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RESEARCH ARTICLE

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On the elemental composition of the Mediterranean euhalophyte *Salicornia patula* Duval-Jouve (Chenopodiaceae) from saline habitats in Spain (Huelva, Toledo and Zamora)

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Abstract

A complete survey is presented on the inorganic composition of the euhalophyte annual succulent species *Salicornia patula* (Chenopodiaceae), including materials from the Iberian Peninsula, littoral-coastal Tinto River basin areas (SW Spain: Huelva province), and mainland territories (NW and central Spain: Zamora and Toledo provinces). The aim of this contribution is to characterize the elemental composition of the selected populations and their soils and compare the relationship between them and the macro- and micronutrient plant intake; all these nutrients may allow this species to be considered an edible plant. Using analytical techniques such as ICP-MS (inductively coupled plasma mass spectrometry), our results revealed high values of Na and K followed by Ca, Mg, Fe and Sr in stems. These data demonstrate the importance of annual halophytic species as edible plants and their potential uses in phytoremediation procedures involving soils with certain heavy metals (Pb, Sr, As, Cu, Zn).

Keywords Halophytes · *Salicornia* · Nutrients · Edible plants · Heavy metals · Phytoremediation

Introduction

Halophytes include a series of taxa that grow naturally in saline environments (Flowers et al. 1986; Loconsole et al. 2019).

Salicornia L. is one of the most important euhalophyte genera in the Chenopodiaceae family and includes medium-sized therophytes with succulent and articulated stems and inflorescences. The flowering segments host two triflora tops containing three vertical brown seeds with no perisperm and a conduplicate embryo. Its geographical distribution covers four continents: Africa, America, Asia and Europe.

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Salicornia taxa accumulate inorganic salts and water in their stems (Grigore and Toma 2017). The most common elements found are Na, Ca, K and Mg, among others, and are present in the stem, leaves and roots (Rhee et al. 2009; Lu et al. 2010; Ventura et al. 2011). Like other chenopods such as *Sarcocornia perennis* Mill. and *Arthrocnemum macrostachyum* (Moric.) Moris, recently introduced for human consumption (Barreira et al. 2017), *Salicornia patula* is also an excellent candidate due to its mineral content. In Korea, tender *Salicornia* shoots are processed in drinks such as nuruk (a type of fermentation initiator), makgeolli (a Korean rice wine) or vinegar (Song et al. 2013; Kim et al. 2013); the crisp salty aerial parts are used in salads, and their consumption is a source of salt in the diet (Patel 2016). Other studies also report new uses of *S. patula* with a long history of gathering from the wild as a source of food (Urbano et al. 2017).

Recent taxonomic studies of this genus separate different species of *Salicornia* from the European continent in different clades (Kadereit et al. 2007). *S. patula* is one of the most representative species in Mediterranean flora (Sajna et al. 2013; Gasparri et al. 2016).

Salicornia patula is well known from the Iberian flora growing in temporarily flooded salt flats both on the coast/

littoral and in brackish lagoons on the mainland. *S. patula* formations can be considered as pioneer plant communities that usually cover the wettest microenvironments, although the communities have a poor and variable floristic composition that mainly reflects their geographic distribution, continentality, soil chemical composition and environmental disturbance regime.

The concentration of nutrients in the soil is a vital factor in controlling the distribution, growth and development of plants (Zhao et al. 2014), whose response to the soil elements depends on the plant species, the total concentration and the bioavailability of the element itself (Milic et al. 2012).

A comparison is made of the chemical composition of *S. patula* growing in different geographical locations, specifically in continental inland salty lagoons (in Toledo and Zamora provinces) and littoral-coastal salt marshes (Huelva province).

