submerged in distilled water for 2 min, dried at 60°C for 48 h and milled to a fine powder in a grinder. The samples (0.5 g) were digested (mili-Q H_2O, H_2O_2, HNO_3) in autoclave[6]. In the digested extracts, the As concentration was determined by FI-HG-AAS. The bioconcentration factor (BCF) and translocation index (TI) were calculated. Chlorophylls, thiols and malondialdehyde were determined in fresh leaves at 0, 30 and 90 days of the assay. Chlorophylls were extracted by homogenizing 0.5 g fresh weight (FW) of leaf tissue in 80% acetone and estimated as Chl a (mg L^{-1}) (Moreno-Jimenez *et al.*[6]). Acid soluble thiols were extracted using 0.1 g FW. The supernatant was diluted with 0.2 mL of HCl (35%) heated at 30°C for 2 min. The absorbance was determined at 412 nm. MDA was extracted from 0.1 FW. The supernatant was heated at 90°C for 30 min, cooled and centrifuged. The absorbance of the supernatant was measured at 532 and 600 nm. For the absorbance determination, a Shimadzu UV-1601 was used[1].

Toxic effects of As in *L. microcarpus*: After 6 month from the beginning of the experiments, leaves and roots were separated and the soil particles were manually removed. Plant material was rinsed under tap water for 5 min and submerged in distilled water for 2 min, dried at 60°C/2 days until constant weight and then ground and sieved. Later, samples were calcined (425±25°C) for 12 h. Once the ash had cooled, 5 mL of 10% HNO_3 was added, the mixture was evaporated in the sand bath and the calcination process was repeated until white ash was obtained. The white ash was dissolved in 5 mL of 50% v/v HCl and 5 mL of reducing solution (5% m/v KI+5% m/v ascorbic acid). After 30 min, the resulting solution was diluted to volume with 50% v/v HCl and filtered into a 25 mL volumetric flask. The filtered acid digest were analyzed for As concentration by FI-HG-AAS. All results were expressed in dry matter[8,24]. The BCF and TI were calculated using discussed equations.

Arsenic concentrations in *A. atacamensis*, *A. halimus*, *L. microcarpus* and *T. absinthioides*: Arsenic concentration in leaves, stems and roots of each one plant species were measured by means of the procedure described earlier and BCF and TI was calculated using discussed equations.

Statistical analysis: The statistical analysis was based on the mean values concentrations of different soil-elements and As in leaves, stem and roots, with its standard deviations, variation coefficient for pH values, electrical conductivity, organic matter and soil-elements. Analysis of variance (ANOVA) of the mean values of As concentrations, chlorophyll, thiols and MDA for plants cultivated in As-soil, as well as BCF and TI. Duncan test ($p \leq 0.05$) was used to check for statistically significant differences. All statistical tests were performed through the SPSS 13.0 software package.

RESULTS AND DISCUSSION

The main physico-chemical characteristics of control soil and experimental soil collected from the central zone of Chile and Chiu-Chiu, respectively was shown in Table 1.

The remarkable differences between the experimental and control soils can be observed from Table 1, especially in parameters such as electric conductivity and capacity of cationic exchange, which includes most of chemical elements, especially As, B, Cu, Fe, Mn, Pb, Zn, some of which were toxic. The high concentration of Pb in the control soil with respect to the soil of Chiu-Chiu is significant, as well as the high concentration of Na in the soil from Chiu-Chiu, which along with the high electric conductivity and low organic matter content, explain the main characteristic of these soils like it is its marked aridity. Likewise, the results of the high concentration of As and B, characteristic toxic elements in the soils of Antofagasta Region.

The concentrations of chlorophyll, total thiols and malondialdehyde in leaves of *A. atacamensis and A. halimus* cultivated in soil was given in Table 2 which was collected in Chiu-Chiu (experimental) and in soil obtained from the central area of Chile (control).

From Table 2, it can be observed that the levels of chlorophyll increased in both species cultivated in the experimental soil, which contains high levels of As and B and high salinity (Table 1), with respect to the plants that grew in the control soil.

In plants of the *Atriplex* genus, numerous studies indicate that chlorophyll concentration in the leaves, is not a good stress indicator, with respect to soil elements, especially As, likely due to their halophytic character and the C4 photosynthesis mechanism[5,25].

