Correlation of elemental hyperaccumulation among the succulent and non-succulent halophytes of Gujarat, India

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Abstract

This paper presents new data on the salt tolerance and avoidance mechanisms among various groups of halophytes in India. The halophytic flora in general has positive effect of high saline environments on growth and physiology. The coastal area of the Kachchh district in Gujarat include about 350 km along the Gulf of Kachchh. This study presents data on the element accumulation mechanisms in soil and halophytic flora (succulent and non-succulent). The halophytes were divided into two groups namely succulent with thick and fleshy leaves and stems and non-succulent with thin leaves and stem. The succulent halophytes included species such as *Salicornia brachiata*, *Suaeda fruticosa* and *Suaeda nudiflora*. The non-succulent halophytes include *Aeluropus lagopoides* and *Urochondra setulosa*. Plant parts namely leaves or (Phylloclade), stems and roots were analyzed monsoon season. The results of soil and plants mineral ion content differed widely across the intertidal zones in the same habitat. Likewise, the intra species have varied in all nutrient levels and salt concentration. The accumulation of element concentration was high during the monsoon season in the succulent *Salicornia brachiata*, especially in leaves that showed Na^{+} reaching high up to 7.6 meq.g^{-1}, whereas Cl^{-} was noted to be 4.34 meq.g^{-1}. In the non-succulent halophytes, the accumulation of mineral ion concentration was lower when compared to succulent plants.

1. Introduction

Soil salinity continues to threaten the productivity of the land across the world. Scientist have predicted that the salinity will impact over half of the total arable land globally by 2025 leading to 70% increase in the demand for food recourses (Szabo et al., 2016). The total land area impacted by salinity has been estimated at about 1125 million hectares (Wicke, B, 2011). Now in current situations, the coastal agricultural regions face several problems, like some glycophytes agricultural crops do not tolerate a significant amount of salt, a major disadvantage of salinity can change groundwater ions and it directly affects the human population as well as agriculture. In Bangladesh, some less positively use of salt-affected land as shrimp culture-led land use activity, where another farmer handle this problem by applying lime, gypsum, etc. (Ziaul Haider 2013). In India Northern-west regions include, Hariyana, Punjab, Rajasthan (desert regions) and the coastal belt of Gujarat suffering saline problems. Some good approaches to utilize this land as growing medicinal plant and algal cultivation that performed and yield well under saline irrigation (Tomar and Minhas, 2004).

Nevertheless, the halophytes are suitable plant candidates for the phytoremediation phenomenon. One of the succulent halophyte *Suaeda fruticosa* has the ability to tolerate lead and zinc metals, in presence of trace metal elements in its root portion, it has basic characteristics to tolerant high capacity of phytostabilization of trace metal elements in its belowground structures (Bankaji, 2016). Halophytes have adaptations to survive in extreme salinity. Steiner (1935) has classified halophytes under three groups, (i) succulent halophytes with special characteristics to accumulate salt in cell sap and increase succulence, (ii) non-succulent halophytes with special salt-secreting gland, and (iii) the accumulating halophytes that do not have any kind of mechanisms for salt removal so they accumulate high concentration of salts till death. Some physiologically active molecules play a key role in the saline environment such as proline (Wagh A P, 1982). Ca^{+2} reduced when accumulation of Na^{+} increased (Greenway, 1980). According to Khan, M.A (2000), the water and osmotic potential of halophytic plant *S. fruticosa* became more negative with increasing salinity; they also noted that Ca^{+2}, Mg^{+2} and K^{+} concentration decreases when salinity increases in leaf. The presence of Na^{+} and Mg^{+2} content is responsible for the alleviating the effects of K^{+}. Under the higher concentration of Na^{+}, Mg^{+2} and Ca^{+2} reported decrease in K^{+} content, K^{+} in concentration is high or when rest of the cation decrease (Diem, B. and Godbold, D.L., 1993). Mg^{+2} ions in phylloclade positively correlates with K^{+}. According to Marschner, 1986, K^{+} and Mg^{+2} plays parallel key roles for the control of osmoregulation, enzyme activation and cellular pH. Succulent halophytic plants accumulate more salt than that of non-succulent plants in their foliar organs. Results also reveal that the non-succulent plant can store a high amount of Ca^{2+}, Mg^{+2} and K^{+} in all parts compare to succulent plants. Leaf and stem of succulent plant has a high amount of Na^{+}, S and Mg^{+2}, when there is low concentration of Ca^{2+} and K^{+} (Matinzadeh, Z., et al., 2019). *Salicornia fruticosa* accumulate a high amount of Na^{+}, *Cakile maritima* tissues have the highest values of Ca^{+2}, P^{-} and S^{-2}. Another finding *C. minimum* showed Na^{+} ion accumulation higher when salinity increases and it directly affects Ca^{+2} and Mg^{+2} low accumulations. (Agudelo, et al., 2021). The current research focused on salinity variation in the different coastal areas of Kachchh district with salt accumulating plants, the future scope of the current research is to the reclamation of coastal salt-affected agriculture regions by selected halophytic groups.