The littoral-coastal salt flats studied correspond to the salt marshes of Huelva, in the southwest of the Iberian Peninsula, particularly the estuaries that form the mouths of the Tinto and Odiel Rivers. Both rivers begin and circulate through the Iberian Pyritic Belt, an area that is especially rich in S and Fe and other elements such as Cu, Zn, As and Pb, which condition the biogeochemical characteristics of the waters of both rivers. Specifically, the Tinto River is considered one of the most important examples of extreme acidic environments, with high and medium course waters with average pH values of 2.3 (López-Archilla et al., 2001). The mixture of river waters—acidic and rich in metals—and seawater in the estuary is particularly interesting. The vegetation in the estuary is halophytic and adapted to partial or total recurring daily flooding from the tides. *S. patula* grows as pioneer species in this environment, occupying areas that are totally or partially flooded with daily tides, either in the areas closest to the sea or in depressions in somewhat more remote territories.

Material and methods

Material

Table 1 and Fig. 1 shows the data on the different geographical locations of the selected samples and includes the habitat and phenological status of *S. patula* populations at the time of collection.

A soil sample and three specimens of *S. patula* were collected for each location.

Soil samples were collected from the substrate in contact with the plant roots. The samples were air-dried, screened through a 2-mm mesh and stored for further analysis.

Plant material was cleaned with distilled water in the laboratory and air-dried, and fleshy stems were selected to be crushed until approximately 500 mg was obtained per sample.

Methods

Soil and plant analysis

The elemental content was analysed and quantified by inductively coupled plasma mass spectrometry (ICP-MS), a highly sensitive technique for the determination of multiple elements.

Soil samples (500 mg) were digested with a mixture of HCl and HNO_3 at 60 °C in an MSD-2000 CEM microwave digestion (US) at medium pressure.

Plant samples were analysed using the protocol described by Zuluaga et al. (2011), which optimizes the digestion process of plant matter and allows the optimal recovery of a large number of elements in a single semi-quantitative analysis. After cleaning, a plant and soil sample of approximately 500 mg from each locality was weighed in a Teflon tube for acid digestion in a mixture of 8 ml of 65% HNO_3 and 2 ml of 30% H_2O_2 inside a MLS Ethos 1600 URM Milestone high-

Table 1 Information on the localities sampled for *Salicornia patula*, identification number (ID), geographical location, latitude and longitude coordinates, ecology, phenology and collection date

ID	Locality	Longitude/latitude	Ecology/habitat	Phenology and collection date
1	La Rábida, Tinto River (Huelva, Spain)	7 29 17.9218 W/0 4 33.3925 N	Zones subjected to partial to complete flooding by daily tides	Vegetative stem 22.09.09
2	El Terrón, Odiel River (Huelva, Spain)	7 29 17.9121 W/0 2 33.1582 N	Zones subjected to partial to complete flooding by daily tides	Vegetative stem 19.09.07
3	Monumento a Colón Tinto river (Huelva, Spain)	7 29 17.9239 W/0 4 53.1664 N	Zones subjected to partial to complete flooding by daily tides	Fructification, with seeds 14.12.17
4	Otero de Sariegos (Zamora, Spain)	53,622.75 W/ 414,919.92 N	Saline lagoons from the interior of the Iberian Peninsula. Edges of the lagoon where plants are subjected to temporal and seasonal flooding	Fructification, with seeds 14.09.18
5	Laguna larga de Villacañas (Toledo, Spain)	7 29 17.8756 W/0 0 30.1316 N	Saline lagoons from the interior of the Iberian Peninsula. Edges of the lagoon where plants are subjected to temporal and seasonal flooding	Fructification, with seeds 30.10.16