The total levels of thiols for each plant species remained constant, which matches with equal results measured in the aerial organs of halophytic plants, as it is the case of the *Atriplex* genus[26].

The MDA concentration increases in *A. halimus* cultivated in soil collected in Chiu-Chiu and possibly due to high As concentration in this soil and also probably of B, all elements of which their phytotoxic effects are known[1,18].

The results of the visual toxicity symptoms in *L. microcarpus* are shown in Fig. 2. Plants that grow in the plots that contained soil from Chiu-Chiu, showed all of the visual symptoms of toxicity: Foliar chlorosis (Fig. 2a), necrosis of the leaf tips and margins (Fig. 2b), leaf wilting (Fig. 2c) and stunted (Fig. 2d) by the end of the assay. These symptoms implied the death of all plants at the end of the study. On the other hand, it is important to point out that neither of control lupine plants suffered any toxicity symptoms.

The above mentioned effects, suggest a restriction in water movements into the plant, showing that these As-treated plants, were suffering from water stress. This situation is not observed on plants species resistant to As[27,28], as it was mentioned above in the case of the species *A. atacamensis* and *A. halimus*, which grew normally and did not show visual symptoms of toxicity. Therefore, it may be assumed that As-resistant plants either compartmentalize and/or transform As to other less phytotoxic As-species, to withstand high cellular As-burdens[29].

As-concentration (mg kg^{-1}, dry weight) in soil samples, leaves and roots of *L. microcarpus* and values of BCF and TI are shown in Table 3.

The highest As-concentrations in *L. microcarpus* were measured in the root, both the plants grown in experimental

Table 2: Chlorophyll (mg kg^{-1}, w/w), total thiols and malondialdehyde (MDA, µg kg^{-1}, w/w), in leaves of *A. atacamensis* and *A. halimus*

		Stress indicators		
Days	Plant species	Chlorophyll	Thiols	MDA
0	*A. atacamensis*	0.34±0.03	27.3±1.0	0.83±017
	A. halimus	0.47±0.06	35.5±3.2	0.41±0.15
30	*A. atacamensis* control	0.38±0.01^{a}	29.9±1.3	0.91±0.22
	A. atacamensis experimental	0.63±0.04^{b}	26.2±0.7	0.90±0.11
	A. halimus control	0.48±0.11	36.3±4.2	0.42±0.07^{a}
	A. halimus experimental	0.63±0.01	37.5±2.3	0.96±0.22^{b}
90	*A. atacamensis* control	0.37±0.00^{a}	29.6±5.1	0.79±0.16
	A. atacamensis experimental	0.62±0.03^{b}	28.9±6.4	1.11±0.19
	A. halimus control	0.40±0.00^{a}	37.2±16.4	0.42±0.09^{a}
	A. halimus experimental	0.64±0.00^{b}	39.6±7.2	0.67±0.06^{b}

Different letters in the columns indicate differences between the different soil types, according to Duncan's test ($p \leq 0.05$)[1], Mean values±standard deviation, n = 3