2. Materials And Methods

2.1 Study area

Kachchh district consist of approximately 300 km coastal belt out of 1600 km total coastline of Gujarat. Different types of coastal habitats were surveyed and selected for the study. Appropriate number of soil and plant samples were collected from the selected locations during monsoon season. For sample collection coastal area of Kachchh district was divided into four zones, based on the intertidal area viz., zone 1 (20 km), zone 3 (5 km), zone 2 (100 m) and zone 4 (15 km) of the intertidal area.

2. 2. The experimental works

2.2.1 Sample collection:

From the selected locations along the coast of Kachchh district dominant plant samples from the selected location were collected from natural habitats in monsoon during 2019. Soil samples (0-30 cm) were collected from each selected site supporting the coastal vegetation. The soil were sun-dried, passed through a 20-mesh sieve before analysis. The plant samples were thoroughly washed to remove dust, mud and salts and blotted to dryness. It was dried in the oven at 75-80°C to a constant weight. Dry material so obtained, were finely powdered and preserved. The samples were once more dried in an oven, before using for analysis of mineral ions.

2.2.2 Sample preparation

2.2.3 Plant analysis

Plants were divided into leaves, stems and roots (in case of *S. brachiata phylloclade* were taken). Samples were weighed, oven-dried and grounded to powder. Mineral extraction was carried out by 1 g d/w of each sample, ashing with muffle furnace and treated with HNO_3 and HCL after that the extract was filtered through Whatman filter paper 44, final volume was made to up to 250 ml for the further analysis (Chopra, S. L., & Kanwar, J. S. 1976).

2.2.4 Soil analysis

100 gm dried soil in 200 ml distilled water were taken for purpose of soil mineral analysis. Extract of 1:2 (Soil: water) was made up to 250 ml for analysis of Ca, Mg, Na and mineral ions. Pure extract was used for EC and Cl analysis (Chopra, S. L., & Kanwar, J. S. 1976).

2.2.5 Analytical work

Analysis of different physic-chemical and mineral ions were carried out. Electrical conductivity (EC) was done by using (EC meter (Systronics), Mineral constituents were measured as follows; Ca^{2+} and Mg^{2+} by EDTA titration (Vogel 1978), Na^{+} and K^{+} measured by flame photometry (FPM Systronics), chloride according to (Argenometric method).

2.2.6 Statistical analysis

Primary data of mineral ions were subjected to statistical tools by using SPSS, ANOVA and Pearson correlation coefficients were perform for observing the significant variation within the parts of each plant as well as between the group of plants from different zones.

3. Result

In succulent and non–succulent halophytic plants, five halophytic plants were analyzed for the experimental works. Plant distinguished into three parts leaves, stems and roots.

3.1 Accumulation of elements in succulent plants.

3.1.1. Salicornia brachiata

S. brachiata, a succulent perennial halophytic plant species showed electrical conductivity 5.95 (mS/cm) of soil supporting the species, it also reflected that, EC of the *phylloclade*, 5.56 (mS/cm) was marginally near to the habitat of plant. The EC of stem and root were noted to be 0.85 and 0.92 mS/cm respectively. The elemental composition in the soil was ranging between 0.19 to 8.47 (meq.g^{-100}). The highest accumulation of (6.16 meq.g^{-1}) was noted for Na^{+} in the *phylloclade* of S. brachiata, whereas K^{+} 0.14 meq.g^{-1} was observed in stem and roots of this succulent halophytic species. The concentration of these mineral ions followed a sequence of the accumulation ratios in *phylloclade* are, Na^{+}> Cl^{-}>Mg^{+2}> Ca^{+2}> K^{+}, in stem and root it is, Na^{+}> Mg^{+2}> Cl^{-} > Ca^{+2}> K^{+}. *S. brachiata* accumulate a high amount of salt in phylloclade compare to rest of plants (Table 1).