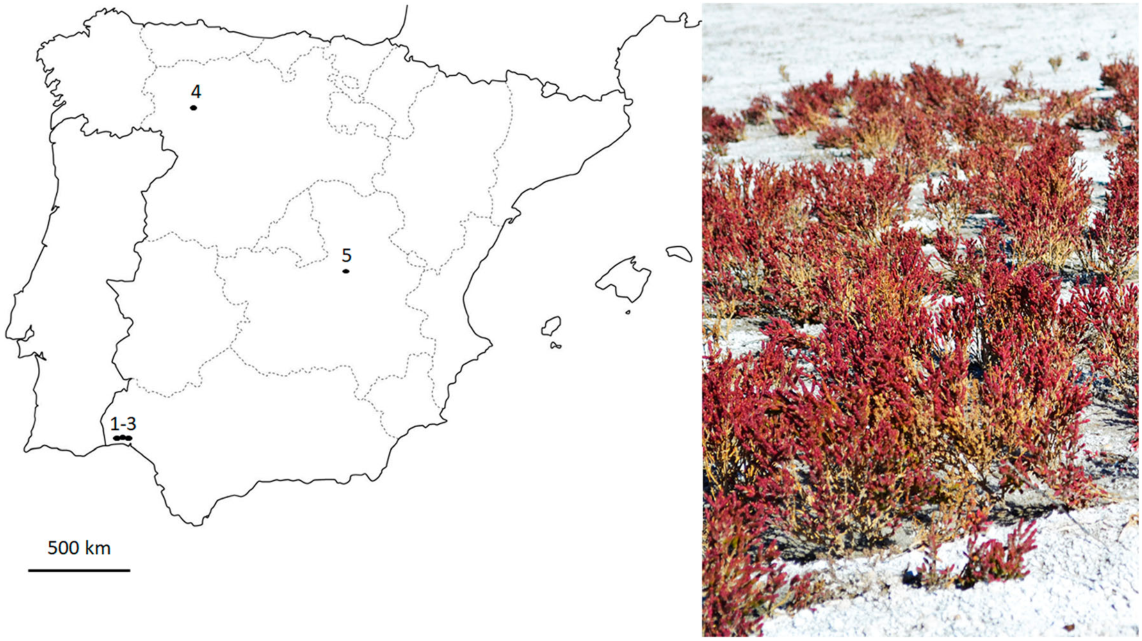

Fig. 1 Left: map (geographical locations of the samples); Right: an image of *S. patula* from Zamora with the habitat

pressure microwave digester. The volume of each sample was subsequently adjusted to 25 ml with deionized water.

Aliquots of the solutions obtained from both soil and vegetable samples were analysed for Na, Ca, Mg, K, Mn, Fe, Ni, Cu, Zn, As, Pb and Ba by ICP-MS using an ICP ELAN-600 PE Sciex Instrument (Toronto, Ontario, Canada).

This technique determined the concentrations in mg/kg, based on the dry weight of the digested sample. The ICP-MS technique has an inherent error of 15%.

Soil-plant ratio

The plant's ability to absorb chemical elements from the soil was evaluated with a ratio known as the biological absorption coefficient (BAC):

$$BAC = Cp/Cs$$

where Cp is the concentration of the element in the aerial parts of the plant expressed in mg/kg d.w. and Cs is the concentration of the element in the soil under the plant expressed in mg/kg (Brooks 1983; Kabata-Pendias and Pendias 2001).

Statistical analysis

Statistical analysis was performed in the Statgraphics 18.0 program. Mean and standard deviations were calculated. The data were transformed logarithmically after verifying normality with the Shapiro-Wilk test ($p > 0.05$). To test the possible differences between three or more groups, they were compared using ANOVA. Bonferroni corrections between means were calculated only if an F test was significant at the probability level of 0.05. * $p > 0.05$; ** $p > 0.01$; *** $p > 0.001$.

Results

Soils

The analysis of the elemental composition of the soils shows differences in the contents of the various elements analysed (Table 2).

Samples from the Huelva salt marshes contain Fe (20.262–55.773 g/kg) and Na (20.818–48.366 g/kg) as the main elements. Other elements present in a high proportion are Mg, Ca, K, Zn and Cu were found in one order of magnitude higher than As, Sr, Ba and Mn. Arsenic is the element with the highest concentration in all cases. Ni and Pb are minor elements with values between 12 and 60 mg/kg.

