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Ecological and Economic Potential of Major Halophytes and Salt Tolerant Vegetation in India

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Abstract

Soil salinization is a global and climatic phenomenon that affects various spheres of life. The present rate of salinization is perilously fast because of global climate change and associated events leading to enhanced land degradation, loss of soil fertility and crop productivity. In this chapter, we tried to focus on the arid and semiarid regions of India along with our coastal zone which are economically fragile regions and need much closer attention. In future, India will face extreme pressure on its land resources in agriculture because of likely rapid degradation of these resources. Thus, salt affected soils must be brought under cultivation by adopting site specific strategies to ensure national food and nutritional security. In this regard, a comprehensive review of the major halophytes of these ecological zones, its mechanism of salt tolerance, ecological and economic potential is done. The potential applications of saline land vegetation including halophytes in climate change mitigation, phytoremediation, desalination, food, secondary metabolite and nutraceutical production, medicine, and saline agriculture have been discussed. Further, we tried to focus on popular farmer adopted halophytic species including edible ones, their uses, products of economic significance etc. which is highly imperative for effective utilization of these saline soils leading to improved livelihood and sustenance of resource poor farmers along with improved ecological balance.

Keywords: coastal soil, dry land, ecology, economic products, halophytes, saline vegetation, salinity stress

1. Introduction

Food security and ecological security are the two pillars of all societies. The incessant growth of human population across the world is evident from the United Nations projection of 9.7 billion people by 2050 [1]. The global food demand is expected to rise by 70–100% and to meet this additional food demand, a predicted 50% increase in yields of the major food crops will be required [2]. Moreover, our global food security is significantly affected by drastic alterations in the climate [3]. This unpredictable change in climate has resulted in to several abiotic stresses such as salinity, drought, heat and low temperature, threatening the agricultural sustenance and productivity [4]. This has also brought about a significant spike in the occurrences of extreme climatic events like flood, cyclones, storms etc. [5]. Land degradation is one

of the severe consequences of global climate change and it is happening at a viciously alarming pace because of other reasons too, like vegetation loss, soil erosion, inadequate water management, excessive use of fertilizers, soil and groundwater degradation, urbanization and poor agricultural practices [6]. One of the major causes of land degradation is buildup of soil salinity as a result of natural and anthropogenic factors [7, 8]. It is estimated that agricultural soils are decreasing about 1–2% every year especially in the arid and semiarid regions of the world due to soil salinity [9].

On an average, 831 million hectares (Mha) of global soil is affected by salt (397 and 434 Mha of saline and sodic soils, respectively) which is more than 6% of the world's total land area [10]. Out of total irrigated land (230 Mha), almost 20% (45 Mha) area has already been damaged by excess soil salinity [11], whereas 14% (32 Mha) is affected by varying degrees of salt [12]. In India, the total land degraded due to soil salinity and sodicity is estimated to be 6.74 Mha [13] and it is likely to increase to 16.2 Mha by 2050 [14]. Soil salinization is grouped in to two types viz. Primary salinization and secondary salinization. Primary salinization occurs due to the existence of subsoil salts and by other natural processes like weathering of parent material, deposition of sea salt carried by wind and rain, inundation of coastal land by tidal water, etc. Secondary salinization is a consequence of anthropogenic or human induced activities like excessive irrigation, irrigation with salt containing water, poor drainage due to loss of natural water passages, unscientific application of inorganic fertilizers and other soil amendments [14, 15].

The arid and semiarid regions of India along with our coastal zones are economically fragile regions and need much closer attention. Low rainfall and high temperature are two specific features of the arid and semiarid regions of India which are highly conducive to excessive soil salinity [16]. India has a coastline of 7516.6 km viz. 5422.6 km of mainland coastline and 1197 km of Indian islands spread across 9 Indian states and two Union Territories [17]. Soil salinity is estimated to have affected 1.25 Mha soils in these coastal tracts of the nation [13]. The predicted rise in sea level of 1 m due to global warming may aggravate this problem to take on serious dimensions in future [14]. Moreover, there is a predicted increase in water demand by 45% in coastal areas by 2050, which will inevitably result in increased ground water depletion and induce more and more soil salinity [14]. Altogether, in both these ecological zones of the nation, soil salinity has become an important factor limiting the growth of major crops and even some halophytes [18].

Moreover, factors like global climate change, diversion of more and more productive agricultural land towards other nonagricultural purposes as a part of rapid urbanization and the alarming rate of decline in soil organic carbon will lead to further increase in soil salinity [19–24]. So we are running out of options, and the only option left is to bring these saline, sodic and other barren land in to cultivation to meet the growing food demand and more importantly to address the growing climatic and ecological concerns. Major agricultural crops and tress cannot be grown in such soils as they exhibit a low tolerance to salt [25]. So future agricultural production in these saline soils should be based on salt tolerant crops which are edible and/or of economic and ecological significance [26, 27].

Halophytes, salt mangroves, and other salt tolerant plants and trees are the options which can grow and survive in extreme environments. Many halophytes have potential agricultural value and can be grown in these highly saline areas. They not only survive in these conditions, but also produce considerable biomass coupled with various other potential/economic uses in industry, feed, medicine etc. [28]. Indian mangrove vegetation covers about 6749 km² along the 7516.6 km long coast line, including island territories. 82 species of mangroves distributed in 52 genera and 36 families have been identified that are spread across 12 habitats of India [29]. They along with many other associate species thrive well in coastal saline

soils. Moreover, these saline soils can further be brought in to cultivation through agroforestry, silvipasture, nonconventional crops including medicinal and aromatic plants and other high value crops. These will not only utilize the saline barren land for economic growth but will also help significantly in conserving our biodiversity and improvement of ecological and social environment.

A systematic attempt has been made in bringing together critical aspects of saline agriculture, including major halophytes and other saline vegetation of India, its salt tolerance mechanisms coupled with ecological and economic potential of these plants. This is highly imperative for effective utilization of these saline soils leading to improved livelihood and sustenance of resource poor farmers along with improved ecological balance.

2. Halophytes

Halophytes are plants capable of completing their life cycle under highly saline conditions [30]. To be more scientifically concrete, halophytes are those plant species which can successfully survive, grow and reproduce in soils of salt concentration more than 200 mM of NaCl (Electrical conductivity of soil saturation extract (EC_e) of 20 dS m⁻¹) [31]. Some halophytes can even grow well at higher salt concentrations than that of sea water (>500 mM NaCl) [32]. As they prosper well in severely saline soils, they are also considered to be extremophiles [33]. They constitute around 1% of the global flora [15]. The question of how they survive and complete their life cycle under such extreme conditions has led to detailed studies on the various morphological, anatomical, physiological and molecular mechanisms of high salt tolerance. The tolerance of halophytes to salts varies with species and developmental stage. In general, dicot halophytes are reported to be more tolerant (optimal growth in 100–200 mM NaCl) as compared to monocot species (optimal growth in 50–100 mM NaCl) [31].

During 1980s, James Aronson compiled a comprehensive database [34] of 1554 halophyte species, and named it as HALOPH. This database has been converted into an interactive eHALOPH repository [35] that provides online details and bibliography pertaining to halophytes. Till now 2000 to 3000 halophytic plant species are identified [32] in the world mainly belonging to angiosperms. In India, their distribution is mainly confined to arid, semiarid inland and highly saline wetlands along the tropical and sub-tropical coasts [36]. The major halophytes/saline vegetation found across the various ecological hotspots spread across the country are summarized in **Table 1**.

