

Plant height and mineral content of *Opuntia tapona* growing along the coasts of Baja California Sur, México

Alejandra Nieto–Garibay¹, Enrique Troyo–Diéguez¹, Ricardo David Valdez–Cepeda², Edgar Rueda–Puentes³, José Luis García–Hernández⁴, Arnoldo Flores–Hernández⁵, Sergio Zamora–Salgado⁶, Ignacio Orona–Castillo⁴ and Bernardo Murillo–Amador^{1*}

¹Centro de Investigaciones Biológicas del Noroeste, S.C. Marbermejo No. 195, Col. Playa Palo de Santa Rita, Apdo. Postal 128. CP 23090. La Paz, Baja California Sur, México.

²Universidad Autónoma Chapingo. Centro Regional Universitario Centro Norte. Calle Cruz del Sur No. 100, Col. Constelación. CP 98085. Zacatecas, Zac., México.

³Universidad de Sonora. Unidad Regional Norte, Campus Santa Ana, Ave. Universidad e Irigoyen s/n, Col. Ortiz, H. Caborca, Sonora, México.

⁴Universidad Juárez del Estado de Durango. Constitución 404 Sur, Zona Centro. CP 34000. Venecia, Durango, México.

⁵Universidad Autónoma Chapingo. Unidad Regional Universitaria de Zonas Áridas. Carr. Gómez Palacio–Ciudad Juárez. CP 35230. Bermejillo, Durango, México.

⁶Universidad Autónoma de Baja California Sur. Carr. al Sur Km 5.5, Apdo. Postal 19–B. CP 23080. La Paz, Baja California Sur, México.

*Corresponding author: e–mail: bmurillo04@cibnor.mx

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Abstract

Salinity remains one of the world's oldest and most serious environmental problems affecting agricultural production. *Opuntia* species can support strong droughts and abrupt changes of temperature, but they are sensitive to salt concentration in the soil solution or irrigation water. The objective of the present study was to take samples of wild *Opuntia* plants along the coasts of Baja California Sur to measure mineral contents, and to identify possible salt-tolerant genetic materials relating those minerals associated with salt-tolerance such as sodium and chloride. Fourteen sites were located in two transects along Baja California Sur coasts to identify wild prickly pear "nopaleras". Plant height and Ca, Mg, K, Na, Fe, Mn, Zn, Cu, Cl, N, P and B of *Opuntia tapona* plants were evaluated in cladodes and roots. The results showed significant differences in plant height and minerals between sample sites and mineral between tissues. All minerals showed higher content ($P < 0.05$) in cladodes than roots. The probably effect of marine breeze on mineral content of *O. tapona* is discussed in this manuscript. We concluded that is necessary to measure the marine breeze chemical and soil physical-chemical properties to determine the effect of these factors in mineral content, growth and morphological characteristics of wild prickly pear in Baja California Sur.

Keywords: sodium, chloride, salinity tolerance, plant breeding, biodiversity, conservation.

Introduction

Salinity remains one of the world's oldest and most serious environmental problems affecting agricultural production (McWilliam, 1986; López, 1995). The accumulation of soluble salts in the soil diminishes significantly the value of the productivity of cultivated or not cultivated lands (Pessaraki, 1999). This condition cause not only decreases in crop production but also becomes transforming terrestrial areas in sterile areas; those in the past were productive lands (López, 1995). The FAO (1996) estimates that from 237 millions of hectares of irrigated lands, around of 30 millions are gravely affected for the salt; other 80 millions of hectares have been affected in some grade and around 1.5 millions of hectares lost annually because of watering due to the flooding or the salinity. During the past 45 years, much attention has been given to the effect of NaCl on plant growth and production; however, the fundamental mechanisms determining the responses of plants to salinity are still not understood (Amzallag *et al.*, 1990).