The soils from the continental inland salty lagoons (Zamora, Toledo) are very different from each other and also differ from those of the Huelva salt marshes. In general, they have a higher concentration of Ca and Sr and a lower concentration of Fe, Cu, Zn and As.

In the soils of continental inland localities, the majority elements are Ca (12.560–160.287 g/kg), Na (13.775–87.970 g/kg) and Mg (3.724–28.397 g/kg).

Table 2 Elemental soil composition in localities of *Salicornia patula*. All data are expressed in mg/kg. $n = 1$

Element/ Locality	1	2	3	4	5
Ca	5405	4979	3958	12,560	160,287
Mg	4664	6817	8949	3724	28,397
Na	20,818	22,032	48,366	87,970	13,775
K	3112	3460	11,441	2809	10,170
Fe	30,440	55,773	20,262	500.2	12,861
Mn	150.3	170.2	150.1	393.5	235.5
Zn	832.4	1330	43.58	18.70	46.60
Cu	579.3	1096	613.3	6.803	22.70
Ni	26.90	23.60	30.10	3.708	14.23
Ba	26.39	254.3	226.0	27.50	178.4
Sr	210.2	278.1	190.31	340.3	1620
As	613.4	824.5	627.1	29.12	4.880
Pb	12.10	58.30	18.60	4.501	19.70

Other elements with a high concentration are Fe, K, Sr and Mn with values more than 1000 mg/kg in the case of Fe and K, and Sr and Mn are more than 100 mg/kg.

Elements such as Ba, Zn, Cu and As have concentrations of hundreds to tens of mg/kg. The minority elements are again Pb and Ni, with values between 19 and 3 mg/kg.

Sodium content in the soil of the Zamora locality is higher than in the rest of the substrates analysed. All soil values are shown in Table 2.

Plants

Salicornia patula samples show normal values for vascular plants

Significant differences were obtained in the statistical analysis between the mean values of Ca, Mn, Fe, Ni, Cu, As, Pb, Ba and Sr. The rest of the elements were homogeneous.

The pattern of accumulation of the elements is very similar in all locations with the following order: Na > K > Mg > Ca > Fe.

Sodium is the element with the highest concentration in all samples, although the average values obtained are variable. Na content is above 60 g/kg d.w. (dry weight) in all cases, with average values of more than 200 g/kg d.w. After sodium, the elements with the highest concentration are K, Mg and Ca with very variable amounts between 8.9 and 27.6 g/kg for K; between 7.2 and 38.3 g/kg for Mg; and between 2.6 and 20.6 g/kg for Ca. Except for Ca, no significant differences were found between the means of Na, Mg and K, indicating that regardless of the total concentration in the substrates and the phenological state of the plants when they were collected, *S. patula* maintains a similar concentration of these elements. Based on the results obtained for the BAC, it can be generally indicated that, in any situation (salt marshes or mainland lagoons), *S. patula* concentrates more Na, Ca, Mg and K in its tissues than the total concentration in the soils, with levels of Na up to almost five times higher than in the soils.

Iron has average values of over 2 g/kg—considered high for vascular angiosperm plants—although a high variability is also observed among samples from the same locality. The mean concentrations of this element differ significantly, but no relationship was found with the phenological state or the elemental content of the soils.

Another notable element is Sr, with average concentrations between 54 and 310 mg/kg. The differences found between means do not correlate with soil composition or with phenological state.

High values of Cu and As were recorded in samples from the Huelva salt marshes, in particular in the samples from the Tinto River, with higher average values of Cu and As than in the rest of the localities. These elements present statistical differences between inland and saltmarsh samples, highlighting La Rábida locality with the highest values.

BAC values indicate that the concentrations of the elements Fe, Ni, Cu, Mn, Zn, As, Pb, Ba and Sr in *S. patula* tend to be lower than the total concentration in the corresponding substrates. All plant and BAC values are shown in Table 3.