A summary of classification of halophytes by researchers across the globe based on different aspects is compiled and presented below.

2.1 Based on salt tolerance

- i. **Mio-halophytes:** Plants which grows in the habitats of low salinity levels (below 0.5% NaCl) [37].
- ii. **Eu-halophytes:** Plants which grow in highly saline habitats. They have been further sub-divided into the following groups:
 - a. **Mesohalophytes:** Plants that can tolerate salinity range of 0.5 to 1%.
 - b. **Mesoeuhalophytes:** Plants that can tolerate salinity range of 5% and higher.
 - c. **Eneuhalophytes:** Plants that can tolerate salinity range of 1% and above.

Scientific name	Common name	Family	Area of occurrence	Plant type
<i>Aeluropus lagopoides</i>	Mangrove grass, usargas, kharoga	Poaceae	Kachchh, Thar Desert	Tufted grass
<i>Atriplex hortensis</i>	French Spinach, Pahari Paleng	Amaranthaceae	Coastal marshes Ladakh, Kashmir	Herb
<i>Atriplex stocksii</i>	Khati palakh, kharo tanko	Amaranthaceae	Kachchh (Gujarat)	Bush
<i>Avicennia marina</i>	Whitemangrove, tavarian, tivar	Acanthaceae	Kachchh, Kerala Maharashtra, Tamilnadu,	Mangrove
<i>Cenchrus biflorus</i>	Indian sandbur, bhurut	Poaceae	Kachchh, Thar Desert	Grass
<i>Chenopodium album</i>	Lamb's quarters, bathua	Amaranthaceae	Northarn India, Kachchh	Herb
<i>Cressa cretica</i>	Rudravanti, machul	Convolvulaceae	Kachchh, Thar Desert	Sub-shrub
<i>Cyperus conglomeratus</i>	—	Cyperaceae	Kachchh, Thar Desert, Kerala	Herb
<i>Cynodon dactylon</i>	Bermuda grass, doob	Poaceae	Throughout India	Grass
<i>Dactyloctenium indicum</i>	Tantia, ganthio	Poaceae	Kachchh	Grass
<i>Dichanthium annulatum</i>	Marvel grass, karad, bansi	Poaceae	Kachchh, Thar Desert	Grass
<i>Halopyrum mucronatum</i>	Dariyai kans	Poaceae	Kachchh	Grass
<i>Haloxylon salicornicum</i>	Rimth saltbush, khar, lana	Amaranthaceae	Kachchh, Thar Desert	Shrub
<i>Heliotropium bacciferum</i>	—	Boarginaceae	Kachchh, Southern India	Herb
<i>Ipomoea pes-caprae</i>	Atampa, dopatti lata	Convolvulaceae	Kachchh	Herb
<i>Limonium stocksii</i>	Kharia	Plumbaginaceae	Kachchh, North west India	Herb
<i>Portulaca oleracea</i>	Common purslane, lunia, badi-noni	Portulacaceae	Maharastra, Thar desert	Herb
<i>Prosopis juliflora</i>	Mesquite, vilaiti keekar	Fabaceae	Throughout India	Shrub
<i>Salicornia brachiata</i>	Glasswort, umari keera	Amaranthaceae	Kachchh, Thar desert	Herb
<i>Salsola baryosma</i>	Loonuk, lani	Amaranthaceae	Kachchh, Thar desert	Shrub
<i>Salvadora oleoides</i>	Bada peelu, meethi jaal	Salvadoraceae	Kachchh, Thar desert	Shrub
<i>Salvadora persica</i>	Meswak, piludi, khari jaal		Kachchh, Thar desert	Shrub/Tree
<i>Sesuvium portulacastrum</i>	Sea purslane, lunio, dhapa	Aizoaceae	Kachchh, Rajasthan,	Herb
<i>Sporobolus marginatus</i>	poolongi, khevai	Poaceae	Kachchh	Grass

Scientific name	Common name	Family	Area of occurrence	Plant type
<i>Suaeda fruticosa</i>	lunaki, moras	Amaranthaceae	Kachchh, Thar desert	Shrub
<i>Suaeda maritima</i>	Annual sea blite, alur		Maharastra	
<i>Suaeda nudiflora</i>	Muchole		Kachchh	
<i>Tamarix dioica</i>	Red tamarisk, lai, arseli	Tamaricaceae	Kachchh	Shrub
<i>Urochondra setulosus</i>	Kkariyu	Poaceae	Kachchh	Grass
<i>Ziziphus nummularia</i>	Jhar beri, chanibor	Zygophyllaceae	Kachchh, Thar desert	Shrub
<i>Zygophyllum simplex</i>	Bean-Caper, pat lani		Kachchh, Thar desert	Herb

Table 1.
Major halophytic species and other saline vegetation spread across different ecological zones of India.

2.2 Based on mechanism of tolerance

- i. **Salt excluding:** The root architecture of this category of plants is embraced by an ultrafiltration mechanism which leads to establishment of such species in saline conditions. Mangrove vegetation shows such type of tolerance. e.G. *Rhizophora mucronata*, *Bruguiera gymnorrhiza* [38].
- ii. **Salt excreting:** This category of plants release excess salts in their internal tissues to outside via. Specialized structures called as salt glands. e.g. *Avicennia officinalis*, *Avicennia alba*, *Avicennia marina*.
- iii. **Salt accumulating:** These plants are able to maintain very high levels of salt in their tissues either by virtue of succulence or by compartmentation of excess salts in to comparatively safer cellular locations like vacuole. e.g. *Salvadora persica*, *Sesuvium portulacastrum*, *Suaeda nudiflora*.

2.3 Based on ecological aspect

- i. **Obligate halophytes:** They grow only in salty habitats and show satisfactory growth and development under high saline condition. Many plant species belonging to chenopodiceae family comes under this category. e.g. *Salicornia bigelovii* [39].
- ii. **Facultative halophytes:** Plants of this group are able to establish themselves on salty soils, but their optimum growth is observed in a salt free or low salt condition. Most poaceae, cyperaceae, and brassicaceae species as well as a large number of dicotyledons like *Aster tripolium*, *Glaux maritima*, *Plantagomaritima* belong to this group.
- iii. **Habitat-indifferent halophytes:** They normally grow on salt free soils but can thrive better than sensitive species under saline conditions. Plants like *Chenopodium glaucum*, *Myosurus minimus*, and *Potentillaanserina* are categorized as habitat insensitive plants.



Figure 1. Major halophytes and mangroves found in India. (a) *Sporobolus marginatus*, (b) *Salicornia brachiata*, (c) *Chenopodium album*, (d) *Portulaca oleracea*, (e) *Heliotropium curassavicum*, (f) *Haloxylon salicornicum*, (g) *Cressa cretica*, (h) *Aeluropus lagopoides*, (i) *Prosopis juliflora*, (j) *Salvadora oleoides*, (k) *Salvadora persica*, (l) *Sesuvium portulacastrum*, (m) *Suaeda fruticosa*, (n) *Halopyrum mucronatum*, (o) *Tamarix* spp, (p) *Urochondra setulosa*, (q) *Rhizophora mucronata*, (r) *Heritiera fomes*, (s) *Avicennia marina*, (t) *Bruguiera cylindrical*, (u) *Bruguiera gymnorrhiza*.