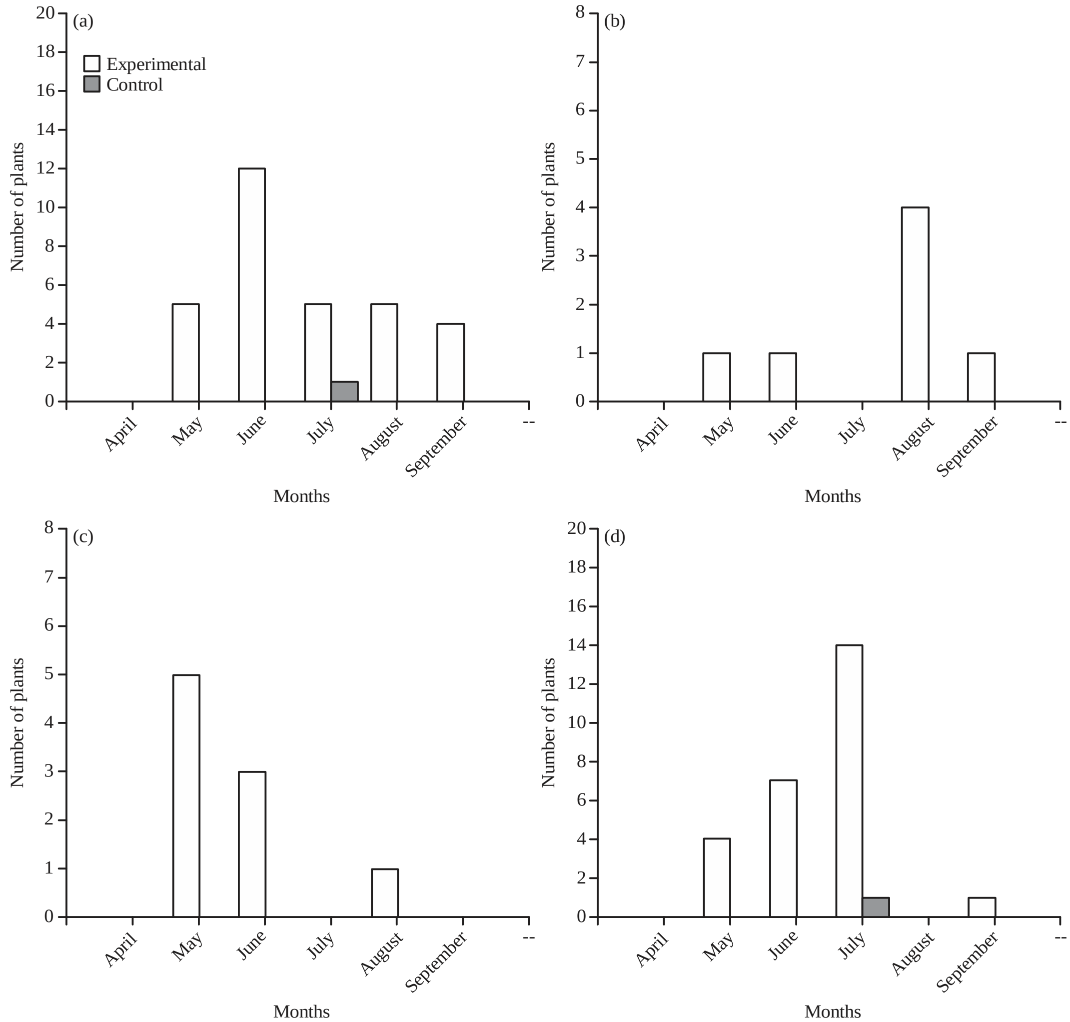

Fig. 2(a-d): Toxic effects of As in lupine (a) Foliar chlorosis, (b) Necrosis of leaf, (c) Leaf wilting and (d) Stunted

Table 3: As-concentration in samples of experimental and control soil, leaves and roots of *L. microcarpus* and values of BCF and TI

	As-concentration (mg kg^{-1})				
Experimental soil	Soil	Leaves	Root	BCF	TI
1	5.3	1.44	9.08	0.27	0.16
2	13.1	0.78	2.28	0.06	0.34
3	14.2	0.94	3.53	0.07	0.27
Control soil	3.1	0.19	0.76	0.06	0.25

Taken from Diaz *et al.*[18]

soil and in control soil. It was noteworthy that the highest concentrations of As measured both in leaves and in roots, corresponded to the plants that growth in experimental soil which showed the lowest concentration of the metalloid (5.3 mg kg^{-1}), which corresponds with the highest value of BCF (0.27) and lowest value of TI (0.16)[18].

With respect to the control soil, this shows lowest levels of As in both leaves and roots (0.19 and 0.76 mg kg^{-1}, respectively). BCF and TI values were similar to obtained in plants cultivated on experimental soils 2 and 3.

According to the experimental results obtained, the highest As-concentrations measured in roots of *L. microcarpus* cultivated both experimental soil and control soil with respect to As-concentration measured in leaves, show that this plant species acts as phytostabilizator on contaminated As-soils. The greatest phytostabilizator efficiency is observed in soils with As-concentrations within the range considered normal

Table 4: As-concentration in leaves, stems and roots of *A. atacamensis, A. halimus, L. microcarpus* and *T. absinthioides* adult species and BCF and TI values