Discussion

The locations in the study have soils with a different elemental content, reflecting the geological substrates on which they develop and the environment where they have formed: salt marsh sediments or seasonal mainland lagoons in the interior of the peninsula and therefore with no tidal influence.

The Toledo lagoon (Laguna Larga de Villacañas) is formed on clay, loam and gypsum substrates where seasonal flooding occurs during the dry season, and the water supply does not

Table 3 Elemental composition of *Salicornia patula* in all collection locations. All data are expressed in mg/kg dry weight. $n = 3$. Mean (M), standard deviation (SD), not detected (Nd). For each column, different superscript letters mean statistically significant variations among samples. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

	Na	Ca**	Mg	K	Mn**	Fe**	Ni**	Cu***	Zn	As***	Pb***	Ba***	Sr***
1													
M	94,051	12039^{a}	14,031	11,423	88.4^{ab}	1923^{a}	8.51^{a}	180^{a}	70.7	8.33^{a}	9.64^{a}	4.72^{a}	93.1^{a}
SD	7728	2124	2747	2422	17.11	429	4.25	97.1	18.4	2.55	3.29	1.38	46.7
BAC	4.51	2.27	3.00	3.67	0.589	0.063	0.316	0.310	0.084	0.013	0.796	0.178	0.443
2													
M	60,201	5394^{b}	7243	13,505	12.1^{b}	207^{b}	2.43^{b}	7.16^{b}	33.2	Nd	2.31^{b}	5.41^{a}	54,4^{b}
SD	1924	197	280	332	0.47	21.3	0.12	0.24	8.51		0.15	0.10	1.84
BAC	2.73	1.08	1.06	3.90	0.071	0.003	0.10	0.006	0.025	–	0.039	0.021	0.195
3													
M	210,023	20600^{b}	15,003	11,990	185^{a}	2571^{a}	10.6^{a}	19.4^{b}	42.3	5.75^{a}	6.41^{a}	5.22^{a}	310^{b}
SD	43,351	2510	2681	37	36.5	1246	4.8	5.7	3.7	3	2.3	1	36.6
BAC	4.78	4.34	1.67	1.04	1.23	0.126	0.432	0.352	0.970	0.009	0.344	0.02	1.63
4													
M	68,618	2601^{ab}	7201	8991	15.8^{b}	200^{b}	4.93^{b}	7.52^{b}	26.2	Nd	Nd	5.55^{b}	61.2 ^{a}
SD	10,432	513	4031	1198	3.63	84,2	0.100	0.534	2.241			11,6	45.1
BAC	0.780	0.207	1.93	3.20	0.040	0.400	1.33	1.10	1.40	–	–	0.201	0.178
5													
M	176,571	14942^{ab}	38,340	27,685	94.2^{ab}	1759^{a} b	5.63^{b}	12.5^{b}	31.2	1.03^{b}	1.35^{b}	14.7^{a}	272^{a}
SD	38,568	5795	5248	2971	23.4	455	1.19	2.10	5.82	0.442	0.410	8.10	81.3
BAC	12.8	0.093	1.35	2.72	0.400	0.136	0.395	0.550	0.669	0.211	0.068	0.082	0.167
Range	60,201–210,023	2601–20,600	7201–38,340	8991–27,685	12.1–185	200–2571	2.43–10.6	7.16–180	26.2–70.7	1.03–8.33	1.35–9.64	4.77–14.7	54.5–310

compensate for the losses through evaporation. This allows residues of saline efflorescence to be deposited on the surface, composed of sulphates and alkaline chlorides such as MgSO4 (Cirujano 1980; Ladero et al. 1984). These types of rocks contribute the majority elements of Ca and Mg in these soils. The pH of these soils is generally basic (Villar 1983), which limits the mobility of certain elements. Salinity is not only due to Na, as although this element is present in high concentrations, it is exceeded by other saline ions such as Mg. However, it is worth highlighting a certain degree of possible eutrophication in these soils due to contamination with organic matter (Cirujano 1980).