2.4 Based on habitat

- i. **Hydro-halophytes:** These are halophytic plants which grow in aquatic conditions. Most of the mangroves and salt marsh species along costal lines belong to this group [40].

- ii. **Xero-halophytes:** They grow in environment, where the soil is saline and the soil moisture content is very low due to high evaporation. Most plant varieties in desert areas and succulents belong to this group.

There is an enormous diversity among halophytes with regard to its ecological hotspots like coastal saline soils, arid and semiarid saline and sodic soils, soils of mangrove forests, wet lands, marshy lands and even agricultural fields [15]. A picturesque view of the major halophytes and mangroves found in India is given in **Figure 1**.

3. Mechanism of salt tolerance

Any review on halophytes/extremophiles is incomplete, without touching on the mechanisms by which these extremophiles survive under saline conditions. Indian Council of Agricultural Research- Central Soil Salinity Research Institute (ICAR-CSSRI) initiated such basic studies long back to critically understand the mechanism of salt tolerance in the local, native dry land saline vegetation [41]. This precise knowledge is highly imperative in developing other crops by a combination of improved salt tolerance and high yield. Another mandate was to document such species and, to the maximum extent, popularize them among the resource poor dry land farmers for better livelihood and sustenance.

3.1 Salt stress and halophytes

Any plant species initially suffers from osmotic stress as a result of increased soluble salts in the soil solution and later gets subjected to ionic stress due to specific accumulation of toxic ions. The osmotic phase of salt stress is characterized by disruption of water potential gradient and thereby leads to reduced water uptake and inhibition of cell expansion [42]. Most plant species tries to adapt to this osmotic stress by accumulation of compatible solutes and thereby lowering water potential of cells, but this process consumes lot of energy and hence growth is heavily compromised.

Another major deleterious effect of salt stress is nutrient imbalance where in which high Na^+ ions in the soil solution reduces the availability of other cations like K^+ , Ca^{++} and Mg^{++} [43]. This second phase of salt induced injury (specific ion toxicity) results from very high levels of Na^+ and Cl^- in the plant cells. In normal soils, plants maintain around 100–200 mM of K^+ and 1–10 mM of Na^+ in cellular cytosol for optimum cellular functions. Any salt concentration above this threshold level disrupts enzyme activity, protein synthesis, photosynthesis and other metabolic activities [44]. The light reactions of photosynthesis are comparatively less affected by salt stress as compared to the carboxylation reactions. A summary of salinity mediated effects and responses of plant cells are presented in **Table 2**.

The cell membrane permeability, composition and integrity gets affected as excess Na^+ replaces Ca^{2+} from its surface [46]. A lot of salt tolerant crop varieties have been developed by various research institutes which can survive up to moderate levels of salt stress. Under these circumstances, it is highly imperative to identify and propagate halophytic species in the arid and semiarid, high salt affected regions of the country, so that the vast tract of unproductive land can be put to cultivation for realization of sustainable income to resource poor farmers.

3.2 Salt induced responses and adaptations in halophytes

Halophytes and glycophytes have similar components in the stress tolerance network, but certain additional characteristics help these halophytes tolerate very high levels of salinity. Similar to glycophytes, halophytes also use osmoprotective and

Causes	Effect	Response/adaptation
Osmotic stress	Reduced water uptake, inhibition of cell elongation and expansion and leaf bud development	Compatible solute accumulation (ions/organic compounds)
Ion specific stress (high levels of Na and Cl in plant cell)	Inhibition of enzyme activity, protein synthesis, photosynthesis and leaf senescence and necrosis	Ion homeostasis through ion accumulation or ion exclusion
Imbalanced ion uptake	Nutritional deficiencies, reduced availability of other cations like K, Ca and Mg	Ion reabsorption
^a Adopted and modified from [45].		

Table 2.
Salt stress mediated effects and adaptations in plants.^a

ion-detoxification strategies consisting of Na⁺ removal from cytosol, Na⁺ transport from root cells to xylem, and ion compartmentation in the vacuoles, involving salt overly sensitive (SOS1), high affinity potassium transporter (HKT1) and Na⁺ H⁺ antiporter (NHX) ion transporters, respectively. Under salt stress, most halophytes accumulate more Na⁺ in their shoots than in their roots while retaining higher levels of K⁺ and, thus, a more optimal K⁺/Na⁺ ratio [47, 48].

Salt stress induced accumulation of specific osmolytes like proline, glycine beta-ine and sugar alcohols have also been reported in both halophytes and glycophytes [47]. Nevertheless, halophytes exhibit a greater capacity to accumulate very high levels of such osmolytes, even under normal conditions which explains its pre-
paredness to stress [49]. In line with this, over accumulation of proteins involved in carbohydrate metabolism have been reported in the leaves of many halophytes [50]. Specific transporter mediated intracellular compartmentalization of excess ions in to vacuole is another key mechanism used by halophytes to maintain a moderate cytosolic K⁺/Na⁺ ratio in the cytosol. Thus, membrane ATPases and ion transporters play vital roles in salt tolerance of halophytes [51].

Salvadorapersica, a very common inhabitant of dry saline tracts was grown at different in situ salinities, and the partitioning of sodium and chloride ions in to different plant parts were studied by [52] (**Figure 2**). The results showed very high content of these ions in the bark and senescing leaf tissue and a comparatively low content in photosynthetically active leaves [53]. The capacity of these sink tissues (bark and senescing leaves) to accumulate more and more salts increased with increasing salinity as well as with age of plant, which indicates a well established salt compartmentation mechanism in this halophyte species [41].

However, recent physiological and molecular observations across the globe indicate that halophytes may employ different mechanisms in ion transportation and homeostasis under salt stress. Latest studies showed that over expression of SOS 1 and HKT 1 in the halophytes *Eutrema salsugineum* and *Schrenkiella parvula* conferred much stronger salinity tolerance than that of their glycophytic counterpart [54]. Many halophytic species have now been understood to be constitutively higher expressers of the component genes of salt overly sensitive (SOS) pathway [55]. Genome studies of *Schrenkiella parvula* via. next generation sequencing (NGS) plat-
form revealed the presence of three tandem duplicates of *nhx8* and two copies of *hkt1* which clearly explains the higher transcript abundance of these genes as compared to their glycophytic counterpart [56]. Thus genomic variation may be another impor-
tant factor leading to enhanced salt tolerance in these halophytes which needs further confirmation. Moreover, the presence of specific Na⁺/Ca²⁺ converse transportation mechanism also facilitates better adaptation to salt stress in halophytes [57].