3.1.2. Suaeda nudiflora

S. nudiflora plant growing under less saline soil compare to the other succulent halophytes. The EC value of soil is 1.30 (mS/cm), generally the habitat of this plant has low salt concentration. The element concentration in soil of this plant between 0.06 to 2.62 (meq.g^{-100}). Leaves has high EC value, 5.29 (mS/cm), whereas in stem and root portion EC value is 1.34 and 0.94 (mS/cm) respectively. Highest accumulated element was Na^{+} 3.87 (meq.g^{-1}) in the part leaves, where as K^{+} in low amount (0.15 meq.g^{-1}) in roots. The storage of elements in leaves is followed this high to low value, Na^{+}> Cl^{-} > Mg^{+2}> Ca^{+2}> K^{+}, in stem it is, Na^{+}> Mg^{+2}> Cl^{-}> Ca^{+2}> K^{+}, where in root, only changing a Mg ions, Mg^{+2}> Na^{+}> Ca^{+2}> Cl^{-}> K^{+} (Table 2).

3.1.3. *Suaeda fruticosa*

S. fruticosa was the second highest salt accumulator plant in current research. EC value of soil was 4.02 (mS/cm), whereas other elements ranging between low to high concentration 0.19 to 4.94 (meq.g^{-100}). Higher accumulated element was Na^{+} which is 4.37 (meq.g^{-1}) and lowest was K^{+} 0.14 (meq.g^{-1}). The mineral accumulation in leaves high to low amount, Na^{+}>Cl^{-}> Mg^{+2}>Ca^{+2}>K^{+}, in stem it was, Na^{+}>Mg^{+2}>Ca^{+2}>Cl^{-}>K^{+}, when root has, Mg^{+2}> Na^{+}> Cl^{-} > Ca^{+2}> K^{+}(Table 3).

3.2 Accumulation of elements in non-succulent plants

3.2.1. Aeluropus lagopoides

In the current research non-succulent halophytic grass plant *A. lagopoides* showed high salt tolerance. The EC value of soil was (4.89 mS/cm), other elements ranging between higher to lower 5.86 to 0.08 (meq.g^{-100}), respectively. Here also a high element accumulator part was leaves same as succulent halophytic plants. EC value of leaves was lowest compare to succulent plant which was 1.81 (mS/cm), Na^{+} was in higher value 1.47 (meq.g^{-1}), when K^{+} in lowest amount was (0.10 meq.g^{-1}). Major element composition elements-wise, were, Na^{+} > Cl^{-}> Mg^{+2}> Ca^{+2}> K^{+}, these ratios followed by leaves. The amount of elements in stem was, Na^{+}> Mg^{+2}>Ca^{+2}>Cl^{-}>K^{+}, and in roots was, Na^{+}>Mg^{+2}>Cl^{-}>Ca^{+2}>K^{+}. Most of the elements in a high amount in leaves, but in stem the Mg^{+2} with a high amount 0.93 (meq.g^{-1}) when root high with concentration of Ca^{+2} 0.59 (meq. g^{-1}) (Table 4).

3.2.2. *Urochondra setulosa*

Comparatively, *U.setulosa* was accumulates low elements than *A.lagopoides*, but interestingly it growing under a high saline environment than *A.lagopoides*, the soil of this plant has high value of Na^{+}, Cl^{-}, was 6.32 and 6.77 (meq.g^{-100}) respectively. EC of soil was 5.88 (mS/cm), when other element concentration wise high to low ranged was, 6.77 to 0.12(meq.g^{-100}). The value of EC highest in leaves, 1.66 (mS/cm), elements concentration ranging from high 1.19 (meq.g^{-1}), to low 0.06 (meq.g^{-1}). The ratios of accumulated elements in leaves, Na^{+}>Mg^{+2}>Cl^{-}> Ca^{+2}> K^{+}, whereas in stems, Mg^{+2}>Na^{+}>Ca^{+2}>Cl^{-} >K^{+}, these ratio followed by roots. The major Ione stored in the stem and root of *U.setulosa* is Mg^{+2}(Table 5).