The *Opuntia* species can support the strong droughts and the abrupt changes of temperature but the majority are sensitive to the concentration of salt in the soil or irrigation water (Nobel *et al.*, 1984; Berry and Nobel, 1985; Silverman *et al.*, 1988, Nerd *et al.*, 1991; Le Houérou, 1996; Murillo-Amador *et al.*, 2001). The concentration of 1/5 seawater can decrease or inhibit the root growth of agaves and cacti (Nobel, 1998). Species such as *O. quimilo* from Argentina and *Cereus validus* are more tolerant to NaCl than other *Opuntia* species (Nobel, 1998). *Opuntia ficus-indica* reduces its growth by half when exposed continually to NaCl concentrations (1/10 of seawater) (Nobel, 1998).

Baja California Sur, Mexico has 2,230 km of coasts, where grows a variety of wild species such as Opuntias. In this geographic area of Mexico, Opuntias of rackets (cladodes) are not abundant. However, some of them are located in the Ocean Pacific where grow species of reduced height (Diguet, 1912). The habitat of these species is located in plateaus, hillsides and rocky slopes and is distributed from the Vizcaino Desert to the Sierra La Laguna (Roberts, 1989). Six species of prickly pear such as *Opuntia pycnantha* Engelm. in Coulter, *Opuntia corks* Engelm. in Coulter, *Opuntia (platyopuntia) spp.*, *Opuntia lagunae* K. Brandegeee, *Opuntia orecola* and *Opuntia tapona* are reported. *Opuntia lagunae* K. Brandegeee is endemic of the Sierra La Laguna. *Opuntia orecola* is broadly distributed in the Peninsula, which offers a refuge and food for rabbits, mice, birds and reptiles, it is broadly distributed coastwise of the Ocean Pacific (Leon de la Luz and Coria, 1992). *Opuntia tapona* is endemic of the Peninsula, which is distributed from Comondu and Loreto until the Del Cabo region and many Islands of California Gulf (Roberts, 1989). Some *Opuntia* plants are frequently near or along the coast, exposed to the marine breeze or growing in saltpetre. This characteristic allows to *Opuntia* species to adapt, distribute in different environments and to change its morphological aspects, depending of the environmental conditions of the places where are growing (Kiesling, 1999).

These species could be a source of wild germplasm for the reforestation of natural protected areas, as well as its possible use in national programs of plant breeding for salt-tolerance under cultivated conditions, since in arid zones, saline water is often used in agriculture because of fresh water is scarce.

Based on the perspectives of this natural resource, the objective of the present study was to take samples of wild *Opuntia* plants in two transects along the coasts of Baja California Sur to measure plant height and mineral contents, and to identify possible salt-tolerant ecotypes relating those minerals associated with salt-tolerance such as sodium and chloride.

Materials and methods

Sampling sites

Fourteen sites (Figure 1) were located in two transects along coasts of Baja California Sur to identify wild prickly pear “nopaleras” nearest to the coasts. Seven sites were situated in the first transect, which was along the Ocean Pacific (OP) from Laguna of San Ignacio to Cabo San Lucas, and seven sites were situated in the second transect which continued from Cabo San Lucas to La Paz city along California Gulf (CG).