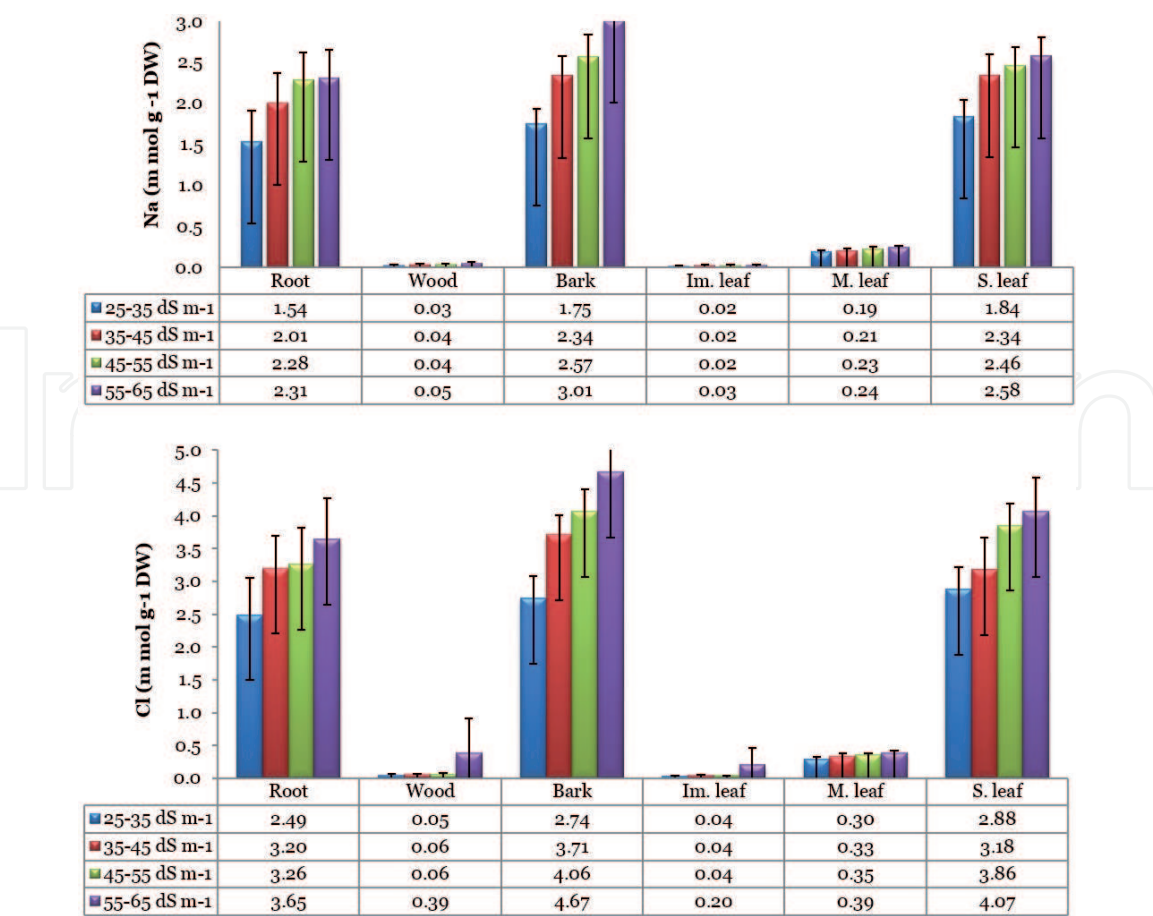


Figure 2.
Sodium (Na^+) and chloride (Cl^-) ion partitioning in *Salvadora persica* grown at different in situ salinities. Data represents mean of 2nd, 3rd and 4th years [43]. DW = dry weight, Im. Leaf = immature leaf, M. leaf = mature leaf & S. leaf = senescing leaf.

Epidermal bladder cells (EBCs) is another important feature of certain halophytes by which they secrete excess salt. 50% of the existing halophytes have been reported to contain these EBCs [31]. Removal of these EBCs resulted in enhanced salt sensitivity in a facultative halophyte called quinoa (*Chenopodium quinoa*) [58]. These EBCs are 1000-fold bigger than the general epidermic cells in volume, indicating its enhanced sodium excretion ability [59]. EBCs are similar to the trichome cells of *Arabidopsis* and transcriptomic analysis of quinoa EBCs showed enhanced expression of salt stress responsive genes, genes belonging to transporter family, sugar transporters, while photosynthesis-related genes showed reduced expression [60]. Nevertheless, the genetic determinants of EBCs coupled with the molecular mechanism of sodium pumping in to the EBCs is far from clear except a few studies in *Arabidopsis* [61]. This EBCs mediated strategy to tolerate high salt stress is not present in all halophytes. So certain other mechanisms are adopted by those halophytes which do not rely on EBCs. One category of halophytes called as succulent halophytes, further classified in to stem succulent and leaf succulent, accumulate large quantities of salt in its cells and tissues instead of secretion or compartmentation [40].

Succulence aids them in resisting the salt induced toxicity which can even reach up to 60% of leaf dry weight [62]. *Suaeda* is a classic example of this category of halophytes which can tolerate very high levels of salt without external secretion [31, 63]. Several other succulent halophytes have been reported belonging to amaranthaceae family [26, 64]. *Sesuvium portulacastrum* is another typical example of succulent halophyte often called as euhalophyte which accumulates lot of salt in its succulent leaf tissue [65].

3.3 Photosynthetic adaptation in halophytes

Photosynthesis is the most vital physiological process in plants, which if affected by any kind of stress, leads to significant yield reduction. Under salt stress, stomatal conductance gets reduced in order to save water, so internal CO₂ also gets reduced leading to reduced photosynthesis [66]. This reduced CO₂ limits the dark reactions of photosynthesis and leads to accumulation of reducing powers in grana thylakoid, thereby damaging the photosystem [67]. The differential effect of salt stress on photosystem II activity of halophytes has been studied in *Spartina versicolor* as compared to the glycophyte *Cyperus longus*. *Cyperus* displayed a significant reduction in the activity of photosystem II (PSII) under salt stress, but on the contrary, *Spartina* did not show distinct reduction [68]. Moreover, a deeper mechanism oriented study showed that halophytes were able to absorb light even under high salt stress, indicating a much stronger PSII complex [69]. Proteomic study showed that the halophytic relative of wheat was able to accumulate more chlorophyll a-b binding protein (CP24) protein under high salt stress, which in turn stabilized the PSII complex [70]. The ability of halophytes to change their carbon assimilation pathways from C3 to C4 and even crassulacean acid metabolism (CAM) according to stress levels is highly unique and vital trait for tolerance to high salt stress [57]. Altogether, the ability to protect PSII from oxidative damage coupled with situation specific shift of carbon assimilation pathways is the photosynthetic adaptive mechanism in halophytes under salt stress.

3.4 Molecular signatures of halophytes

The unique molecular signatures of halophytes place them very high on the salt tolerance hierarchy as compared to glycophytes [71]. A concentrated effort is made to bring together diverse research attempts on the various signaling aspects under salt stress conditions in halophytes, starting from sensing, activation of downstream signaling elements and all other potential candidates in the salt stress signaling network. A much stringent regulation of gene expression has been reported in halophytes as compared to its glycophytic relatives. Research attempts to exploit the rich source of salt responsive genes and promoter regions of diverse halophytes have also yielded significant achievements in the recent past [72]. Moreover, halophytic gene sequences are more complex with the presence of transposons and intergenic sequences [73]. The copy number of genes related to salt tolerance is also high in halophytes as depicted by the presence of three copies of calcineurin B-like 10 (*CBL 10*) in *Thellungiella parvula* as compared to one copy in *Arabidopsis* [74]. *SOS1*, *NHX1* and many other salt stress related genes have constitutive expression in halophytes as compared to salt induced expression in *Arabidopsis* [75]. Further, the transcript abundance of H⁺ ATPase gene was low in the halophyte *Chenopodium quinoa* as compared to *Arabidopsis*, but the activity of the transporter protein was much higher, indicating some kind of post translational modification in halophytes [76].