3.3. Comparative accumulation of elements in succulent and non-succulent halophytes.

Results shows among these both halophytic groups, elements accumulation in three parts, has been varying at each part. Succulent plants stored the majority of the component in foliar organs when in non-succulent plants is to be in root. The Mg^{+2} among these both groups, in non-succulent accumulation of Mg^{+2} in the stem is high when in succulents it is higher in foliar parts (Fig. 2).

3.4. Spearman's correlation coefficients studies

Statistical analysis showed significant interactions among elements in different parts of succulent and non-succulent halophyte plant species. The primary data were subjected to a correlation statistic tool, it reflected that in leaves Na^{+} and Ca^{+2} ions were negatively correlated (r =-1.000**) with each other. Root K^{+} and leaves Na^{+} has also highly negative relations (r =-1.000**). It was noted that Na^{+} and K^{+} content in stem and leaves respectively showed significant positive variation (r =1.000**). Similarly, the trend was observed in Ca^{+2} and Cl^{-} content within the root and leaves respectively at a positive significant variation (r =1.000**). Correlation between K^{+} (Root) and Ca^{+2} (Leaves) showed significant variation (r =1.000**). There is a significant correlation between root Na^{+} and leaves for K^{+} content at the level of 0.01 (r =1.000**). An interesting significant correlation was noted for Ca^{+2} content of roots and Cl^{-} leaves. Furthermore for the roots, Mg^{+2} and Na^{+}, within the root and stem showed a highly significant positive correlation (r =1.000**), where root Cl^{-} and stem Ca^{+2} showed a highly positive correlation (r =1.000**) (Table 6).

Considering the non-succulent halophytic group, it was noted that there is a strong positive correlation of Ca^{+2} content (r =1.000**) between stem and leaves of non-succulent species. A similar trend was observed between the Mg content of leaves with Na^{+} and Cl^{-} content of stem at a significant level of 0.01 (r =1.000**). Cl^{-} content of root and leaves showed a significant correlation between each other. There is also a significant positive correlation between stem Mg^{+2} and root Cl^{-} with leaves Cl^{-}. Interestingly, Cl^{-} the content of stem was positively correlated with Na^{+} content of stem (r =1.000**). Whereas, some negative correlation also found, Mg^{+2} of leaves and K^{+} of the stem (r =-1.000**), Na^{+} and Cl^{-} of the stem was strongly negative correlate with leaves K^{+} (r =-1.000**). Cl^{-} of leaves and K^{+} of the stem also negative relations. Whereas within stem Mg^{+2}, K^{+}, root Cl^{-} and stem K^{+} has a highly negative correlation. The overall findings reveled that Cl^{-} showed maximum positive and negative correlation with different parts of the non-succulent with other mineral ions (Table 7).

4. Discussion

Mineral ion assessment in *Aeluropus lagopoides*, etc., leaves and soil sediment of *A. lagopoides* shows efficient K^{+} uptake and shows maximum Fe^{+2}, Mn^{+2}, P^{-} and N content than *C. tagal*. Leaves of *A. lagopoides* show high Na^{+} 2.75 and Cl^{-} about 3.64 g/100 g dry weight, it has significant compare to *C. tagal* and *L. racemosa*. The leaves of the majority of halophyte plants accumulation of salt ions and other mineral ions, it is especially stored in foliar organs (Joshi, A. J. (1981, 1982, 1987, 2004, Vyas S. J., 2014). According to (Milić, D., Luković, 2013), *S. europaea*, *S.maritima* and *S. soda*, above-ground organs of these halophytes accumulate more Na than Mg^{+2}, Ca^{+2} and K^{+}, they also revealed that in different habitats these halophytes having more cations in maritime saline areas than inland saline areas. One of the interesting studies revealed by (Matinzadeh, Z, 2019) in the Eu-halophytes succulent and salt-recreating plants shows a high concentration of Na^{+}, S^{-2}, and Mg^{+2} and a low concentration of Ca^{+2} and K^{+} ions Whereas in pseudo-halophytes, facultative halophytes and eury-hygro-halophytic species, which lack succulent shoots, resulted in low concentration of Na^{+}, S^{-2} and Mg and high in Ca^{+2} and K^{+} in their leaves, although the study also targets some taxonomic identical families for this kind of elemental variation, in the family, Chenopodiaceae and Plumbaginaceae accumulate high Na^{+} and Mg^{+2}, and low Ca^{+2} and K^{+}, other families Caryophyllaceae having high K^{+}, whereas Poaceae with low Na^{+2}. The amount of foliar Ca^{+2} is high in Asteraceae, Boraginaceae and Brassicaceae families. If the level of salinity increases, it has been observed by Khan, (2000b), the leaves of perennial halophytes, *S. fruticosa* Ca^{+2}, Mg^{+2} and K^{+} concentration decreases. Another stem succulent plant, *H. recurvum*, the stage of succulence increases with low salinity and decreases with high salinity, here changes*u* in different parts of plant-like, in shoot and root values of Ca^{+2}, Mg^{+2} and K^{+} content reduces at high salinity. (Gulzar, S., & Khan, M. A., 2008), some grass species like *A.lagopoides* and *U.setlosa*, high salt-tolerant non-succulent plant, concluded that it can be cultivated using saline water, and *S.ioclados* is comparatively less salt-tolerant, these plant species growing under its suitable habitat, where brackish water is accessible, when water potential and osmotic potential is negative at that time in aerial parts of *A. lagopoides* salinity increases.