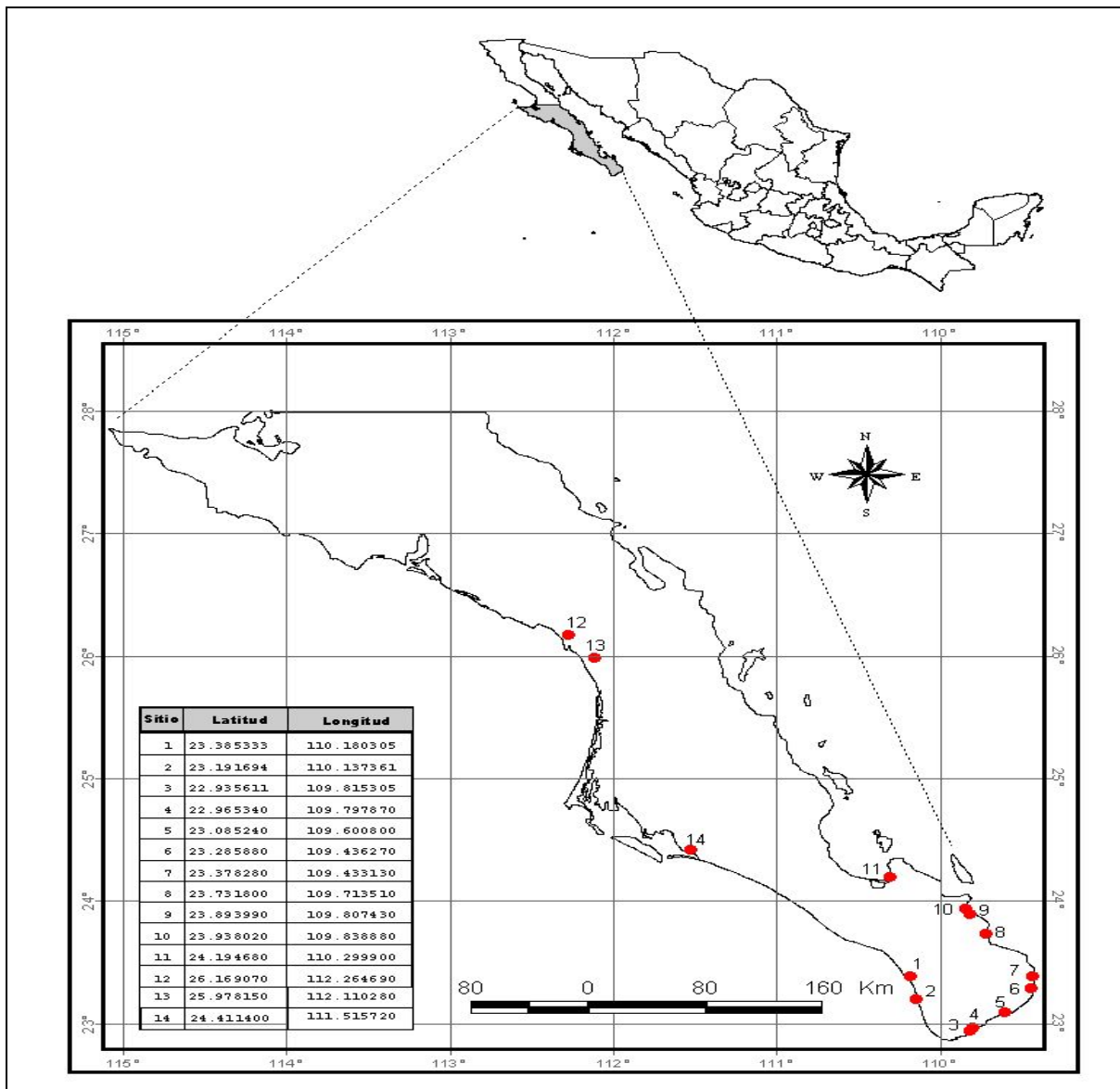


Figure 1. Sample sites of wild prickly pear plants in two transects along Ocean Pacific and Gulf of California coasts in Baja California Sur, Mexico.

Field description and variables measured

In both transects, wild prickly pear of *Opuntia topona* species nearest to the coast were located, collecting plants with the most exhibition to the marine breeze. The sample sites were positioned

geographically using a global positioning system (Garmin GPS IV). In each site, four plants were collected and plant height was measured. Each plant was considered as a replication. The collected plants were introduced in paper bags, labelled, stored in cardboard containers and moved to the laboratory.

In the laboratory, the plants were separated into roots and cladodes, before drying at 80 °C for 48 h in oven. Root tissue was rinsed by dipping three times for a few seconds in distilled–deionised water. Root and cladode dried tissue was finely ground in a blender (Braun 4–041 Model KSM–2).

Mineral content

The mineral content was measured in root and cladode dried tissue. The Na, Ca, Mg, Mn, Fe, Cu, Zn, and K content was determined by atomic absorption spectrophotometer (Shimadzu AA–660, Shimadzu, Kyoto, Japan) after digestion with H₂SO₄, HNO₃, and HClO₄. Chloride was extracted in boiling water and determined by ion chromatography (Shimadzu HIC–6A, Shimadzu, Kyoto, Japan). Phosphorous was estimated colorimetrically as phosphomolybdate blue complex method at 660 nm from the same extract. Total nitrogen was determined by Kjeldhal digestion using a sulphuric acid and salicylic acid mixture with copper and potassium sulphate such as catalysts followed by ammonium estimation using the Nessler calorimetric method. Boron was estimated through spectrophotometric method based on colorimetric technique with previous digestion using chlorhydric acid and curcumin in the presence of oxalic acid.