4. Ecological and economic potential of halophytes and other saline vegetation

Harnessing the huge economic potential of the diverse halophytic plants and other saline vegetation is highly imperative to reduce the damage caused by soil and water salinization with special reference to the poor rural agrarian sector. This section of the chapter deals with the wide range of utilization of halophytes in various ecological zones of India as food, fodder, bio fuel, medicine and industrial raw

materials for mass production of various compounds. The commercially untapped economic potential of certain abundantly found halophytes are also discussed as a possible livelihood source to the resource poor farmers of these saline dry lands. The oldest known attempt to use halophytic plants was the utilization of *Alhaji maurorum* as a soil ameliorant. However, Israel has to be credited for the prolific rediscovery and utilization of halophytes in saline tracts [77]. The first half of this section deals with the prime potential of halophytes that has to be harnessed from a national point of view, relating to replanting and ecological recovery of barren saline dry tracts, cheap biomass for renewable energy, climate change mitigation, CO₂ sequestration and biological reclamation. The second part consists of the economic potential of halophytes related to use as food, fodder, medicine, chemicals, sea weed, mangrove based aquacultures etc. which can be a possible livelihood source to the resource poor farmers of these saline lands.

4.1 Halophyte mediated climate change mitigation

The climate foot print of present agricultural practices is univocally accepted to be similar to that of fossil fuel burning. The sustainability of current agricultural practices is questioned as they squander rich resources and acts as priming agents to global climate change [78]. So there has to be an inevitable change in the ethos of research and policy making to focus more on crops that grow well on limiting resources. Next generation agriculture should also be based on alternative crops like halophytes and mangroves which are water and nutrient use efficient and have sustainable yields across varying environmental conditions. The climate change mitigation potential of halophytes can be explained by just one example ie. *Suaeda fruticosa* that can survive and complete its life cycle under soil salinity of 65 dS m⁻¹, pH of 10.5 and under little or no water [79]. Such halophytes and other saline vegetation has tremendous potential in saving water, preventing soil erosion and replanting barren saline and sodic soils which is highly imperative in the current scenario of global change. Moreover, halophytes are suited to our brackish or saline water resources there by helping in fresh water conservation and replenishment. Scientific management of halophytic fields has tremendous potential to prevent further salinization of aquifers and groundwater of adjacent landscape. Due to climate change, global flood has become quite common and it is accompanied by post flood rise in water table and waterlogging. Under such situation, halophytes possess the ability to reduce saline water table and reclaim the affected land [53].

Mangroves species play a pivotal role in protection of our coastal ecosystem. The abundant aerial roots of these species are home to hundreds of creatures which are mostly endangered. Many species are true to sandy beaches and hence prevent soil erosion. More importantly, the role of mangroves as a livelihood to resource poor farmers cannot be underestimated [28, 80, 81]. As per National cyclone risk mitigation project (NCRMP), 308 cyclones of varying intensity impacted the eastern coast of India between 1981 and 2000. Extreme wave conditions are very common after effect of such cyclones originating in the Bay of Bengal [82]. As a result thousands of fertile agricultural land gets transformed in to wastelands. To cope with this, ICAR-CSSRI, regional research station (RRS), canning town, West Bengal developed a land shaping technology [83]. In this technique, land was converted in to medium ridge and shallow furrows where suitable halophytic tress along with paddy cum fish cultivation was practiced in *kharif* and in *rabi* season, furrows were used for rice cultivation [83]. Deep furrow and high ridge shaping technique was also practiced on coastal land of Sundarbans to overcome post cyclone stress [84]. Altogether, this technology plays a major role in rain water harvest, improved drainage and there by reduction in soil salinity and reduces environmental foot print by increased carbon sequestration.

4.2 Carbon sequestration potential of halophytes

Carbon sequestration is defined as the process of increasing organic carbon reserves by appropriate scientific land management interventions [85]. A much up scaled effort has to be put forth to harness more and more atmospheric CO₂ and store it in our soil. This has been reported to have enormous potential to reduce greenhouse gas (GHG) emissions [86, 87]. Halophytes helps in restoration of barren saline and sodic soils and sequester more and more carbon to enrich the organic carbon status of our infertile soils. ICAR-CSSRI has worked on the carbon sequestration potential of various agroforestry components in saline sodic soils. Results showed that these trees acts as carbon sink by virtue of their high growth rate, attractive wood and bio drainage properties. *Eucalyptus tereticornis* plantation was able to sequester 9.5 to 22.5 Mg ha⁻¹ carbon in different spacing and 90.6 Mg ha⁻¹ in block plantations along the canal after 6 years of planting in waterlogged saline soils of northwestern India [88–90]. Six years old *Eucalyptus tereticornis* plantation in sodic land showed a cumulative carbon stock (above ground biomass C+ below ground biomass C + soil carbon) of 122.6 Mg ha⁻¹ with CO₂ mitigation capability of 369.2 Mg ha⁻¹. Moreover, carbon storage in soil was found to be 44.4% higher in agri-silviculture as compared to rice wheat cropping system in partially saline and sodic soils [91]. Several other studies by ICAR-CSSRI research groups showed very high carbon sequestration potential of tree species like *Eucalyptus tereticornis*, *Syzygium cumini*, *Pongamia pinnata* and *Populus deltoides* [92, 93].

4.3 Source of bioenergy

The dream of producing bioenergy can only be conceptualized if we can identify alternate species that can grow and survive in barren saline and sodic soils and therefore, would not compete with our conventional agricultural components. Halophytes are potential candidates as bioenergy crops as they can be watered even with sea water without any significant reduction in biomass or seed yield. Second generation biofuels are the topic of discussion, where nonfood biomass is used as raw material for biofuel production. Four prominent raw materials used for second generation biofuel production in India are the lignocellulosic biomass of four halophytes namely *Pongamia*, *Jatropha*, *Panicum virgatum* and *Miscanthus* [94]. Two significant attributes of such fuels are reduced environmental foot print and improvement in soil quality [95]. The salt excluder category of halophytes is better suited to biofuel production as fouling is a common problem in fuel developed from salt accumulating halophytes as salt is non-combustible. The latest review on major halophytes used for second generation biofuel production in China is the benchmark reference [96]. *Salicornia* (glasswort), *Suaeda* (sea-blite), *Atriplex* (saltbush), *Distichlis* (arid salt grass) and *Batis* spp. are another set of promising halophytes rich in lignocelluloses content [26, 97]. Abundantly found halophytic species like *Salicornia*, sea grass along with two mangrove species, *Avicennia berminans* (black mangrove) and *Rhizophora mangle* (red mangrove) has found a place in the green lab of National Aeronautics and Space Administration (NASA), USA as a viable alternative energy resource [98]. Another innovative and attractive concept that has emerged is to develop an integrated seawater energy and agriculture system (ISEAS) where there will be a coupling of biofuel feed stock, aquaculture and mangrove silviculture for the ultimate aim of producing sustainable aviation fuel [99].