Zamora lagoon (Otero de Sariegos) has alluvial soils and sandy strata that contain a greater proportion of Si (López-Sáez et al. 2017). They have a high content of salts—mainly sodium and magnesium chloride—and a lower content of other elements. This is consistent with the data obtained: a high concentration of Na and low concentration of K, Mg and Fe, among others.

The soils in the salt marshes of the Tinto and Odiel Rivers are composed of quartz, feldspar, dolomite and calcite, with naturally occurring high concentrations of Na, Mg, P, Cu, Ca, K, Fe and S (Rufo et al. 2007). The composition of these soils is greatly influenced by the content of the waters and sediments carried by the Tinto and Odiel Rivers, namely, metals from their headwaters in the Iberian Pyrite Belt, some of which are very mobile and are found in high concentrations in the estuary of these rivers. These soils are also neutral-acidic, with a pH of 6.3, which facilitates the bioavailability of the most mobile elements. This is consistent with the high concentrations of Fe, Cu, Zn and As found. The tidal influence in this area supplies the sodium in these soils.

These soils have a low concentration of macronutrients such as K, Ca and Mg, with the majority element being Fe. Metal content—except for Ni and Mn—is generally high, particularly Zn and Cu (both mobile elements) that are present in higher concentrations than in soils in inland locations. The As and Pb contents are also high, well above the inland locations.

Our results for sodium in *S. patula* show that the highest content of this element occurs in the locality of El Terrón, with values over 210 g/kg. Previous studies on ionic relationships in halophytes revealed that other *Salicornia* species such as *S. persica* Akhani. accumulate large amounts of sodium, with values of 17 g/kg, being the main element for that species (Flowers and Colmer 2008; Matinzadeh et al. 2013). As a succulent euhalophyte, *S. patula* presents a crassicaule morphology with abundant parenchymal tissue, containing cells with large vacuoles filled with water and salts, mostly sodium, revealing a clear adaptation to halophyticism.

In the salt marshes of the Tinto River, *S. patula* is the chenopod with the highest content of Na; other species studied in the same area such as the woody perennials *Sarcocornia pruinosa* Fuente, Rufo and Sánchez- Mata, *S. perennis* and *Arthrocnemum macrostachyum* with sodium concentrations between 1000 and 52 g/kg (Fuente et al. 2009, 2018).

Using other techniques such as atomic absorption spectrometry, various authors have obtained similar results in *Salicornia bigelovii* Torr., *S. herbacea* L. and *S. neei* (Lag.) M.A. Alonso & M.B. Crespo, (Rhee et al. 2009; Lu et al. 2010; Riquelme et al. 2016). Ventura et al. (2011), using ICP-OES, highlights the high presence of sodium in stems of *S. persica* and *Sarcocornia fruticosa* (L.) A.J. Scott.

*Given the high sodium values, the maximum daily intake for this micronutrient recommended by EFSA (*2017*), which is 2 g per day, would be easily exceeded with just a small portion of this vegetable, so, for food use, boiling process is recommended to reduce this level.*

Potassium is one of the main macronutrients in *Salicornia patula* and one of the most abundant in plants (Very and Sentenac 2003).

The values obtained for potassium are higher than those described for other species, such as *Salicornia bigelovii* containing 1.76 g/kg d.w. (Lu et al. 2010), and higher than in other chenopods such as stems of *Sarcocornia ambigua* Michx, or leaves of *Chenopodium album* L. (Poonia and Upadhayay 2015; Bertin et al. 2016). Mitra (2018) has studied *S. brachiata* Roxb., which is used to make different food products such as samosa or kachuri as a source of potassium of the diet.

The calcium data from the Tinto River and El Terrón localities show a greater absorption capacity in the plant in relation with the soil content. The inland populations reveal variations between the calcium content in soils and plants.