Statistical analysis

Data were analyzed by a one–way analysis of variance using the General Linear Model procedure of the Statistical Analysis System (SAS, 1996). Means of the variables were separated by Tukey's HSD test ($p < 0.05$).

Results and discussion

Plant height

The ANOVA showed significant differences ($F_{13, 42} = 5.71$; $p = 0.0001$) of plant height between sample sites. The plants of site eight located in the second transect (CG), showed higher height, while lower were showed by plants of site 14, in the first transect (OP) (Figure 2). In general, plants located in the first transect (OP) showed lower heights with respect to plants located in the second transect (CG). This results are in accordance with Diguët (1912) who reported that in Baja California the Opuntias of rackets (cladodes) are located in Ocean Pacific where growing shorter species. This characteristic could be associated to the environmental conditions of the coast of OP, which is affected more severely by wind, and consequently the plants are constantly exposed to the marine breeze which is more continuous and strong respect to CG (Flores, 1998).

Mineral content

The analysis of variance of plant mineral content showed significant differences between sample sites (Table 1). Calcium was higher in plants collected in site six (CG) followed by plants of site 12 (OP), while lower content was showed in plants of site two (OP). The plants in sites 11 (CG) and nine (CG) showed high and low Mg, respectively. Potassium was higher in plants of site one (OP) respect to plants of site four (OP). The plants of site 14 (OP) and nine (CG) showed high and low sodium content, respectively.

