NaCl effect on germination and seedling fresh weight of *Stenocereus eruca* (Brandegee) A.C. Gibson & K.E. Horak

F. Alfredo Beltrán-Morales[1], Pablo Misael Arce-Amezquita[1],
Francisco Higinio Ruiz-Espinoza[1], Valeria Beltrán-Valdivia[2], Luis
Guillermo Hernández-Montiel[2], and Bernardo Murillo-Amador[2]*

[1]Universidad Autónoma de Baja California Sur. Carretera al Sur, km. 5.5.
Apartado Postal 19-B. La Paz Baja California Sur, México. C.P. 23080.

[2]Centro de Investigaciones Biológicas del Noroeste, S.C. Av. Instituto
Politécnico Nacional No. 195. Colonia Playa Palo de Santa Rita Sur. La Paz,
Baja California Sur, México. C.P. 23096.

*Corresponding author. E-mail: bmurillo04@cibnor.mx

ABSTRACT

Environmental disruption is particularly determinant for cacti development since they have slow growth and long life cycles. Soil and water salinity are two of the main environmental factors that are considered primordial for the propagation, seedling growth, establishment, and development of coastal cacti. The objective of this study was to evaluate chirinola (*Stenocereus eruca*) seed germination and seedling fresh weight using NaCl as a saline medium. One hundred seeds divided into five replicates of 20 seeds in a completely randomized design, were treated with five salinity levels and distilled water as control (0, 2, 6, 8, and 10 dS m^{-1}). Seeds were picked up from ripe fruits at a wild *Stenocereus eruca* population near San Carlos, Baja California Sur, México. Seedling fresh weight was significantly affected by saline stress, with lower fresh weight at the highest doses of 10 dS m^{-1}, and the greatest fresh weight production was obtained with 0 and 2 dS m^{-1}. However, germination percentage was greater at intermediate levels of 2 and 4 dS m^{-1} and lowest at 10 dS m^{-1} using NaCl; however, more studies should be conducted including other growth variables, seed viability, and salinity levels.

Keywords: *endemic species, salinity, endangered species.*

INTRODUCTION

Cacti generally are found in dry and arid desert or semi-desert regions with high average daytime temperatures and cold nights, and high evaporation rates. Cacti distribution range from Canada to Argentina, most of them develop in the warm and arid areas of the continents of both North and South America across a wide range of different habitats like deserts, sandy coastal stretches, scrublands, dry deciduous forests, high alpine desert, and tropical rain forests (Barthlott and Hunt, 1993; Gibson and Nobel, 1986; Nyffeler, 2002). The main diversity centers are Mexico and southwest USA, central Andes, Brazil, Paraguay, Uruguay, and Argentina with Mexico being the richest and most endemic region (Boyle and Anderson, 2002; Ortega-Baes and Godínez-Alvarez, 2006). The family is classified into three subfamilies, *Pereskioideae*, *Opuntioideae*, and *Cactoideae* (Barthlott and Hunt, 1993). The most apparent characteristic of cacti is the presence of areolas, considered as the growing part similar to the axillary buds of other dicotyledons. A main characteristic of buds or areolas is their ability to form reduced leaves, flowers, new stems, thorns, glands, bristles, hairs, and adventitious roots (Bravo-Hollis, 1978). The ethnobotanical importance of cacti has been described extensively in the literature, including their use as food, medicine, among others. In addition to their taxonomic and ecological importance (Godinez-Alvarez *et al*. 2003), many species (about 45) have been exploited since pre-Hispanic times (Casas, 2002; Luna-Morales, 2004).

Cacti play a very important role in Mexico from a biological and social context. There are about 715 species of cacti, 80 % of them are endemic and nearly all the others are shared with the Southern area of the United States or Central and South America. Many of their fruits and stems are important in Mexicans diet, although they are also used as fodder, ornamentally, or as a source of chemical substances for medical and pharmacological purposes; besides, there is clear evidence pointing out the outstanding ecological role of many cacti maintaining Mexican deserts (Benítez and Dávila, 2002). Additionally, it is also known that this group of plants has been the target of an intense illegal trade (plants and seeds) in the international market, especially in the United States, Japan, and several European countries. This illegal trade has been carried out for several years, and even now, there are signs that it is still practiced. This scenario takes place even though protection measures of wild environments in Mexico are more efficient than in the past. Given the diversity of species and life forms of cacti and the ease with which looters get seeds that can take out of the country covertly and without problems, there is much more that needs to be done in this regard. In Mexico, it is a priority that many of its species remain included in I CITES Appendices (Benítez and Dávila, 2002).

Stenocereus eruca (PNUMA-CMCM, 2011), which is distributed in the Magdalena region of Baja California Sur near the coastal areas (Fig. 1), has thick stalks that can reach up to 2 m long. Stems often form roots on the part where they touch the ground, they grow slowly forward and the oldest part at the end dies; they have unequal thorns grouped between 15 to 21 ribs and flattened yellowish-white spines. The flowers are large, tubular 10 a 12 cm in length, and are pinkish. They bloom around July and August. The fruit occurs in November and it is scarlet red three-spined stickleback and it has a size of a golf ball. *Stenocereus eruca* (chirinola) grows in alluvial sandy soils with low organic matter content (Rebman and Roberts, 2012).