4.4 Phytoremediation potential of halophytes

Recently, large tracts of agricultural lands in arid and semiarid regions have been subjected to heavy salinization and heavy metal pollution, arousing serious health

and environmental concerns. Phytoremediation is defined as the use of plants to remove pollutants from soil and (or) render them harmless [15, 100, 101]. Deep rooted, high biomass producing accumulator category halophytes are potential candidates for phytoremediation of saline heavy metal contaminated soils [102]. It is cost effective and provides additional output in terms of forage [103]. The added advantage of halophytes in phytoremediation is its high tolerance to heavy metals and increased uptake of these heavy metals [104, 105]. Recent research attempts on halophytes mediated phytoremediation of heavy metal contaminated saline soils across the world are more in number indicating its environmental significance [106, 107]. Functional biology or potential of halophytes based studies also took place but are few in number [105, 108, 109]. Halophytes such as *Atriplex halimus* [110], *Spartina alterniflora* [111], *Sesuvium portulacastrum* [112] and *Tamarix africana* [113] are well proven examples in phytoremediation of heavy metal contaminated saline soils.

4.5 Halophytes: potential source of nutrition and value addition

It is next to impossible to grow conventional crops in the barren salt affected soils spread across the country which develop the gap of demand and supply of quality food in such areas. It ultimately creates barrier to food and nutritional security of the resource poor farmers living in such harsh areas. So halophytes have a huge potential as an edible source of nutrition there by securing livelihood of farmers. Such concept is gaining popularity very quickly and has spread across the world [101]. Among other salt tolerant crops, beetroot (*Beta vulgaris*), date palm (*Phoenix dactylifera*), amla (*Emblica officinalis*), karonda (*Carissa carandas*), guava (*Psidium guajava*), jamun (*Syzygium cumini*), pomegranate (*Punica granatum*), ber (*Ziziphus mauritiana*), bael (*Aegle marmelos*) and clusterbean (*Cyamopsis tetragonoloba*) are well known for their food value, and these are successfully grown in such saline soils using saline water irrigation. Also in India there is an extensive traditional use of non-conventional halophyte crops and naturally occurring halophytic vegetation as a nutrition source and further value addition (**Table 3**).

“Saji” or “barilla” is an indigenous value addition of locally available halophytes. It is the soda ash obtained from the air dried foliage materials of chenopod shrubs like *Haloxylon*, *Salsola* and *Suaeda*. It is an essential ingredient of papad, and contributes to organoleptic qualities in terms of crispness and expansion of fried papad. The local Rajasthani *Banwaria* community has expertise in making *Saji*. The *Saji* produced from *Khara lana* (*Haloxylon recurvum*) is of the best quality, whereas *Saji* produced from *Pichki lana* or *luni* (*Suaeda fruticosa*) is of medium quality, and that produced from *lani* (*Salsola baryosma*) is of inferior quality [121]. Another aspect on which ICAR-CSSRI has extended its research is edible cactus (*Opuntia ficus indica*) and its growth and yield potential under saline soils. Certain specific moderately salt tolerant clones have been identified for raised bed planting in saline tracts [122].

Moreover, around 50 species of seed producing halophytes are potential sources of edible oil and proteins. The best part of their use for oilseed is that they generally do not accumulate salts in their seeds. Prominent halophytes such as *Suaeda fruticosa*, *Arthrocnemum macrostachyum*, *Salicornia* spp., *Halogeton glomeratus* and *Haloxylon stocksii* have been reported to produce high grade edible oil with an unsaturation content of 70–80% [123]. Seeds of *Salvadora oleoides* and *S. persica* contain 40–50% fat and are a good source of industrially important lauric acid and myristic acids. Its purified fat is used for soap and candle making. *Terminalia catappa* (seed oil 52%) is another tree species widely used for edible oil production at industrial level. *Salicornia bigelovii* is another halophytic species used for

Plant scientific name/ common name	Plant parts	Nutritional aspects and uses
<i>Anthrocnemum indicum</i>	Phylloclades	Highly nutritious, used in pickles
<i>Amaranthus spinosus</i> (Kanta chaulai, kante bhaji)	Tender shoots, young leaves	High in Ca content, leaves cooked as vegetable, mature stems cooked with small fishes
<i>Aster tripolium</i> (Salt bush)	Leaves	Fresh salads, cooked vegetable
<i>Atriplex hortensis</i> (Pahari paleng)	Leaves	High nutritive value as a green leafy vegetable
<i>Balanites aegyptiaca</i> (Hingor, hingod)	Fruits	Both fresh and dried fruits are edible
<i>Beta maritime</i> (Palak)	Young shoots	Highly nutritious, consumed like spinach
<i>Borassus flabellifer</i> (Palmirah palm)	Edible radicles, fruits	Consumed as toddy, jaggery and vinegar
<i>Capparis decidua</i> (Kair)	Raw Fruits	Used as pickles and high medicinal values
<i>Carissa carandas</i> (Karaunda)	Fruits	Rich in iron, vitamin C, A, Ca and P, immature fruits are pickled and eaten raw.
<i>Centella asiatica</i> (Brahma manduki)	Leaves, young shoots	Widely used in Indian regional cuisines as a culinary vegetable.
<i>Chenopodium album</i> (Bathua)	Leaves, young shoots	High in protein, vitamin A, Ca, P, and K, cooked as vegetable, curries, raita and paratha-stuffed breads in northern India
<i>Corchorus capsularis</i> (Chanachedi, mora-pat)	Leaves, shoots, fruits	Rich in vitamins and minerals, used in salads, leafy vegetable
<i>Eleocharis dulcis</i> (Neerchelli)	Tubers	Rich in vitamin B ₆ , Mn, and K, tubers cooked
<i>Grewia tenax</i> (Gondni, kanger, kaladi)	Fruit, leaves, seeds	Fe-rich fruit, consumed raw or use as refreshing drink or porridge, leaves eaten as a green vegetable
<i>Haloxylon salicornicum</i> (Lana, khar)	Leaves, stem, seed	Fatty acids, vitamin C & A, used as salad and pickles, seeds mixed with bajra for roti making
<i>Hemidesmus indicus</i> (Anantbel, nannari)	Roots	Roots used for pickle, “nannari sharbat” also made from roots
<i>Leptadenia pyrotechnica</i> (Khimp, jivanti)	Pods	Pods are of medicinal value and used as vegetables in Rajasthan
<i>Morinda citrifolia</i> (Noni)	Fruit	Starvation fruit during famine, consumed as raw, pickled and used for extracting juice
<i>Nypa fruticans</i> (Nipa palm)	Young shoots, Fruits	Eaten as a green vegetable and the immature fruit is used in deserts
<i>Oxalis corniculata</i> (Amrit sak)	Young shoots, Leaves	Rich in vitamin C, Ca, beta-carotene and P, consumed as vegetables
<i>Pisonia alba</i> (Chandu, muruval)	Leaves	Leaves are eaten as a green vegetable
<i>Portulaca oleracea</i> (Lunia, badi-Noni)	Above ground part	Vitamin-rich with high omega-3 fatty acids, consume as a salad or with yoghurt
<i>Prosopis cineraria</i> (Khejri)	Pods	Pod called as Singhri or Sangri used in various types of bhaaji and kadhi in Thar desert of India
<i>Salicornia brachiata</i> (Umari keera)	Biomass	High protein edible oil similar to safflower, value- added by-products like vegetable salt
<i>Sesuvium portulacastrum</i> (Lunio, dhapa)	Leaves, stems	Rich in Ca, Fe, and carotene, consumed as vegetables by local peoples in arid region