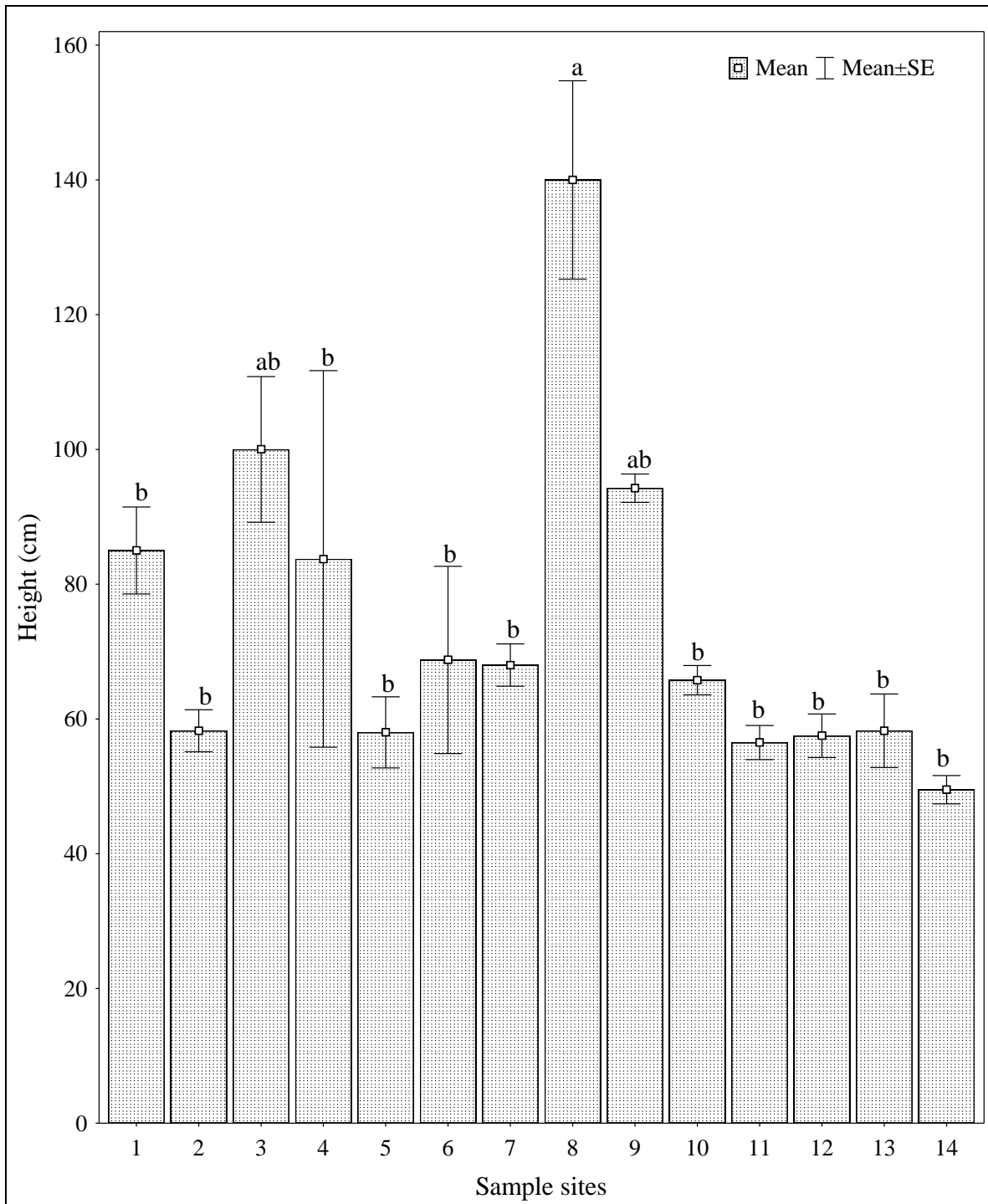


Figure 2. Height of wild prickly pear plants sampled in 14 sites along the coastal of Baja California Sur, Mexico. Each value represents the average of four dates. Means followed by the same letter in each bar are not significantly different (Tukey HSD $p=0.05$).

High Fe content was showed in plants of site five (CG) with low values those plants collected in site 11 (CG). Manganese, zinc and copper were higher in plants of site two (OP) and site nine (CG) for Mn, while plants of site 12 (OP) showed lower Mn and Zn and plants of site 14 (OP) lower Cu.

Chloride was higher in plants of site six (CG) than plants of site 14 (OP). High nitrogen was showed in plants of site 11 (CG) and low content was in plants of site 14 (OP). Plants collected in site 14 (OP) showed higher phosphorus than those plants of site one (OP). Boron was higher in plants of site two (OP) than plants of site 11 (CG) (Table 2). Information on mineral content in cacti species from Baja California Sur México is sparse. However, Ramírez–Orduña *et al.* (2005) in a study with legumes and non legumes species that grows in this geographic area of Mexico, reported that *Opuntia cholla* had the highest Ca content than the other studied species. In the same sense, Ramírez *et al.* (2001) determined the mineral content of 16 browse species growing in northeastern Mexico, and reported that a cacti species (*Opuntia engelmannii*) had the highest Ca (26.7 g kg^{-1}) content and the legume *Prosopis glandulosa* was lowest (5.4 g kg^{-1}). According with Spears (1994) the high soils pH of the arid and semiarid regions may be the cause that shows high Ca content. Also, *O. cholla* was reported with higher content of Mg and K than other species (Ramírez–Orduña *et al.*, 2005). According with Greene *et al.* (1987) and Grings *et al.* (1996) the K content in plants has been associated with factors such as the age, environmental growth conditions, and water availability in the soil (Charley, 1977). Moreover, has been reported that high concentration of ions such as Na and Cl in the root medium, depress the K, Ca, and other minerals uptake by plants (Greenway and Munns, 1980). In the present study, it is difficult to determine if the content of minerals was affected by Na or Cl, therefore, further studies are require to assess whether the wild prickly pear plants suffer mineral deficiency because of interaction of salt ions. A study with Na content in wild *Opuntia* of Baja California Sur shows that *Opuntia cholla* had lowest Na content with respect to other species such as *B. microphylla* (Ramírez–Orduña *et al.*, 2005). In addition, they found that both legumes and non–legumes species increased Na content in spring and when rainfall was lower. These findings has also been reported in other arid areas, although these information showed low and apparently deficient of Na content for shrubs (Kallah *et al.*, 2000; Khanal and Subba, 2001; Moya–Rodríguez *et al.*, 2002). Also, Ramírez–Lozano (2004) reports a low content of Na, P, Cu and Zn in *Opuntia engelmannii* in an arid region of the north of México; nevertheless, this species has higher content of Mn. Plants collected in transect 1 (OP) showed higher sodium than plants of transect 2 (CG). Those located in transect 1 are primarily exposed to marine breeze and strong winds, where plants also showed lower height.