Calcium is present in many edible vegetables such as *Parietaria officinalis* L., *P. judaica* L., *Urtica dioica* L., *Amaranthus retroflexus* L., *Chenopodium murale* L., *Tordylium apulum* L., *Foeniculum vulgare* Mill., *Borago officinalis* L. and *Diplotaxis erucoides* (L) D.C., containing between 400 and 800 mg of Ca /100 g f.w. (Renna 2017*)*, which means that a 100 g portion of fresh material provides between 42 and 84% of the 950 mg per day of daily calcium requirement (EFSA, 2017).

The samples of *Salicornia patula* analysed in this study have considerable amounts of calcium, up to 20.6 g/kg d.w. so the consumption of this vegetable would increase the levels of this macronutrient in the diet. However, it is important to highlight the capacity of plants to form oxalates of reducing the bioavailability of calcium (Renna 2017*)*.

Like other halophytes, calcium is located in the stems, as in *Sarcocornia neei* and *S. ambigua* Michx. (Bertin et al. 2014; Riquelme et al. 2016), or in the leaves as in *Salicornia herbacea* (Min et al. 2002). It should be noted that the accumulation of this element leads to the formation of biominerals such as wedelite, which is present in *Sarcocornia pruinosa* (Fuente et al. 2018).

In all the localities except in Otero de Sariegos, magnesium concentrations of *Salicornia patula* are more abundant than the correspondent soils.

Other halophytes such as *Salicornia europaea* L. present lower values, with 2.6 g/kg in the stems (Furtado et al. 2019); however, the magnesium content in the seeds is very high with over 130 mg/kg (Khan and Ungar 1996).

Other related plants such as *Amaranthus viridis* L. have higher values, with 39 g/kg of magnesium (Datta et al. 2019).

The adaptability of this species implies that the concentration of essential macronutrients such as Na, Mg and K is similar to that of other halophytes, even in the case of Ca, regardless of the elemental concentration in the soil.

Iron is an essential micronutrient for almost all living organisms due to its role in metabolic processes such as DNA synthesis, respiration and photosynthesis (Ciudad Reynaud 2014). Iron is the main element in the Tinto River soils, especially in the estuary area (Cánovas et al. 2007; Rufo et al. 2010). Among our results for iron in *S. patula*, the localities of El Terrón, La Rábida and Villacañas stand out with higher values than described by other authors for the same species: 735 mg/kg (Ancuceanu et al. 2015).

The high iron content in *S. patula*, as in other species such as *S. bigelovii*, makes it a natural source of this micronutrient (Lu et al. 2010) and ideal for consumption. Iron values of 2336 mg/kg have been described in other related plants such as *Amaranthus spinosus* L., giving it anti-anaemic properties (Kone et al. 2012), or in the seeds of *Chenopodium quinoa*, where it has been reported as one of the main micronutrients (Reguera et al. 2018).

The results obtained for manganese in *S. patula* vary in the different sampling points. The localities of El Terrón, La Rábida and Villacañas have concentrations over 90 mg/kg, while the rest of the populations do not exceed 12 mg/kg. The presence of manganese in soils is very noticeable in inland localities, despite the plant's exclusion strategy. Although this element is essential for the development of plant species, it generates toxicity in high concentrations, confirming the importance of maintaining adequate homeostasis for this metal (Ducic and Polle 2005). Despite this, *S. patula* edible stems could be considered as a source of this micronutrient. *S. patula* shows a higher zinc content in marsh localities in common with species such as *Halimione portulacoides* (L) Aellen., *Sarcocornia perennis, Salicornia europaea* and *Spartina alterniflora* Loisel. (Figueroa et al. 1987; Duarte et al. 2010; Cambrollé et al. 2011; Pan et al. 2016). The presence of zinc oxide in the roots of *Salicornia persica* has also recently been described, so halophytes can absorb certain nanoparticles from the soil and transport them through their vascular system to stems and leaves (Balazova et al. 2018).