This endemic species is considered an endangered organism according to the Mexican standard (NOM-059-SEMARNAT-2001). Illegal collection and habitat damage due to farming practices are the main dangers to its survival (Cancino *et al*., 1995). Reduced chirinola seedling recruitment could have a unique mechanism, which is a distinctive characteristic of clonal plants (Del Mandujano *et al*., 1996; Eriksson, 1997). The evidence on clonal diversity indicates that *S. eruca* and *S. gummosus* combine clonal growth and sexual recruitment as mechanisms of regeneration

(Molina-Freaner and Clark-Tapia, 2005). It has been observed that *Stenocereus eruca* has low pollination; therefore, its seed production is low (Bierzychudek, 1981). Moreover, although seed input is low, seeds are available for germination every year. Thus, low seedling recruitment in *S. eruca* is probably due to a lack of favorable conditions for seed germination and establishment (Clark-Tapia and Molina-Freaner, 2004). Additionally, seedling recruitment could be diminished due to the absence of microsites with favorable environments for seed germination and setting (Del Mandujano *et al*., 1996, 1998). Arce-Amezquita *et al.* (2017) evaluated two different solvents for chirinola seed germination; seeds with acetone increased total germination almost double (62 %) as compared to the control (32 %). On the other hand, pretreatment of the seeds with dichloromethane reduced total germination to 0 %. The use of these two solvents for pretreatment of the seeds had different effects on germination, being acetone a suitable solvent to increase total germination of chirinola seeds.

Salinity is one of the most environmental factors limiting the productivity of crop plants because most are sensitive to salinity caused by high concentrations of salts in the soil, and the area of land affected by it gradually increases (Shrivastava and Kumar 2015). A concept of saline agriculture was proposed for the rehabilitation of saline and degraded lands (Nikalje *et al*., 2017). Salinity effects are the results of complex interactions among morphological, physiological, and biochemical processes (Akbarimoghaddam *et al*., 2011). Mahajan and Tuteja (2005) mentioned that salinity negatively influences germination and plant growth, as well as physiological processes (photosynthesis, respiration, and transpiration), nutrient balance, membrane properties, and cellular homeostasis, enzymatic and metabolic activities. Sun *et al*. (2016) found that salinity decreased photosynthetic carbon assimilation, stomatal conductance, and lowered photosynthetic electron transport efficiency. Ion accumulations of Na^+ and Cl^- cause stress and the greatest destructive effects on plant tissues.

Around the world, more than 75 countries are fighting against issues related to salinity (Qadir *et al*., 2007; Alaghmand *et al*., 2016). Approximately, 20 % of the irrigated lands around the world also have issues with salinity (Qadir *et al*., 2008).

Plants exposed to stressful environments produce low amounts of dry matter, leaf area, and low yield (Amirjani, 2011). Furthermore, it has been described that high amounts of salt induce important morphological changes in the plant (Zadeh and Naeini, 2007). The influence of saline stressful conditions has been linked to the modification of some physiological and morphological characteristics like fresh/dry weight and seed germination (Chartzoulakis and Klapaki, 2000).

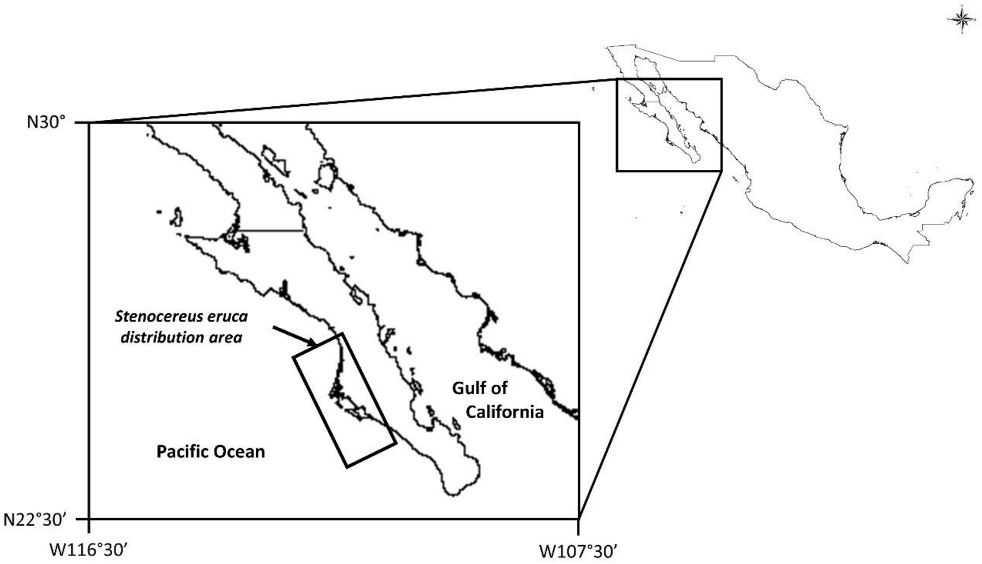

Figure 1. Map of *Stenocereus eruca* distribution in the Magdalena region of Baja California Sur, México (Arce-Amezquita *et al*., 2017).

Naturally, seed germination is strongly affected by salinity, which in turn reduces seedling development of many species (Debez *et al*., 2004). One of the most important stages of a plant cycle is germination, particularly for those species that develop in saline conditions (Song *et al*., 2005). Even though soil contains many ionic compounds with different impacts on development and seed germination (Tobe *et al*., 2002), most of the studies are usually carried out using sodium chloride (Ungar, 1996; Song *et al*., 2005; Nichols *et al*., 2008).