Besides, morphological differences such as abundant and bigger spines were showed by plants collected along transect 1 than plants of transect 2. Contrary to sodium, higher chloride content was found in plants collected along transect two (CG) (Table 2). According to Greenway and Munns (1980), the sensitivity to salinity of certain species depends of the absorption of Cl or Na from root to shoot. The differences of sensitivity between species and varieties to high concentration of Cl or Na in shoots, shows that is higher in glycophytes than in halophytes, and this difference is based in an inadequate ionic cellular compartment in the shoots of glycophytes species.

Opuntia plants collected in site 14 (OP) can survive under high Na content, although it seems that this ion has an adverse effect on plant height (Figure 1). This decrease in height is characteristic of salt–sensitive plants (Greenway and Munns, 1980; Maas, 1986). However, has been demonstrated that some plants are able to adapt to the salinity of the rooting medium by increasing their osmotic pressure and maintaining an osmotic pressure gradient between the cladode and the external solution (Jordan and Nobel, 1984). In this sense, Salisbury and Ross (1994); Miller and Doescher (1995); Curtis and Barnes (2000) report that some plants of arid or semiarid zones, can accumulate Na to alleviate water and saline stress and an osmotic mechanism can occur when the soil becomes driest, salt concentration increase in the soil, osmotic potential become more negative, lowering soil water potential, and water flow into the plant will decrease unless the plant is able to continue to adjust its internal water potential below that of the soil. The increase in osmotic pressure in the

cladodes has been reported by Nerd *et al.* (1991), which was associated with a decrease in cladode water content. Also, they found that the contribution of metabolites exceeded those of the electrolytes when the salinity of the medium was high. This process could be associated with a reduction in accumulation of the major monovalent ions K and Cl at high salinity. The present study showed that *Opuntia* from site 14 (OP) had low Cl and some plants showed low K and other ions content. This result could be associated with the accumulation of metabolites in stressed plants, which is attributed to a decline in the demand for assimilates in the growing region (Nerd *et al.*, 1991).

Table 1. Analysis of variance (mean squares) of mineral content in tissues (cladodes and roots) of wild prickly pear collected in 14 sites along of Baja California Sur, México coast.

Source	d.f.	Ca	Mg	K	Na	Fe	Mn	Zn	Cu	Cl	N	P	B
Sites (S)	13	211.5**	140.5**	356.2**	75.1**	41.7**	0.49**	0.001**	0.00001**	111.6**	16.0**	2.1**	0.0003**
Tissues (T)	1	2351.4**	3245.9**	2743.7**	1343.3**	1152.2**	0.60**	0.0001**	0.01**	2318.7**	215.2**	2.05**	0.003**
S x T	13	261.2**	70.03**	287.4**	33.4**	44.8**	0.22**	0.0005**	0.0001**	107.8**	6.8**	0.5**	0.0002**
Error	84	10.8	2.4	18.9	2.9	2.6	0.06	0.00002	0.000004	4.3	1.2	0.04	0.00001

** Significant at 0.01 probability level.

Table 2. Mineral content (mg g⁻¹ dry-weight) of wild prickly pear collected in 14 sites along of Baja California Sur, México coast.