The presence of copper and lead is higher in both saline soils and in the *S. patula* samples analysed from these locations. In some cases, the copper and lead content in the plant exceeds the tolerable levels for intake of 10 mg/kg and 0.01 mg/kg, respectively (IOM 2001; EFSA 2010). Although plants deploy a strategy to prevent their absorption from the soil (Viehweger 2014), plant-based foods constitute their main source of incorporation in the diet. These two elements accumulate preferentially in the halophyte root, as in *Sarcocornia fruticosa* or *Spartina maritima* (Curtis) Fernald. (Duarte et al. 2010), so the consumption of Salicornia stems is only recommended in soils whose metal content is low. In our data, these elements show statistical differences between localities, highlighting in La Rábida, where higher content was found.

The presence of copper and lead is sohigh in Sarcocornia neii with 3.2 g/kg and 25.40 mg/kg, that its use is studied in the phytoremediation of soils with a high presence of heavy metals (Meza et al. 2018).

Other elements such as arsenic and nickel reveal different strategies

Arsenic is a naturally occurring element in the environment, so food is the main source of exposure when consumed. The concentrations of this micronutrient in *Salicornia patula* are within the reference doses of consumption for humans, between 0.3 and 8 mg/kg, even in cases where there is a high presence in the soil, when it exhibits a strategy for excluding the metal and avoiding its toxicity. This element in other Chenopodiaceae has been detected in *S. brachiata* leaves (Sharma et al. 2010), and *Atriplex* species showed a high arsenic content in the aerial parts, with values between 3 and 5 mg/kg (Tapia et al. 2013). There are low concentrations of nickel in soils and plants in all locations, although in soils with a greater presence of nickel, this species could be used in phytoremediation processes, as occurs with other halophytes such as *Mesembryanthemum crystallinum* L., *Spartina patens* (Aiton) Muhl., *Atriplex nummularia* Lindl. and *Sporobolus virginicus* (L) Kunth (Amari et al. 2014; Eid 2011).

Barium and strontium have very different values. The data for barium are similar in all areas—low in plants and soils—avoiding contamination with this metal. Other authors using the same technique obtained higher barium data in the stems of other halophytes such as *Cakile maritima* Scop. and *Senecio glaucus* L., with values of 41 mg/kg, accumulating in the root (Beheary and El-Matary 2016). Dahl et al. (2001) and Marie (2010), have recommended to incorporate sources of this element into human consumption, due to its action on bone tissue. The strontium data are similar to other Chenopodiaceae such as *Chenopodium album* L. or *Salsola kali* L., and this element is more concentrated in the stems than in the root (Shahraki et al. 2008).

Conclusions

Data of elemental content of natural populations of S. patula in the Iberian Peninsula in relation to soil and plant are provided for the first time. From the results presented in this study, Salicornia patula shows a general accumulation strategy for Na, Mg, K and Ca independent of the concentrations of this element in the substrate in which they are located.

Our results confirm *Salicornia patula* as a wild Mediterranean edible plant, a source of Mg, K, Ca, Fe and Mn. Besides, the absorption of macronutrients from the soil and high concentration of other micronutrients such as iron and manganese could make this a species with high mineral contribution for human nutrition. The high iron content in this species makes it a natural source of this micronutrient essential due to the role in metabolic processes.

It presents an exclusion response to the metals present in contaminated soils, capturing these metals in the roots and not translocating to the aerial part, thus corroborating its potential for phytostabilization of soils with a high presence of metals like Pb, Sr, As, Cu and Zn or to restore salt marshes or lagoons.

The cultivation of *S. patula* for food uses is recommended in soils with a low metal content to avoid the consumption of toxic elements so as not to exceed their tolerated intake. It is necessary that in future studies a correct identification of the samples is included as a guarantee of quality to compare the nutritional value of this Mediterranean species against others.

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