Studies with cacti have demonstrated that increasing salt concentration impacts their germination percentage and seedling biomass production (Beltrán-Morales *et al*., 2015; Orozco *et al*., 2017). The effects of salinity on growth and production of young cladodes "nopalitos" (cladode sprouts) of *Opuntia ficus-indica* (L.) Mill., were investigated by Murillo-Amador *et al*. (2001) using irrigation levels of NaCl with electrical conductivities of 2, 5, 10, 13, 18, and 21 dS m^{-1}. In general, all cladode variables (stem area, number of young cladodes, length and width of cladodes, fresh and dry weight) decreased with increasing salinity. The root-to-stem ratio and young cladode water content decreased significantly as salinity increased. For rooted cladodes, increased salinity decreases fresh weight and succulence and root fresh weight, dry weight, and length. The effect of salinity on *Pachycereus pringlei* seed germination was observed. When the concentration of NaCl was increased, the percentage of germination decreased (Nolasco-Soria *et al.*, 1996). Seeds of *Cereus jamacaru* were submitted to saline stress. The saline treatments showed a significant reduction in germinability as the saline solution concentration increased (Meiado *et al*., 2010). Podda *et al*. (2017) mentioned that *Opuntia ficus-indica* seeds germinated with NaCl in the substrate up to 50 dS m^{-1} of concentration, although lower germination percentages were observed in saline substrates, in comparison with those detected under control condition (0 mM NaCl). *Pachycereus pecten aboriginum* seeds germinated under different salinities decreased their germination percentage when salinity increased (Vega-Villasante *et al*., 1996).

However, there is not enough information about seed germination of *Stenocereus eruca* submitted to NaCl-stress and, more significantly, this would be the first report of seedling fresh weight of this species under salt-stress. The objective of this study was to analyze chirinola (*Stenocereus eruca*) seed germination and seedling fresh weight under saline stressful conditions caused by NaCl at different levels of electrical conductivity.

MATERIALS AND METHODS

Study area

Stenocereus eruca seeds were gathered in November 2018 from established wild mature plants (Figs. 2 and 3) in San Carlos located at 24°49'35'' LN and 112°05' 09'' LW, 10 m.a.s.l., 250 km north of La Paz city in Baja California Sur (BCS), México. This area is situated near Magdalena Bay, in the Sonoran Desert of Baja California Sur, México. This region has dry weather with 100 mm of annual rainfall, most of this rainfall (around 80 %) takes place around July and September (1988-2001, data provided by the Comisión Nacional del Agua, La Paz, B.C.S.).

In the coastal area of Sonora and Baja California, as well as in the lowland frequently flooded by marine water, there is a prevalence of saline soil; sodium-salt soils predominate, with sodium chloride or common salt high content. Alternatively, there may be an accumulation of calcium carbonate (Cervantes-Ramirez, 2002).

Ethics statement

The study carried out herein neither involves experimentation with humans or animals. The collection area is unprotected; though, *Stenocereus eruca,* is an endangered species hence permission was requested and granted by the deputy office of Federal Officer of SEMARNAT (Secretaría del Medio Ambiente y Recursos Naturales) in BCS.

Figure 2. An adult plant of *Stenocereus eruca* showing ripe and immature fruits. Plant located in San Carlos, B.C.S, México (photograph by Beltrán-Morales F.A., November 19, 2018).

Quantification of evaporated water

Before the application of the NaCl-treatments, an experiment was performed to quantify the evaporation rate at each Petri dish. Also, this test was used to identify if salt concentration was raised after replenishing the evaporated water with saline solutions at similar concentrations instead of distilled water, following Beltrán-Morales *et al*. (2015) method.

Figure 3. Adult plants of *Stenocereus eruca* associated with wild sarcocaulescent and scrubland vegetation (photograph by Beltrán-Morales F.A. November 19, 2018).

Seed acquisition

Ripe fruits were picked-up from healthy chirinola plants (NOM-007-SEMARNAT-1997). Seeds were separated from the pulp of the fruit and then sterilized by soaking them in a 5 % calcium hypochlorite solution for 5 min. The seeds were rinsed three times with sterilized distilled water and finally dried at 25 °C.

Saline solutions

The salinity treatments were 0 (distilled water as control), 2, 4, 6, 8, and 10 dS m^{-1} prepared with NaCl to evaluate seed germination and fresh weight accumulation by *Stenocereus eruca* seedlings.

Germination conditions

The experiment was developed under laboratory conditions at the Universidad Autónoma of Baja California Sur located at 24° 08' 32'' LN and 110° 18' 32'' LW (INEGI, 2017). *Stenocereus eruca* seeds were treated with different salinity levels or electrical conductivities (0, 2, 4, 6, 8, and 10 dS m^{-1}) following the same method carried out by Beltrán-Morales *et al*. (2015).

The germination percentage was registered daily, and total germination was registered after 7 days. The germination rate was quantified using Maguire's equation: $M= n_1/t_1 + n_2/t_2 +...n_7/t_7$;

where n_1, n_2, ... n_7 are the germinated seeds at times t_1, t_2, ... t_7 (in days). Germination was considered when a 1 mm long radicle was observed (Fig. 4).

Experimental design

Five replications of 20 seeds, arranged in a completely randomized design were submitted to six saline levels or electrical conductivities (0, 2, 4, 6, 8, and 10 dS m^{-1}) using NaCl as the main source of salt. A limited number of seeds per replication (twenty seeds only) were used due to a restricted number of ripe fruits available. The collecting permission granted let us collect only a limited number of fruits of *Stenocereus eruca* based on the standards of protection and management of this species (NOM-007-SEMARNAT-1997).

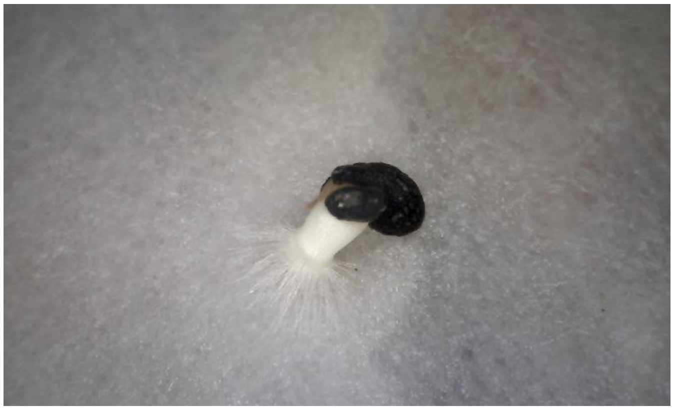

Figure 4. Seed of *Stenocereus eruca* germinated under 0 dS m^{-1} (photographed by Beltrán-Morales F.A. January 30, 2019).