5. Conclusion

The mineral ion accumulating plant parts of succulent and non-succulent halophytic groups showed strongly association with different ions. Succulent species *Salicornia brachiata*, were observed to be growing on muddy saline areas; whereas other succulent plant *Sueada nudiflora* was dominantly growing on wasteland areas of Kachchh coast. It was interestingly observed that in succulent species has the adaptive mechanism of salt avoidance whereas non-succulent halophytic species are adapted to salt tolerance mechanisms. Non-succulent plants excreting salts from its leaves, hence it accumulate a low concentration of salt. K^{+} is in the lowest amount in the soil as well as in plant parts, but it strongly associated with salinity in succulent plants, the amount of Ca^{+2}, Mg^{+2} and K^{+} is decreasing, when the NaCl value increase. It was concluded based on the results of soil supporting the succulent and non-succulent halophytic species. The adaptive natures of succulent have accumulated elemental concentration in higher amount in phylloclades and leaves. Excess mineral ion content is divided towards phylloclade and leaves which has adaptive nature handling stress mechanisms to transforming the excess mineral ion into secondary metabolites and shows succulence in that organ (Phylloclade, leaves). Roots of succulent plants are penetrated deeper than that of non-succulents halophytic plants (Monocots) is on surface of soil. The present study relates the accumulation of mineral ions concentration in different parts of succulent and non-succulent halophytic plant species reflecting a promising approach of utilization hyper accumulation capacity of succulent and non-succulent halophytes for the purpose of phytoremadiation.

Declarations

Author contribution

SV designed and planed present research, KG conducted field visits. KG, SG and KD performed the data analysis and composed the first manuscript draft with the help of S.V All authors contributed research work during and after the fieldwork, discussed and interpreted the results and revised the manuscript.

Declaration of Competing Interest

The authors don’t have any competing interests.

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Tables

Table 1

Elements compositions in sea green bean, Salicornia brachiata

S. brachiata	Phylloclade	Stem	Root	Soil
EC	5.56 ± 0.23 4.73^{ns}	0.85 ± 0.13 421.69^{ns}	0.92 ± 0.19 612.86^{ns}	5.95 ± 0.54 15.80*
Ca^{+2}	0.37 ± 0.03 53.77**	0.25 ± 0.05 50.86**	0.23 ± 0.05 12.77*	0.98 ± 0.35 3298.2^{ns}
Mg^{+2}	0.86 ± 0.04 5.87^{ns}	0.53 ± 0.08 37.60**	0.55 ± 0.11 121.81***	1.38 ± 0.15 295.81^{ns}
Na^{+}	6.16 ± 0.66 50.26**	1.43 ± 0.83 216.12^{ns}	1.14 ± 0.50 252.87^{ns}	8.28 ± 0.80 27.55**
K^{+}	0.17 ± 0.02 77.6***	0.14 ± 0.01 7.31*	0.14 ± 0.01 11.49*	0.19 ± 0.01 20.61**
Cl^{-}	2.50 ± 0.62 40.38**	0.41 ± 0.16 186.09^{ns}	0.50 ± 0.19 190.62^{ns}	8.47 ± 0.87 10.04*

(EC; (mS/cm), Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}; (for plant, meq.g^{-1} and soil meq.g^{-100}) Each value of parameter represents mean value of triplicate samples from four zones, mean± SE and F value of ANOVA is also indicated, when P<0.05).