Sample sites	Coast	Ca	Mg	K	Na	Fe	Mn	Zn	Cu	Cl	N	P	B
1	OP	15.1 bcd	13.2 bc	44.4 a	6.8 bcd	1.8 ef	0.14 d	0.018 fg	0.034 ab	14.79 ab	3.64 d	0.41 f	0.026 bc
2	OP	5.4 f	6.8 fgh	27.3 bcd	6.1 cd	5.2 bcd	0.72 a	0.076 a	0.035 a	7.42 efg	6.33 bc	0.83 cde	0.035 a
3	OP	10.1 def	6.4 gh	33.7 b	6.7 bcd	3.8 def	0.44 abcd	0.032bcd	0.032 bc	8.83 cdef	6.29 bc	0.80 cde	0.025 bcd
4	OP	9.0 ef	15.8 b	16.6 f	6.0 cd	7.8 ab	0.64 ab	0.039 b	0.032 bc	7.72 defg	4.98 bcd	0.47 ef	0.028 b
5	CG	15.2 bcd	10.1 de	26.3 bcde	7.4 bc	8.3 a	0.16 d	0.03 cde	0.032 bc	9.20 cdef	4.84 bcd	0.75 cdef	0.022 cde
6	CG	24.7 a	12.7 cd	27.1 bcde	7.4 bc	3.0 def	0.59 abc	0.025 def	0.031 bc	16.38 a	4.26 d	0.91 bcd	0.025 bcd
7	CG	13.5 cde	8.5 efg	29.6 bc	8.7 bc	6.7 abc	0.24 bcd	0.03 cde	0.032 bc	10.85 cde	4.44 cd	0.90 bcd	0.022 cde
8	CG	9.8 def	13.2 bc	19.7 ef	4.1 de	3.3 def	0.18 cd	0.022 efg	0.033 ab	9.88 cdef	6.66 ab	0.96 bcd	0.019 ef
9	CG	10.0 def	5.4 h	21.5 def	2.9 e	3.3 def	0.73 a	0.026 def	0.033 ab	4.65 gh	5.09 bcd	0.77 cdef	0.028 b
10	CG	9.8 def	15.1 bc	25.0 cde	9.4 b	4.3 cde	0.33 abcd	0.027 de	0.034 ab	11.24 bcd	4.11 d	0.64 def	0.018 efg
11	CG	17.7 bc	18.8 a	24.9 cde	4.0 de	1.5 f	0.6 abc	0.029 cde	0.034 ab	12.07 bc	8.31 a	0.63 def	0.012 h
12	OP	20.4 ab	9.5 ef	25.6 cde	4.4 de	1.9 ef	0.04 d	0.016 g	0.032 abc	6.75 fgh	3.81 d	1.20 b	0.013 gh
13	OP	9.9 def	10.2 de	23.6 cdef	6.3 cd	3.1 def	0.11 d	0.019 fg	0.033 ab	5.20 gh	4.15 d	1.12 bc	0.015 fgh
14	OP	12.9 cde	4.9 h	23.0 cdef	15.4 a	7.0 abc	0.14 d	0.037 bc	0.029 c	3.31 h	3.17 d	2.54 a	0.019 def

Each value represents the average of eight dates. Means followed by the same letter in each column are not significantly different (Tukey HSD $P = 0.05$).

The analysis of variance of mineral content showed significant differences between tissues (roots and cladodes) (Table 1). All minerals showed higher content ($P<0.05$) in cladodes than roots (Table 3). Contrary to the results of this study, Nerd *et al.* (1991) in cultivated *Opuntia ficus-indica* found that Na was higher in roots than in cladodes, which could be due to wild ecotypes of *Opuntia* were evaluated. Likewise, they found that K was higher than Na content. Similar results of K content have also been reported for *O. ficus-indica* by Berry and Nobel (1985), Murillo–Amador *et al.* (2001), Franco–Salazar and Véliz (2007) and for other cactus species such as *Opuntia humifusa* (Silverman *et al.*, 1988). The present study showed that potassium was higher in cladodes than roots. Similar results were reported by Nerd *et al.* (1991) who besides found that K decreased moderately when salinity increased. In this study, chloride was lower in roots than in cladodes. Different patterns of Cl were observed in cladodes and roots by Nerd *et al.* (1991), while Cl in cladodes increased significantly at 50 mol m^{-3} , in roots increased when salinity increased, approaching the level of cladodes at highest salinity level. In turn, Murillo–Amador *et al.* (2001) found that Cl in young cladodes was higher than in rooted cladodes. Similar results were found by Franco–Salazar and Véliz (2007). There is evidence that in nonhalophytes salt sensitivity is due to excess Na and Cl in shoots (Greenway and Munns, 1980; Maas, 1986). Likewise, Sepaskhah and Maftoun (1981), Flowers *et al.* (1977), and Harvey (1985) reported that tolerance of cultivar within crop species has been correlated with Na and Cl exclusion from shoots. Although in *Opuntia humifusa*, Silverman *et al.* (1988) found that salt–tolerance of two ecotypes was associated with those group that accumulated more Na in cladodes. This result are in agreement with the present study because of higher Na was found in cladodes than in roots, contrary to the results founded by Nerd *et al.* (1991) who reported that *O. ficus-indica* was able to restrict Na and Cl accumulation in their cladodes when salinity was raised. This result could be another adaptation mechanism which enables to limit growth under salinity stress. The fact that Na content in plants from site 14 (OP) was higher than Cl, show that in a saline environment, the ability to take up and confine Na to upper tissues such as leaves and cladodes, facilitate the water uptake and transport, diminishing the metabolic cost for the osmolytes production (Hasegawa *et al.*, 2000). However, trace amounts of sodium are required for growth of plants using the C4 pathway of carbon fixation and may also be important in plants with crassulacean acid metabolism (Jennings, 1976).