Plant scientific name/ common name	Plant parts	Nutritional aspects and uses
<i>Suaeda fruticosa</i> (Khario luno)	Leaves, shoots	Protein rich, eaten by local people as vegetables
<i>Suaeda maritimum</i> (Luno, lano)	Young leaves	Leafy vegetable, can be used in combination foods as seasoning
<i>Suaeda nudiflora</i> (Morus)	Leaves	Pickles, salad, and as a vegetable
<i>Terminalia catappa</i> (Deshi badam)	Fruits	Sweet fruit and edible kernel
<i>Ziziphus nummularia</i> (Jhar beri, chanibor)	Fruits	Fruits eaten raw

Source: [114–120].

Table 3.
List of halophytes, other salt tolerant crops, their edible portion and nutritional properties.

commercial oil production in the western states of India. The seed (31% protein) is pressed for its high quality edible oil (28%) which is an alternative source of omega-3 polyunsaturated fatty acids [124].

Quinoa (*Chenopodium quinoa*) is another annual facultative halophyte which has every potential to become a highly economic crop in saline areas of India. The exceptional tolerance of this crop to soil salinity has already been reported [125]. Protein content of quinoa ranges from 12 to 17% depending on variety, environment and crop management practices [126]. This is higher than our conventional cereal crops like rice (6–7%), wheat (10.5–14%) and barley (8–14%). More importantly, it is rich in lysine and methionine which are the two amino acids absent in cereals and pulses respectively [127]. ICAR-CSSRI has initiated a network project on morpho physiological characterization and standardization of agronomic practices of quinoa (*Chenopodium quinoa*) for salt affected agro-ecosystems. Nineteen germplasm lines were evaluated under four levels of irrigation water salinity ie. best available water, 8 dS m⁻¹, 16 dS m⁻¹ and 24 dS m⁻¹. Germplasm EC 507740 gave maximum grain yield of 9.20 g per plant at highest levels of salinity (24 dS m⁻¹) [128].

“Kharchia 65” is a wheat race native to Pali district of Rajasthan which is commonly called as red wheat. It is universally recognized as highest salt tolerant genotype. This genotype has been extensively used in the development of salt tolerant wheat varieties by ICAR-CSSRI, Karnal, namely KRL1-4, KRL 19 and KRL 39. It is a universal donor to salinity breeding in wheat coupled with high yield and has been registered in ICAR- National Bureau of Plant Genetic Resources (NBPGR), New Delhi (registration number: INGR99020). The main reason for growing this wheat variety in the arid and semiarid regions of the country is that it is highly salt tolerant and requires very less water as compared to other hybrids and can also be grown as rain fed crop purely on conserved soil moisture. Another useful trait of this genotype is that the plants are tall with high straw content which can be effectively used as a fodder to cattle as it is much preferred by animals as compared to other wheat straw [129].

4.6 Silvipastoral system for ecological restoration of saline sodic soils

Biodrainage is a term that is getting more and more popularized which signify the use of salt tolerant trees and grasses for reducing salinity and waterlogging [130].

Apart from reclamation of these saline lands, silvipastoral system aids in improved carbon sequestration [131], increased soil rhizosperic activity [20], reduced greenhouse gas emissions [132] and long term adaptation to changing climates [133]. Mesquite (*Prosopis juliflora*) combined with Kallar grass (*Leptochloa fusca*) was reported to be a promising silvipastoral system in sodic soils [134]. Other successful silvipastoral combinations are *Acacia nilotica* + *Desmostachya bipinnata*, *Dalbergia sissoo* + *Desmostachya bipinnata* and *Prosopis juliflora* + *Desmostachya bipinnata* [134]. *Tamarix articulate* is another very productive halophytic tree species with a biomass production of 93 Mg ha⁻¹ in 7 years [135]. Aromatic grasses like lemon grass (*Cymbopogon flexuosus*) and palmarosa (*Cymbopogon martinii*) were studied by ICAR-CSSRI and found to be suitable to moderate alkali soils up to pH 9.2. Moreover, the most popular aromatic grass called vetiver (*Vetiveria zizanioides*) was found to be dual tolerant to high pH and waterlogged soils [136]. Licorice (*Glycyrrhiza glabra*) was reported by ICAR-CSSRI to be highly tolerant to sodicity level up to 9.8 [81]. Other promising grasses suitable to saline sodic soils are *Aeluropus lagopoides*, *Dichanthium annulatum*, *Chloris gayana*, *Bothriochloa pertusa*, *Eragrostis spp.*, *Sporobolus spp.* and *Panicum spp.* [130]. Other farmer preferred halophytes in saline sodic soils are *Ziziphus*, *Atriplex*, *Kochia*, *Suaeda*, *Salsola*, *Haloxylon* and *Salvadora* as they are preferably browsed by camel sheep and goat [137].

Salvadora persica is an oil yielding salt bush that has been extensively studied by ICAR-CSSRI. A *Salvadora persica* based silvipastoral system was developed and popularized with forage grasses like *Leptochloa fusca*, *Eragrostis sp.* and *Dichanthium annulatum* on the saline Vertisols of Gujarat, India [138]. This model was successful in saline soils of electrical conductivity ranging from 25 to 70 dS m⁻¹. Moreover, high biomass producing halophytic trees like *Acacia tortilis* (hybrid), *Ziziphus mauritiana*, *Pithecellobium dulce*, *Melia azedarach*, *Cassia fistula*, *C. javanica*, *Callistemon lanceolatus*, and *Acacia farnesiana* were popularized among the resource poor farmers of the saline and sodic soil tracts of northern India. The waterlogged soils of semiarid regions of northern India were also subjected to reclamation via *Eucalyptus* based agroforestry [81, 139]. *Eucalyptus tereticornis* was the preferred species. *Elaeagnus angustifolia* is another tree species recently found to be effective for bio drainage based on its water use efficiency, salt tolerance and growth rate [89].

4.7 *Salicornia*: a case study in western coasts of India

Salicornia is an obligate halophyte belonging to chenopodeaceae family commonly found at the edges of wetlands, marshes, sea shores, and mudflats [140]. It is commonly called as pickleweed, glasswort, sea beans and sea asparagus across India. Some species of *Salicornia* can even tolerate and complete its life cycle under 3% NaCl [141]. In India, this halophyte has been used as an edible crop as well as for non-edible purposes. Use of this plant as a source of soda for glass manufacture is time immemorial. *Salicornia brachiata*, a leafless shrub, was indeed the first source of salt produced from plants in 2003 by Council of Scientific and Industrial Research (CSIR)- Central Salt and Marine Chemicals Research Institute (CSMCRI), Gujarat, India. This vegetable salt, unlike common salt contains salts of potassium, calcium, magnesium and iron. On farm trials have shown that it has the potential to produce 3–4 tons of vegetable salt/hectare which can fetch a market of Rs 10–12 per Kg to the resource poor farmers of these barren saline tracts [142]. Further, recurrent selection mediated germplasm improvement was also carried out for better yield. In order to minimize the cost of cultivation, this species (improved variety: SOS 10) were sown in monsoon along the western coast of India in a large scale. Public private partnership based salt product named “*Saloni*” was also developed on a commercial scale in Gujarat [142].