Table 2

elements compositions in Suaeda nudiflora

S. nudiflora	**Leaves**	**Stem**	**Root**	**Soil**
EC	5.29 ± 0.31 0.56^{ns}	1.34 ± 0.67 365.13**	0.94 ± 0.31 63.74*	1.30 ± 0.17 2.26^{ns}
Ca^{+2}	0.44 ± 0.05 1^{ns}	0.28 ± 0.01 0.48^{ns}	0.35 ± 0.02 10^{ns}	0.34 ± 0.09 304.2**
Mg^{+2}	1.47 ± 0.40 0.13^{ns}	0.61 ± 0.16 10.98^{ns}	0.48 ± 0.11 52.9*	0.30 ± 0.13 729**
Na^{+}	3.87 ± 0.47 518.71**	0.91 ± 0.11 9.38^{ns}	0.44 ± 0.13 4.84^{ns}	2.09 ± 0.31 9.34^{ns}
K^{+}	0.24 ± 0.09 57.8*	0.17 ± 0.06 450**	0.15 ± 0.01 0.10^{ns}	0.06 ± 0.00 0.29^{ns}
Cl^{-}	1.65 ± 0.40 166.99**	0.51 ± 0.20 43278.95^{ns}	0.34 ± 0.19 29.35*	2.62 ± 0.49 63.15*

(EC; (mS/cm), Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}; (for plant, meq.g^{-1} and soil meq.g^{-100}) Each value of parameter represents mean value of triplicate samples from four zones, mean± SE and F value of ANOVA is also indicated, when P<0.05).

Table 3

Elements compositions in Shrubby Seablite, Suaeda fruticosa

S. *fruticosa*	**Leaves**	**Stem**	**Root**	**Soil**
EC	4.45 ± 1.22 68.09*	0.80 ± 0.03 0.9^{ns}	0.92 ± 0.26 562.52**	4.02 ± 2.69 28.68*
Ca^{+2}	0.34 ± 0.09 800**	0.34 ± 0.07 200**	0.27 ± 0.08 115.6**	0.70 ± 0.49 2452.3***
Mg^{+2}	0.59 ± 0.14 98.76**	0.57 ± 0.07 655.60**	0.53 ± 0.007 10.53*	0.84 ± 0.36 315.26**
Na^{+}	4.37 ± 0.24 1.54^{ns}	0.74 ± 0.09 92.86*	0.37 ± 0.05 26.98*	4.94 ± 2.61 2140.1***
K^{+}	0.18 ± 0.001 1.99^{ns}	0.14 ± 0.02 8.05^{ns}	0.15 ± 0.008 4.53^{ns}	0.13 ± 0.07 24.26**
Cl^{-}	1.48 ± 0.63 375.77**	0.29 ± 0.04 5^{ns}	0.28 ± 0.09 3.46^{ns}	5.48 ± 2.37 12446^{ns}

(EC; (mS/cm), Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}; (for plant, meq.g^{-1} and soil meq.g^{-100}) Each value of parameter represents mean value of triplicate samples from four zones, mean± SE and F value of ANOVA is also indicated, when P<0.05).

Table 4

Element compositions in Mangrove Grass, Aeluropus lagopoides

A.lagopoides	**Leaves**	**Stem**	**Root**	**Soil**
EC	1.81 ± 0.04 5.54*	1.54 ± 0.14 2.41^{ns}	1.37 ± 0.16 103.11^{ns}	4.89 ± 1.58 101.14**
Ca^{+2}	0.52 ± 0.04 4.99^{ns}	0.50 ± 0.14 37.63**	0.59 ± 0.15 6.44*	0.90 ± 0.37 1514.4^{ns}
Mg^{+2}	0.77 ± 0.12 1.68^{ns}	0.93 ± 0.18 21.73***	0.71 ± 0.14 7.54*	1.04 ± 0.13 8.64*
Na^{+}	1.47 ± 0.17 27.00**	1.16 ± 0.19 13.44	0.97 ± 0.26 172.01***	5.86 ± 1.25 109.91***
K^{+}	0.16 ± 0.05 222.55^{ns}	0.14 ± 0.01 7.6*	0.10 ± 0.01 69.46*	0.08 ± 0.02 16.94*
Cl^{-}	0.87 ± 0.14 56.57***	0.49 ± 0.15 24.86**	0.63 ± 0.30 446.18^{ns}	5.83 ± 1.85 835.9^{ns}

(EC; (mS/cm), Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}; (for plant, $meq.g^{-1}$ and soil $meq.g^{-100}$) Each value of parameter represents mean value of triplicate samples from four zones, mean± SE and F value of ANOVA is also indicated, when P<0.05).