Table 3. Mineral content (mg g^{-1} dry–weight) in cladodes and roots of wild prickly pear collected in 14 sites along of Baja California Sur, México coast.

Tissue	Ca	Mg	K	Na	Fe	Mn	Zn	Cu	Cl	N	P	B
Cladodes	17.7 a	16.1 a	31.2 a	10.3 a	1.1 b	0.43 a	0.03ns	0.04 a	13.7 a	6.3 a	1.0 a	0.02 a
Roots	8.5 b	5.4 b	21.3 b	3.4 b	7.6 a	0.29 b	0.02ns	0.02 b	4.6 b	3.6 b	0.7 b	0.01 b

Means of four plants per replication. ns= not significant. Means followed by the same letter in each column are not significantly different (Tukey HSD at $p=0.05$).

Important aspects of the study

The regions with the greatest area of young cladodes “nopalitos” cultivation in Mexico are Milpa Alta, Distrito Federal, and Tlalnepantla, Morelos, generally where do not use irrigation (Flores, 1995). However, regions in the Northwest of Mexico such as Mexicali and Valley of the Coast in Baja California, Del Yaqui and Mayo valley in Sonora, Del Fuerte Valley in Sinaloa, Santo Domingo valley in Baja California Sur and other productive areas, crop production requires irrigation. Specifically in Baja California Sur, underground water used for crop irrigation has a salinity range of 2.5 to 7.0 dS m^{-1} (Navejas, 1995). One third of the irrigated lands around the world are affected by salinity, then this represent one of the most important problems that affects the irrigated agriculture (El–Saidi, 1997). Since salinity is one of the most important factors that limit the productivity and distribution of plants, the studies of the effect of salinity has been conducted during long time. However, the mechanism of salinity resistance has not be totally understood (Mansour, 1997). In this sense, the present study is the first knowledge of mineral content of this species which can to identify possible tolerant genetic materials to the salinity that can be a source of wild germplasm for the reforestation of natural protected areas in Baja California Sur, as well as its possible use in national programs of plant breeding of the species for salt–tolerance under cultivated conditions. In Mexico, from ancestral times this species is broadly utilized with ecological, nutritious, medicinal, cultural, and others uses, although salt–tolerance studies in *Opuntias*, it is found in development. This study proposes to continue the research at least two additional transects along Baja California

Peninsula coasts and to collect prickly pear ecotypes along OP and CG. In this first study we concluded that significant differences in mineral content were found between the *Opuntia* plants collected in the different sample sites and between tissues (cladodes and roots). However, it is necessary to measure the marine breeze chemical content and soil physical–chemical properties to determine the effect of these factors in mineral content, growth and morphological characteristics of wild prickly pear in Baja California Sur. Plants of *O. tapona* from sites 14, six and one, should to be studied in details to determine if some of this ecotypes could be identify as a possible salt–tolerant genetic materials.

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