Statistical analysis

Variance homogeneity was assessed by Bartlett's test. Data were analyzed using a one-way ANOVA where salinity levels (0, 2, 4, 6, 8, and 10 dS m^{-1}) were used as a fixed factor. Significant differences between all variables among treatments were considered at $p \leq 0.05$. Tukey's HSD multiple range test at $p \leq 0.05$ was used to determine differences of all variables between means of each treatment. A simple correlation analysis (Pearson) was performed. Statistical analyses were carried out with Statistica v. 13.5 (TIBCO Software Inc., 2018). Germination percentage data were transformed using arcsine function before the ANOVA analysis (Sokal and Rohlf, 1995).

RESULTS

Germination rate

Germination rate of *Stenocereus eruca* was influenced by level of salinity-stress ($p \leq 0.01$). The germination rate decreased as salinity increased ($r=-0.60$; $p \leq 0.01$; n=30). Germination rate was highest at 2 dS m^{-1}, followed by 0, 4, 8, and 6 dS m^{-1}, while germination rate at 10 dS m^{-1} decreased significantly (Table 1).

Germination percentage

Germination percentage of *Stenocereus eruca* was influenced by salinity-stress ($p \leq 0.01$). The germination percentage decreased as salinity increased (r=-0.51; $p \leq 0.01$; n=30). Germination percentage was higher at 4 and 2 dS m^{-1}, followed 0, 8, and 6 dS m^{-1}, while at 10 dS m^{-1} germination decreased reaching down to 14 % (Table 1).

Seedling fresh weight

Seedling fresh weight was significantly affected by saline stress ($p \leq 0.01$). Seedling fresh weight decreased as salinity increased (r=-0.77; $p \leq 0.01$; n=30). Seedling fresh weight was highest at 0 and 2 dS m^{-1}, followed by 4 dS m^{-1}. Fresh weight decrased significantly at 10 dS m^{-1} (Table 1).

Table 1. Effects of salinity-stress by NaCl on seeds germination rate, germination percentage, and seedling fresh-weight of *Stenocereus eruca*.

Salinity (dS m^{-1})	Germination rate	Germination (%)	Seedling fresh-weight (mg)
0	2.15 ± 0.22 ab*	31.00 ± 5.33 ab	211.78 ± 25.26 a
2	2.37 ± 0.90 a	39.00 ± 7.14 a	158.74 ± 49.05 a
4	1.42 ± 0.57 ab	42.00 ± 6.81 a	119.70 ± 19.78 ab
6	0.46 ± 0.12 ab	20.00 ± 6.12 ab	38.62 ± 9.24 b
8	0.68 ± 0.14 ab	22.00 ± 4.35 ab	47.38 ± 12.91 b
10	0.37 ± 0.09 b	14.00 ± 1.87 b	25.54 ± 3.85 b
LSD	1.98	24.34	108.64

*Values with the same letter within each column are not significantly different at $p \leq 0.05$ (Tukey´s HSD multiple range test). LSD=Least significant difference. N=5 replications of 20 seeds each.

DISCUSSION

Stenocereus eruca seedling fresh-weight accumulation and seed germination were significantly influenced by salinity stress. This response has been previously reported in other cacti species. For example, fishhook barrel cactus (*Ferocactus peninsulae*) (Romero-Schmidt *et al*., 1992) and Mexican giant cardon (*Pachycereus pringlei*) seeds can germinate at salinities of 2.5 and 5 dS m^{-1} (Nolasco-Soria *et al*., 1996). According to Khajeh-Hosseini *et al*. (2003), salinity may influence the germination of seeds, either by creating an osmotic potential external to the seed preventing water uptake, or by the toxic effects of Na^+ and Cl^- ions on germinating seed. Deleterious effect of high salinity levels on germination of *Stenocereus eruca* seeds agrees with Vega-Villasante *et al*. (1996) who reported that high salinity levels, 10 and 20 dS m^{-1}, reduced *Pachycereus pringlei* seed germination and was completely inhibited at 30 dS m^{-1}. Likewise, *Opuntia* species, resistant to droughts and large temperature fluctuations, are affected by some concentrations of salt contained in the soil or irrigation water (Nieto-Garibay *et al*., 2011). Using a fraction of seawater (1/5) for irrigation has been mentioned to harm the root system development of agaves and cacti (Nobel, 1998). *Opuntia quimilo* and *Cereus validus* from Argentina have a higher capacity to survive in the presence of salt than other

Opuntia species. *Opuntia ficus-indica* decreases its growth by half when exposed to certain amounts of seawater (Nobel, 1998).

Other plant species respond more negatively to high salinity levels during seedling development and early growth stages as compared to sprouting, *i.e. Cucumis melo* L. is a clear case of this response (Botia *et al*., 2005). Saline stress could affect via different mechanisms during *Stenocereus eruca* seed germination; for example, can cause an inadequate water uptake or can create a toxic environment for the embryo (Azza *et al*., 2007). Munns (2002) described that increasing the amount of salts in the substrate induces osmotic changes in plants or even toxic conditions that affect germination. Reduced *Stenocereus eruca* seed germination at high levels of salinity correlates with other literature reports (Abdul *et al*., 1992; Breen *et al*., 1977; Abbad *et al*., 2004; El-Tayeb, 2005).

Sodium and chlorine ions influence protein functioning within cells due to changes in ionic strength, which in turn could affect protein structure (Waisel, 1972). Therefore, the presence of these ions could affect enzymes directly associated with germination processes (Flowers, 1972).