Table 5

Elements compositions in Urochondra setulosa

U.setulosa	**Leaves**	**Stem**	**Root**	**Soil**
EC	1.66 ± 0.08 109.74^{ns}	0.80 ± 0.12 375.63^{ns}	0.66 ± 0.12 102.50***	5.88 ± 1.18 124.51**
Ca^{+2}	0.54 ± 0.11 169.36***	0.41 ± 0.19 1195.36^{ns}	0.56 ± 0.12 292.15^{ns}	0.94 ± 0.30 1514.4^{ns}
Mg^{+2}	0.86 ± 0.15 470.17^{ns}	0.63 ± 0.22 3855.46^{ns}	0.82 ± 0.08 53.43**	0.91 ± 0.15 8.64*
Na^{+}	1.19 ± 0.04 0.06^{ns}	0.59 ± 0.10 17.80**	0.74 ± 0.15 174.36***	6.32 ± 0.67 109.91***
K^{+}	0.14 ± 0.01 26.54**	0.092 ± 0.008 16.43*	0.069 ± 0.01 154.08***	0.12 ± 0.04 16.94*
Cl^{-}	0.78 ± 0.14 403.74^{ns}	0.39 ± 0.03 397.82^{ns}	0.33 ± 0.02 28.26**	6.77 ± 0.90 835.9^{ns}

(EC; (mS/cm), Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}; (for plant, $meq.g^{-1}$ and soil $meq.g^{-100}$) Each value of parameter represents mean value of triplicate samples from four zones, mean± SE and F value of ANOVA is also indicated, when P<0.05).

Table 6

Spearman correlation of elements in different parts of succulent halophytes

Parts		L					S					R				
		Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}
L	Ca^{+2}	1.00														
	Mg^{+2}	0.60	1.00													
	Na^{+}	-1.000**	-0.60	1.00												
	K^{+}	0.00	0.80	0.00	1.00											
	Cl^{-}	-0.20	0.20	0.20	0.40	1.00										
S	Ca^{+2}	-0.40	-0.40	0.40	-0.20	0.80	1.00									
	Mg^{+2}	-0.80	-0.80	0.80	-0.40	0.40	0.80	1.00								
	Na^{+}	0.00	0.80	0.00	1.000**	0.40	-0.20	-0.40	1.00							
	K^{+}	0.80	0.00	-0.80	-0.60	-0.40	-0.20	-0.40	-0.60	1.00						
	Cl^{-}	-0.21	0.63	0.21	0.95	0.63	0.11	-0.11	0.95	-0.74	1.00					
R	Ca^{+2}	-0.20	0.20	0.20	0.40	1.000**	0.80	0.40	0.40	-0.40	0.63	1.00				
	Mg^{+2}	-0.80	-0.80	0.80	-0.40	0.40	0.80	1.000**	-0.40	-0.40	-0.11	0.40	1.00			
	Na^{+}	0.00	0.80	0.00	1.000**	0.40	-0.20	-0.40	1.000**	-0.60	0.95	0.40	-0.40	1.00		
	K^{+}	1.000**	0.60	-1.000**	0.00	-0.20	-0.40	-0.80	0.00	0.80	-0.21	-0.20	-0.80	0.00	1.00	
	Cl^{-}	-0.40	-0.40	0.40	-0.20	0.80	1.000**	0.80	-0.20	-0.20	0.11	0.80	0.80	-0.20	-0.40	1.00

(L; Leaves, S; Stem and R; Root)