	As-concentration (mg kg^{-1}, dry weight)					
Species	Soil	Leaves	Stem	Root	BCF	TI
A. atacamensis	111.0±19	2.6±0.7	3.2±0.9	6.9±1.2	0.02	0.4
A. halimus	111.0±19	5.6±1.8	4.7±0.5	16.3±3.8	0.05	0.5
L. microcarpus	5.6±1.0	9.7±1.6^{a}	2.5±0.9^{b}	1.6±0.4^{b}	1.80	6.1
T. absinthioides	53.0±9.9	5.9±1.0^{a}	5.1±0.4^{a}	3.4±0.2^{b}	0.10	1.7

Different letters in columns, indicate significant differences between organs of native plant species for As-concentration, according to Duncan's test ($p \leq 0.05$)[1,8]

(5-8 mg kg^{-1}), decreasing its phytostabilizator capacity in those soils that contain As levels higher than 10 mg kg^{-1}. These soils are considered As contaminated soils in other regions of the world[30].

As-concentrations in adult species of *A. atacamensis*, *A. halimus*, *L. microcarpus* and *T. absinthioides,* collected in their natural environment are presented in Table 4.

Arsenic concentration in the leaves of *L. microcarpus* (9.7±1.6 mg kg^{-1}), was significantly higher than those As levels measured in the stems and roots. The soil in which the plant was collected, showed the lowest concentration of the element (5.6±1.04 mg kg^{-1}), with respect to the As concentration measured in the samples of soil where the other species grew. This fact demonstrates the great capacity of *L. microcarpus* to bioaccumulate and to translocate the metalloid, which is demonstrated by the highest value of BCF (1.80) and TI (6.1), with respect to the obtained in the other analyzed vegetal species. The BCF must be greater than 1.0 for phytoremediation techniques are feasible[31]. Therefore, the species *L. microcarpus* has an interesting potential use in phytoremediation. TI was higher than 1 in *L. microcarpus* and *T. absinthioides* indicating that these plants accumulate more As in the leaves and therefore, these species show a behavior as indicator plants of As. *L. microcarpus* showed the highest TI (6.1) than the other species, showing a remarkable ability to translocate As to the leaf. These result concurrent with the values of As concentration measured in leaves and roots of *L. microcarpus* experimentally cultivated in soil with low levels of the element (5.3 mg kg^{-1}, Table 3). In that case, lower values of As levels were obtained in leaves and roots with respect to those informed in the Table 4, because the individuals did not complete their life cycle, possibly due to the synergic action between the As phytotoxic action and the high salinity of the soil, which was determined by Carbonell-Barrachina *et al.*[28].

The physico-chemical characteristics of the Ayquina soil, where the samples of *L. microcarpus* adult were collected are different to those measured for the Chiu-Chiu soil, where this specie was cultivated (Table 1). Ayquina soil, presents a lower pH, higher percentage of silt-clay and organic matter, as well as less electric conductivity than the Chiu-Chiu soil, which would explain the differences on the levels of As concentration in the organs of *L. microcarpus* adult with respect to that grown experimentally[8].

On the other hand, the high concentration of As in the root of *A. halimus* (16.3±3.3 mg kg^{-1}) and *A. atacamensis* (6.9±1.2 mg kg^{-1}) in Table 4 show that the dominant mechanism was phytostabilization of As[1,9].

The As concentration in the aerial organs of *T. absinthioides* is similar to that found in *A. halimus*. However, the highest value of TI measured in *T. absinthioides* (1.7) unlike *A. halimus* (0.5), allows deducing that this species has greater capacity to translocate the metalloid from the root to the aerial organs, demonstrating similar behavior to *L. microcarpus*. Besides, the differences in the As concentration in the leaves of *T. absinthioides* and *L. microcarpus*, were significant (Table 4), which demonstrates the capacity of bioaccumulation of the metalloid mainly in the leaves, behaving both species as phytoextractors. The concentration of As in the leaves of *T. absinthioides*, is similar to the obtained by Tapia *et al.*[1] equivalent to 5.1±0.70 mg kg^{-1}.

CONCLUSION

Agricultural soils of the arid desert of the Antofagasta Region in Chile, showed high salinity, low organic matter content and varied concentration of elements.

Atriplex atacamensis and *Atriplex halimus* by its rapid generation of biomass justify recommending these species as vegetative cover for soils that have been developed for mining activities. At the same time, *Atriplex halimus* and *Lupinus microcarpus* can be recommended to perform phytoremediation programs in agricultural soils with high As-levels. In these conditions, these species act like phytostabilizators and phytoextractors of As in agricultural soils, respectively.

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