Moreover, high concentrations of salts decrease water uptake reducing water potential of seeds and at the same time affecting germination (Rhoades *et al*., 1992). Apparently, metabolic processes induced by saline stress lead to increased amounts of phenolic compounds which, in turn, affect germination process as well (Rehman *et al*., 1997).

Stenocereus eruca seedlings reduced freshweight accumulation at high levels of salt is a typical response observed for other plant species (Gupta and Sharma, 1990; Läuchli and Epstein, 1990; Ebert *et al*., 1999; Al-Thabet *et al*., 2004).

Previous studies (Gupta and Srivastava, 1989; Saboora and Kiarostami, 2006) reported that root and shoot biomass were significantly affected when NaCl concentrations increases, a similar response was observed in *Stenocereus eruca* seedlings. The decrease of fresh weight of *Stenocereus eruca* seedlings could be attributed to dehydrated cells. This cellular condition is reversible; however, it affects growth rate hampering cell division and elongation (Munns, 2002). Moreover, salinity may injure sensitive tissues at cotyledons and hypocotyl, thus delaying germination and seedling emergence (Miyamoto *et al*., 1985; Esechie *et al*., 2002).

Mineral analysis was not carried out because of the limited amount of fresh weight produced by the seedlings. However, ionic imbalances, triggered by excessive amounts of sodium and chloride ions, are suggested as one of the causes of fresh weight reduction. This circumstance generates toxicity absorption problems of other minerals necessary for plant growth (Yokoi *et al*., 2002). The presence of high concentrations of sodium has an antagonistic effect on potassium and calcium absorption in roots and has also had a negative impact on other absorption processes (Hu and Schmidhalter, 2005). A high concentration of sodium, besides interfering with absorption processes, inhibits root growth reducing seedling biomass accumulation (Tester and Davenport, 2003).

The present study is relevant since *Stenocereus eruca* is an endangered species endemic to an area where water with a high concentration of salt is regularly used to irrigate crops because of the lack of fresh water. This is especially confirmed in Baja California Sur since it has no running rivers, hence underground water is used in agriculture. Salts presence in Baja California Sur aquifer has contributed to structure and fertility soils degradation (Álvarez-Morales *et al*., 2014). Large extensions of agricultural lands worldwide have excess of salt and represent a problem in crops production (El-Saidi, 1997). A high concentration of salts is one of the greatest problems that limit plant growth. Many studies about the effect of salts in many different plants have been carried out; however, salinity resistance mechanisms are not completely understood (Mansour, 1997).

Average chlorine amount in plants are between 2-20 mg per gram of dry weight; however, optimal plant growth requires 0.2-0.4 mg of chlorine per gram of dry weight (Navarro and Navarro, 2013). Furthermore, chlorine is an important element since chloride ions binding to photosystem II are essential for water oxidation. Also, it is part of more than 130 important molecules, for example, the auxin 4-chloroindoleacetic acid (Salisbury and Ross, 2000). To our knowledge, this is the first study regarding salinity effect on *Stenocereus eruca* seed germination and seedling fresh weight accumulation. This study could help to identify chirinola genetic ecotypes, resistant to saline-stress, which in turn could help to recover this threatened species.

CONCLUSIONS

Seedling fresh-weight of *Stenocereus eruca* was higher at 0 and 2, followed by 4 dS m^{-1}, and decreased at 6, 8 and 10 dS m^{-1}. Germination rate was higher at 2 dS m^{-1} and lower at 10 dS m^{-1}, while germination percentage was higher at 4 and 2 dS m^{-1} and lower at 10 dS m^{-1}. More studies must be done, including other growth variables and salinity levels.

ACKNOWLEDGMENTS

The corresponding author thanks the institutional funds "Modelo de aprovechamiento y eficiencia máxima de agua salinizada acoplado a un sistema unidireccional de acuaponia-agricultura (CONACYT-PN-2017-I-4631)", a project supported by FOINS. Projects (PAZA) from CIBNOR also supported this study.

CONFLICT OF INTEREST STATEMENT

The research has no financial or commercial purpose that must be interpreted as a potential conflict of interest in the future.

AUTHORS' CONTRIBUTIONS

FABM, PMAA, and BMA generated the idea and designed the research . FHRE, VBV, FABM, and PMAA developed the research. BMA and LGHM analyzed the data. VBV and LGHM contributed materials, reagents, and analysis tools. VBV, FABM, BMA, and LGHM wrote, revised, and edited the paper. FABM, PMAA, FHRE, VBV, LGHM, and BMA approved the latest paper version.

REFERENCES

Abbad, A., El Hadrami A., Benchaabane, A. 2004. Germination responses of the Mediterranean Saltbush (*Atriplex halimus* L.) to NaCl treatment. *Journal of Agronomy* 3:111-114.

Abdul, K.M.D., Utsunomiya, N., Shigenaga, S.H. 1992. Effects of sodium chloride on germination and growth of hexaploid triticale at early seedling stage. *Japanese Journal of Crop Science* 61:279-284.

Akbarimoghaddam, H., Galavi, M., Ghanbari, A., Panjehkeh, N. 2011. Salinity effects on seed germination and seedling growth of bread wheat cultivars. *Trakia Journal of Sciences* 9:43-50.

Alaghmand, S., Beecham, S., Woods, J.A., Holland, K.L., Jolly, I.D., Hassanli, A., Nouri, H. 2016. Quantifying the impacts of artificial flooding as a salt interception measure on a river-floodplain interaction in a semi-arid saline floodplain. *Environmental Modelling and Software* 79:167-183.

Al-Thabet, S.S., Leilah, A.A., Al-Hawass, I. 2004. Effects of NaCl and incubation temperature on seed germination of three canola (*Brassica napus* L.) cultivars. *Scientific Journal of King Faisal University* 5:81-91.