Low content of seed sodium makes it a very good source for human heart, apart from its other medicinal properties against diabetes, asthma, hepatitis, gastroenteritis and cancer [143]. Moreover, the edible oil from its seeds is rich in poly unsaturated fatty acids and similar to safflower in fatty acid composition. It is also used as a green salad in the western areas of India. Antibacterial, antitubercular and antioxidant activities of *Salicornia brachiata* has been previously reported [144]. It is very popular and commonly used by villagers of western and eastern coast as an animal fodder, herbal salt and as a source of oil, while the ash of the whole plant has been reported to be useful in itch treatment [145, 146]. Most recently, prolific study on its polysaccharides and other phytochemical profile for phenolic compounds, oils, proteins, flavanoids, sterols, saponins, alkaloids and tannins are under way and shows promising results [147]. The oligosaccharide profiling of Indian species *Salicornia brachiata* was performed and the results showed this plant to be rich source of dietary supplements [148]. The ecological benefits of large scale cultivation of this plant along the coasts of India may be summarized as utilization of barren saline lands, upscaling of green belt, coastal development and protection and biodiversity conservation [89]. Finally, the equity benefits are vast export income and private industrial and institutional collaboration. So, this plant is a plant of future which needs special mention.

4.8 Medicinal halophytes: a formidable source of medicine, nutraceuticals and other products

One of the major physiological adaptations of halophytes to saline stress is the production of different biomolecules which possess highly useful biological activities like antioxidant, antimicrobial, anti-inflammatory and antitumoral [149]. So, if introduced in to our diet, it has the potential to prevent a lot of diseases like cancer and cardiac disorders [36]. These biomolecules also enhances the nutraceutical value of halophytes as the concentration is very high as compared to their glyco-phytic counterparts [150]. Moreover, certain biomolecules are specific to halophytes and hence have great agri food, pharmaceutical and cosmetic value [151]. Presence of a wide array of compounds like alkanes, fatty acids, carbohydrates, aminoacids, alcohols, terpenoids, flavanoids etc. have been reported from major halophytes [152]. Halophytes have long been used as folklore medicine by villagers and very little documentation is done in this aspect. A few glimpses off current use of halophytes as medicine in India is discussed here. *Salicornia* sp. is widely used as a folk medicine for constipation, diabetes and cancer [153]. *Suaeda* sp. and *Atriplex* sp. are widely known to possess hypoglycaemic and hypolipidaemic activities [154].

Catharanthus withstands EC of 12 dS m⁻¹ and produces about 130 *catharanthus* alkaloids compounds, including vinblastine and vincristine, two drugs used to treat cancer. Mangroves are also good source of biomolecules. For instance, the mangrove *Cynometra ramiflora* oil has antibiotic properties and is used in skin diseases [155]. Among other notable use of halophytes as medicine, use of *Pandanus odoratissimus* in leprosy, scabies, heart diseases, *Salvadora persica*, in cough, rheumatism, toothache and piles, *Salsola baryosma*, *S. kali* as anthelmintic, emmenagogue, diuretic, *Tamarix articulata* in eczema, ulcers, piles, sore throat, diarrhea, liver disorders and *Cress cretica* as tonic, aphrodisiac, stomachic deserves special mention [28]. Among other products, biopetrol/diesel from *Jatropha curcas* and *Euphorbia anti-syphilitica*, multiple bioactive compounds from *Salsola baryosma*, essential oil from *Pandanus* sp., *Terminalis catappa*, aromatic oil from *Grindelia camporum*, *Larrea tridentate* and *Simmondsia chinensis*, rubber from *Chrysothamus nauseosus* and *Parthenium argentatum*, multiple beverages from the mangrove palm *Nypa fruticans*, pulp and fiber from *Phragmites australis*, *P. karka*, *Juncus rigidus* and *J. acutus* deserves special mention [28].

4.9 Seaweeds: valuable resource pool

Sea weeds are an integral component of coastal ecosystems that lend invaluable support to the diverse marine life. The economic value of these sea weeds is of significant importance to the resource poor farmers of saline coastal areas. It is used as a food, but more importantly the phycocolloids derived from it is of significant export value [156]. In India, apart from phycocolloid production, sea weeds are being used for the commercial production of crop growth stimulating agents. Moreover, the agar and alginate industry full depends on this valuable coastal resource. Off late, they are extensively being explored for biofuel, nutraceuticals, medicines and food additives [157]. In Indian context, carrageenophytes (red sea weeds), *Gracilaria* spp. and *Gelidiella* spp. for agar production, *Sargassum* spp. and *Turbinaria* spp. for alginate production, *Kappaphycus alvarezii*, *Hypnea musciformis* and *Sarconema filiforme* for phycocolloid kappacarrageenan production is of major economic importance [156]. Another matter of pride for Indian Council of Agricultural Research (ICAR) is the endorsement of ICAR-CIFT (Central Institute of Fisheries Technology) by world health organization (WHO) to fight COVID-19 pandemic. The research group proposed that sulphated polysaccharide from seaweed can be a potent molecule to fight against the COVID-19 Pandemic, hence, is a candidate molecule to be studied against SARS-CoV-2 [158].

5. Conclusion and future ideas

Tangible evidences of global climate change and land degradation due to salinization are quite evident and so it is highly imperative to bring more and more salt affected land into cultivation to satisfy the food and nutritional security of our burgeoning population. In this context, halophytes and other saline vegetation has paramount importance to ensure economic returns and maintain ecological balance. India has a very rich source of halophytic, mangrove and other saline vegetation which has huge potential in monetary as well as environmental terms. It can reduce the gap between demand and supply of food and fodder for livestock, besides being a source to numerous other products of economic significance. The role of halophytes in climate change mitigation, carbon foot print reduction, renewable energy source and greening of our barren saline lands has to be conceptualized on field basis. Moreover, deteriorating water resources and lower availability of good quality water for agriculture demands a paramount shift to edible halophytic crops like quinoa, already being termed as super food, highly tolerant to drought and salinity stress.

Identification and documentation of region specific halophytes, access to seeds, establishment of halophytic nurseries, optimizing package of practice and development of processing plants are immediate requirements to spread the concept of halophyte based biosaline agriculture. Long term experiments are the need of the hour to prove the sustainability of halophyte based cultivation and economic security. More importantly, breeding programs should be initiated to improve traits such as yield, taste, biomolecule quantity and quality for faster adoption of halophyte based production. Another major issue to be tackled is the low or nonexistent demand on the market and a lack of value chain. For this consumer awareness need to be created and a value chain which consists of different players need to be established. Let us all hope that the ultimate dream of greening our barren saline lands and replenishing soils with saline water table in to sites of bio saline agriculture gets fulfilled in coming years as a boon to mankind.

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Conflict of interest

The authors declare no conflict of interest.

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