**Correlation is significant at the 0.01 level

Table 7

Spearman correlation of elements in different parts of non-succulent halophytes

Parts		L					S					R				
		Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}
L	Ca^{+2}	1.00														
	Mg^{+2}	0.80	1.00													
	Na^{+}	0.20	0.40	1.00												
	K^{+}	-0.80	-1.000**	-0.40	1.00											
	Cl^{-}	0.40	0.80	0.80	-0.80	1.00										
S	Ca^{+2}	1.000**	0.80	0.20	-0.80	0.40	1.00									
	Mg^{+2}	0.40	0.80	0.80	-0.80	1.000**	0.40	1.00								
	Na^{+}	0.80	1.000**	0.40	-1.000**	0.80	0.80	0.80	1.00							
	K^{+}	-0.40	-0.80	-0.80	0.80	-1.000**	-0.40	-1.000**	-0.80	1.00						
	Cl^{-}	0.80	1.000**	0.40	-1.000**	0.80	0.80	0.80	1.000**	-0.80	1.00					
R	Ca^{+2}	0.40	0.20	0.80	-0.20	0.40	0.40	0.40	0.20	-0.40	0.20	1.00				
	Mg^{+2}	0.20	0.40	-0.60	-0.40	0.00	0.20	0.00	0.40	0.00	0.40	-0.80	1.00			
	Na^{+}	0.40	0.80	0.00	-0.80	0.60	0.40	0.60	0.80	-0.60	0.80	-0.40	0.80	1.00		
	K^{+}	0.80	0.40	-0.40	-0.40	-0.20	0.80	-0.20	0.40	0.20	0.40	0.00	0.40	0.20	1.00	
	Cl^{-}	0.40	0.80	0.80	-0.80	1.000**	0.40	1.000**	0.80	-1.000**	0.80	0.40	0.00	0.60	-0.20	1.00

(L; Leaves, S; Stem and R; Root)

**Correlation is significant at the 0.01 level

Figures

Figure 1

Coastal belt of Kachchh, Gujarat, India

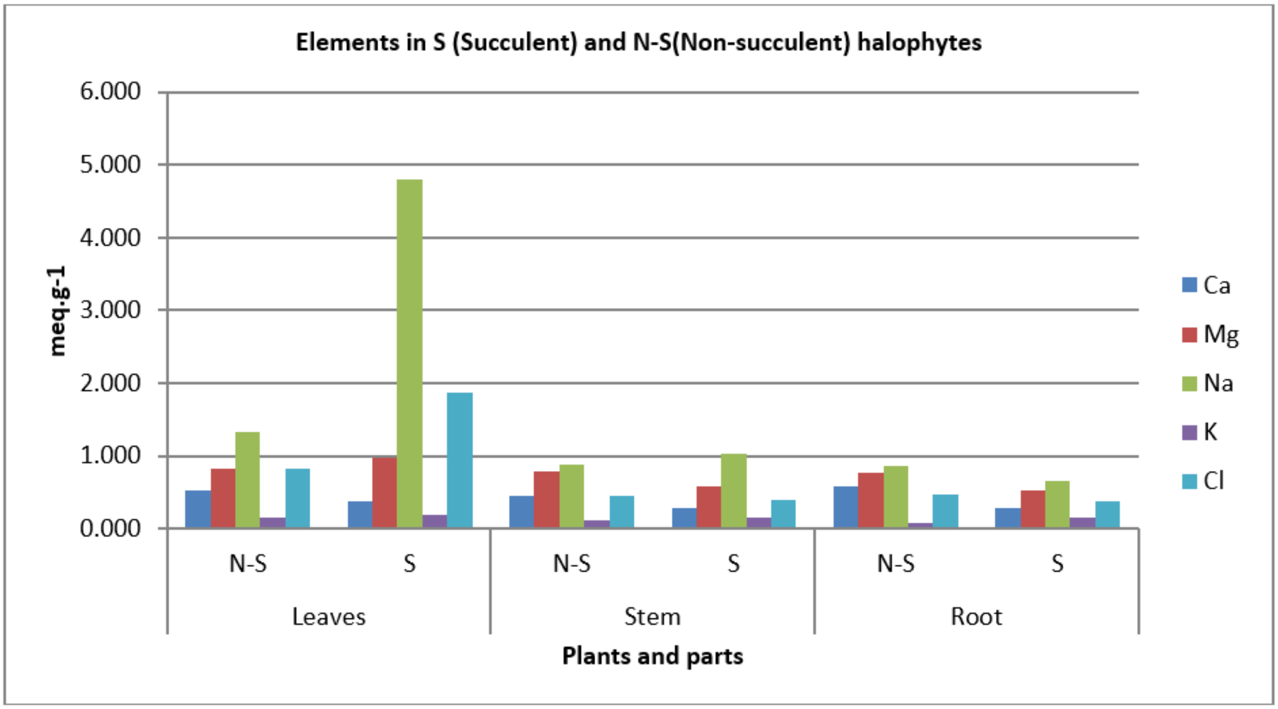

Figure 2

comparative elements in succulent and non-succulent halophytes among different parts