Álvarez-Morales, Y., Troyo-Diéguez, E., Nieto-Garibay, A., Beltrán-Morales, F.A., Murillo-Amador, B., Cruz-Falcón, A., Navejas-Jiménez, J. 2014. Vulnerabilidad hidroclimática y degradación del suelo en regiones agrícolas semiáridas.Terra Latinoamericana 32:47-58.

Amirjani, M.R. 2011. Effect of salinity stress on growth, sugar content, pigments, and enzyme activity on rice. *International Journal of Botany* 7:73-81.

Arce-Amezquita, P.M., Cota-Carballo, M.A., Ruiz-Espinoza, F.H., Murillo-Amador, B., Beltrán-Morales, F.A. 2017. Solvent pre-treatment effect on germination of creeping devil cactus (*Stenocereus eruca)* seeds. *Journal of the Professional Association for Cactus Development* 19:58-66.

Azza, M.A.M., Fatma, A.M., El-Quensi, E.M., Farahat, M.M. 2007. Responses of ornamental plants and woody trees to salinity. *World Journal of Agricultural Science* 3:386-395.

Barthlott, W.D., Hunt, D.R. 1993. Cactaceae. In: Kubitzki, K, Rohwer, J.G., Bittrich, V. (Eds). The Families and Genera of Vascular Plants. Flowering Plants Dicotyledons. Magnoliid, Hamamelid and Caryophyllid Families. Springer-Verlag: Berlin. Vol. 2, pp. 161-197.

Beltrán-Morales, A., Córdoba-Matson, M.V., García-Hernández, J.L., Troyo-Diéguez, E., Azadi, H., Ruiz-Espinoza, F.H., Valdez-Cepeda, R.D., Murillo-Amador, B. 2015. Salinity effects on germination and seedlings biomass of *Pachycereus pecten aboriginum*: an endangered species. *Journal of the Professional Association for Cactus Development* 17:107-122.

Benítez, H., Dávila, P. 2002. Las cactáceas mexicanas en el contexto de la CITES. CONABIO. *Biodiversitas* 40:8-11.

Bierzychudek, P. 1981. Pollinator limitation of plant reproductive effort. *The American Naturalist* 117:838-840.

Botia, P., Navarro, J.M., Cerda, A., Martínez, V. 2005. Yield and fruit quality of two melon cultivars irrigated with saline water at different stages of development. *European Journal of Agronomy* 23:243-253.

Boyle, T.H., Anderson, E.F. 2002. Biodiversity and Conservation. In: Nobel, P.S. (Ed). Cacti. Biology and uses. University of California Press, Los Angeles, 125-141 pp.

Bravo Hollis, H. 1978. Las Cactáceas de México. Vol. I. Universidad Nacional Autónoma de México. México, D.F. México. 743 p.

Breen, C.M., Everson, C., Rogers, K. 1977. Ecological studies on *Sporobolus virginicus* L. Kunth with particular reference to salinity and inundation. *Hydrobiologia* 54:135-140.

Cancino, J., Romero-Schmidt, H., Ortega-Rubio, A., León de La Luz, J.L. 1995. Observations on distribution and habitat characteristics of the endangered Mexican endemic cacti *Stenocereus eruca*. *Journal of Arid Environments* 29:55-62.

Casas, A. 2002. Uso y manejo de cactáceas columnares mesoamericanas. CONABIO. *Biodiversitas* 40:18-23.

Cervantes-Ramírez, M.C. 2002. Plantas de Importancia Económica en las Zonas Aridas y Semiáridas de México. Instituto de Geografía. Universidad Nacional Autónoma de México. 159 p.

Chartzoulakis, K., Klapaki, G. 2000. Response of two greenhouse pepper hybrids to NaCl salinity during different growth stages. *Scientia Horticulturae* 86:247-260.

Clark-Tapia, R., Molina-Freaner, F. 2004. Reproductive ecology of the rare clonal cactus *Stenocereus eruca* in the Sonoran Desert. *Plant Systematics and Evolution* 247:155-164.

Debez, A., Hamed, K.B., Grignon, C., Abdelly, C. 2004. Salinity effects on germination, growth, and seed production of the halophyte *Cakile maritima*. *Plant and Soil* 262:179-189.

Del Mandujano M. C., Montaña, C., Eguiarte, L.E. 1996. Reproductive ecology and inbreeding depression in *Opuntia rastrera* (Cactaceae) in the Chihuahuan desert: why are sexually derived recruitments so rare? *American Journal of Botany* 83:63-70.

Del Mandujano, M. C., Montaña, C., Méndez, I., Golubov, J. 1998. The relative contributions of sexual reproduction and clonal propagation in *Opuntia rastrera* from two habitats in the Chihuahuan Desert. *Journal of Ecology* 86:911-921.

Ebert, G., Casierra, F., Ludders, P. 1999. Influence of NaCl salinity on growth and mineral uptake of lulo (*Solanum quitoense*). *Journal of Applied Botany. Angewandte Botanik* 73:31-33.

El-Saidi, M.T. 1997. Salinity and its effect on growth, yield, and some physiological processes of crop plants. pp. 111-127. In: Jaiwal P.K., Singh P.R., Gulati, A. (Eds.). Strategies for improving salt tolerance in higher plants. Science Publishers, Inc. Enfield, New Hampshire, U.S.A. 443 p.

El-Tayeb, M.A. 2005. Response of barley grains to the interactive effect of salinity and salicylic acid. *Plant Growth Regulation* 45:215-224.

Eriksson, O. 1997. Clonal life histories and the evolution of seed recruitment. In*:* de Kroon, H., van Groenendael, J. (Eds). The Ecology and Evolution of Clonal Plants. Backhuys Publishers, Leiden, pp 211-226.

Esechie, H.A., Al-Saidi, A., Al-Khanjari, S. 2002. Effect of sodium chloride salinity on seedling emergence in chickpea. *Journal of Agronomy and Crop Science* 188:155-160.

Flowers, T.J. 1972. The effect of sodium chloride on enzyme activity from four halophyte species of Chenopodiaceae. *Phytochemistry* 11:1881-1886.

Gibson, A.C., Nobel, P.S. 1986. The Cactus Primer. Harvard University Press, Cambridge, Massachusetts, USA. 286 p.

Godinez-Alvarez H, Valverde T, Ortega-Baes P. 2003. Demographic trends in the cactaceae. The Botanical Review 69: 173-203.

Gupta, S.K., Sharma S.K. 1990. Response of crops to high exchangeable sodium percentage. *Irrigation Science* 11:173-179.

Gupta, S.C., Srivastava, C.P. 1989. Effect of salt stress on morpho-physiological parameters in wheat (*Triticum aestivum* L.). *Indian Journal of Plant Physiology* 2:169-171.

Hu, Y., Schmidhalter, U. 2005. Drought and salinity: A comparison of their effects on mineral nutrition of plants. *Journal of Plant Nutrition and Soil Science* 168:541-549.

INEGI (Instituto Nacional de Estadística Geografía e Informática). 2017. Anuario Estadístico Geográfico de Baja California Sur, México. Instituto Nacional de Estadística Geografía e Informática. Gobierno del Estado de Baja California Sur. Aguascalientes, Aguascalientes, México. 415 p.

Khajeh-Hosseini, M., Powell, A.A., Bingham, I.J. 2003. The interaction between salinity stress and seed vigour during germination of soybean seeds. *Seed Sciences Technology* 31:715-725.

Läuchli, A., Epstein, E. 1990. Plant responses to saline and sodic conditions. In: Agricultural Salinity Assessment and Management. Tanji, KK (Ed), Manual and Reports on Engineering Practice. American Society of Civil Engineers, New York, USA, pp 113-137.

Luna-Morales, C.C. 2004. Recolección, cultivo y domesticación de cactáceas columnares en la Mixteca Baja, México. *Revista Chapingo Serie Horticultura* 10: 95-102.

Mahajan, S., Tuteja, N. 2005. Cold, salinity and drought stresses: An overview. *Archives of Biochemistry and Biophysics* 444:139-158.

Mansour, M.M.F 1997. Cell permeability under salt stress. In: Jaiwal PK, Singh RP, Gulati A (Eds.). Strategies for Improving Salt Tolerance in Higher Plants. Oxford and IBH, New Delhi. pp. 87-110.

Meiado, M.V., de Albuquerque, L.S.C., Rocha, E.A., Rojas-Aréchiga, M., Leal, I.R. 2010. Seed germination responses of *Cereus jamacaru* DC. ssp. jamacaru (Cactaceae) to environmental factors. *Plant Species Biology* 25:120-128.

Miyamoto, S., Piela, K., Patticrew, J. 1985. Salt effects on germination and seedling emergence of several vegetable crops and guayule. *Irrigation Science* 6:159-170.

Molina-Freaner, F., Clark-Tapia, R. 2005. Clonal diversity and allelic relationships between two closely related species of columnar cacti from the Sonoran Desert: *Stenocereus eruca* and *S. gummosus*. *International Journal of Plant Science* 166:257-264.

Munns, R. 2002. Comparative physiology of salt and water stress. *Plant Cell and Environment* 25:239-250.

Murillo-Amador, B., Cortés-Ávila, A., Troyo-Diéguez, E., Nieto-Garibay, A., Jones, H.G. 2001. Effects of NaCl salinity on growth and production of young cladodes of *Opuntia ficus-indica*. *Journal of Agronomy and Crop Science* 187:269-279.

Navarro, G.G. and Navarro, G.S. 2013. Química Agrícola. Química del Suelo y de los Nutrientes Esenciales para las Plantas. 3ra Edición. Ediciones Mundi-Prensa, Impreso en España, 453 p.

Nichols, P.G.H., Craig, A.D., Rogers, M.E., Albertsen, T.O., Miller, S., McClements, D.R., Hughes, S.J., D'Antuono, M.F., Dear, B.S. 2008. Production and persistence of annual pasture legumes at five saline sites in southern Australia. *Australian Journal of Experimental Agriculture* 48:518-535.

Nieto-Garibay, A., Troyo-Diéguez, E., Valdez-Cepeda, R.D., Rueda-Puente, E.O., García-Hernández, J.L., Flores-Hernández, A., Zamora-Salgado, S., Orona-Castillo, I., Murillo-Amador, B. 2011. Plant height and mineral content of *Opuntia tapona* growing along the coasts of Baja California Sur, México. *Journal of the Professional Association for Cactus Development* 13:77-87.

Nikalje, G.C., Srivastava, A.K., Pandey, G.K., Suprasanna, P. 2017. Halophytes in biosaline agriculture: Mechanism, utilization, and value addition. *Land Degradation and Development* 29:1081-1095.

Nobel, P.S. 1998. Los Incomparables Agaves y Cactos. Editorial Trillas. México, D.F. 211 p.

Nolasco-Soria, H., Vega-Villasante, F., Romero-Schmidt, H. L., Díaz-Rondero, A. 1996. The effects of salinity, acidity, light, and temperature on the germination of seeds of cardón (*Pachycereus pringlei* (S. Wats.) Britton & Rose, Cactaceae). *Journal of Arid Environments* 33:87-94.

Norma Oficial Mexicana. (NOM-007-SEMARNAT-1997). Que establece los procedimientos, criterios y especificaciones para realizar el aprovechamiento, transporte y almacenamiento de ramas, hojas o pencas, flores, frutos y semillas. Diario Oficial de la Federación. México. 28 de mayo de 1997. 7 p.

Norma Oficial Mexicana. (NOM-059-SEMARNAT-2001). Proteccion ambiental-Especies nativas de Mexico de flora y fauna silestre-Categoria de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo. Diario Oficial de la Federación. México. 06 de marzo de 2002. 85 p.

Nyffeler, R. 2002. Phylogenetic relationships in the cactus family (Cactaceae) based on evidence from trnK/matK and trnL-trnF sequences. *American Journal of Botany* 89:312-326.

Orozco, A., Gardea, A.A., Rascon-Chu, A., Sánchez, A. 2017. Effect of salinity on seed germination, growth, and metabolic activity of pitaya seedlings [*Stenocereus thurberi* (Engelm.) Buxb.] *Journal of the Professional Association for Cactus Development* 19:67-78.

Ortega-Baes, P., Godínez-Álvarez, H. 2006. Global diversity and conservation priorities in the Cactaceae. *Biodiversity and Conservation* 15:817-827.

PNUMA-CMCM. 2011. Lista de Especies CITES. Parte 1. Secretaría CITES, Ginebra, Suiza y PNUMA-CMCM, Cambridge, United Kingdom. 554 p.

Podda, L., Santo, A., Leone, C., Mayoral, O., Bacchetta, G. 2017. Seed germination, salt stress tolerance and seedling growth of *Opuntia ficus-indica* (Cactaceae), invasive species in the Mediterranean Basin. *Flora* (Jena) 229:50-57.

Qadir, M., Oster, J.D., Schubert, S., Noble, A.D., Sahrawat, K.L. 2007. Phytoremediation of Sodic and Saline-Sodic Soils. Advances in Agronomy. Academic Press. pp. 197-247.

Qadir, M., Tubeileh, A., Akhtar, J., Larbi, A., Minhas, P.S., Khan, M.A. 2008. Productivity enhancement of salt-affected environments through crop diversification. *Land Degradation and Development* 19:429-453.

Rebman, J.P., Roberts, N. C. 2012. Baja California Plant Field Guide. 3rd Edition, San Diego Natural History Museum, Sunbelt Publications, San Diego, California, USA. 451 p.

Rehman, S., Harris, P.J.C., Bourne, W.F., Wilkin, J. 1997. The effect of sodium chloride on germination and the potassium and calcium content of Acacia seeds. *Seed Science and Technology* 25:45-57.

Rhoades, J.D., Kandiah, A., Mashali, A.M. 1992. The Use of Saline Waters for Crop Production. FAO. Irrigation and Drainage. Paper No. 48. Rome, Italy. 145 p.

Romero-Schmidt, H.L., Vega-Villasante, F., Nolasco, H., Montaño, C. 1992. The effect of darkness, freezing, acidity and salinity on seed germination of *Ferocactus peninsulae* (Cactaceae) *Journal of Arid Environments* 23:389-395.

Saboora, A., Kiarostami, K. 2006. Salinity (NaCl) tolerance of wheat genotypes at germination and early seedling growth. *Pakistan Journal of Biological Sciences* 9:2009-2021.

Salisbury, F.B., Ross, C.W. 2000. Fisiología de las Planta. International Thompson Editores Spain. Paraninfo S.A. Madrid, España. 988 pp.

Shrivastava, P., Kumar, R. 2015. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences* 22:123-131.

Sokal, R.R., Rohlf, F.J. 1995. Biometry: The Principles and Practice of Statistics in Biological Research. Third edition. W.H. Freeman and Company: New York. 887 p.

Song, J., Feng, G., Tian, C, Zhang, F. 2005. Strategies for adaptation of *Suaeda physophora*, *Haloxylon ammodendron* and *Haloxylon persicum* to a saline environment during seed germination stage. *Annals of Botany* 96:399-405.

Sun, Z.W., Ren, L.K., Fan, J.W., Li, Q., Wang, K.J., Guo, M.M., Wang, L., Li, J., Zhang, G.X., Yang, Z.Y., Chen, F., Li, X.N. 2016. Salt response of photosynthetic electron transport system in wheat cultivars with contrasting tolerance. *Plant Soil and Environment* 62:515-521.

Tester, M., Davenport, R. 2003. Na^+ tolerance and Na^+ transport in higher plants. *Annals of Botany* 91:503-527.

TIBCO Software Inc. 2018. Statistica (data analysis software system), version 13. http://tibco.com.

Tobe, K., Li, X., Omasa, K., 2002. Effects of sodium, magnesium and calcium salts on seed germination and radical survival of a halophyte, *Kalidium capsicum* (Chenopodiaceae). *Australian Journal of Botany* 50:163-169.

Ungar, I.A. 1996 Effect of salinity on seed germination, growth, and ion accumulation of *Atriplex patula* (Chenopodiaceae). *American Journal of Botany* 83:604-607.

Vega-Villasante, F., Nolasco, H., Montaño, C., Romero-Schmidt, H.L., Vega-Villasante, E. 1996. Efecto de la temperatura, acidez, iluminación, salinidad, irradiación solar y humedad sobre la germinación de semillas de *Pachycereus pecten-aboriginum* “cardón barbón” (Cactaceae). *Cactáceas y Suculentas Mexicanas* 41:51-61.

Waisel, Y. 1972. Biology of halophytes. Academic Press, New York, USA. 410 p.

Yokoi, S., Bressan, R., Mike, H.P. 2002. Salt stress tolerance of plants. *JIRCAS Working Report* 25-33.

Zadeh, H.M., Naeini, M.B. 2007. Effects of salinity stress on the morphology and yield of two cultivars of canola (*Brassica napus* L.). *Journal of Agronomy* 6:409-414.