



Diversity and Utilization of Halophytes of Hot Arid Rangelands: A Review

J.P. Singh^{1*}, V.S. Rathore², S. Mangalassery³ and Devi Dayal³

¹ICAR-Central Arid Zone Research Institute, Jodhpur 342 003, India

²ICAR-Central Arid Zone Research Institute, Regional Research Station, Bikaner 334 004, India

³ICAR-Central Arid Zone Research Institute, Regional Research Station, Kukma-Bhuj 370 105, India

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Abstract: Increasing agricultural production to match the predicted population growth along with reducing availability of good quality land and water is an important challenge of 21st century. This challenge is particularly more relevant in arid regions characterized by water scarcity, poor soil and high biotic pressure. Livestock production is a major livelihood activity of hot arid region and rangelands are the backbone of the traditional pasture-based livestock rearing activity. Halophytes are a vital component of vegetation in hot arid rangeland. This review focuses on the diversity, economic and ecological significances of halophytes in Indian hot arid region and provides a comprehensive summary of utilization of halophytes for forage, feed, food, source of bioactive chemicals, oilseed, energy and bio fence purposes. The potential applications of halophytes for restoration of degraded lands have also been discussed. We argue that halophytes may be suitable alternative to augment availability of agricultural products along with many ecological services particularly in saline lands.

Key words: Halophyte, feed, hot arid India, ecological restoration, rangelands.

Rangelands provide multiple biological and social benefits which are a key component of global sustainability (Reynolds *et al.*, 2007; Munasinghe, 2009). They occupy about half of the terrestrial surface of the earth (Prentice *et al.*, 1992), support approximately 50% of the world's livestock (Briske and Heithmidt, 1991), contain 36% of the total biomass carbon (Solomon *et al.*, 1993) and sustain millions of people. In India, rangelands are the backbone of the traditional pasture-based livestock rearing activity which is the mainstay of the economy of the rural population. It is estimated that grasslands supply about 40% of the total available forage (Shankar and Gupta, 1992).

In India, rangelands occupy an area of 5,48,850 km² and covering 16.6% of country's geographical area (GOI, 2007). The economy of the hot arid region in Rajasthan and Gujarat is largely livestock-based, and animal husbandry is the major occupation of the people (Chaudhry *et al.*, 2011). In Gujarat about 8,490 km² area is under grassland and constitute 4.33% of the geographical area of the State. Although the grasslands in Gujarat is spread in 8 districts, majority of its area occur in Kachchh district spreading in an area of 5,077 km² which is 24% of the district area and amounting to 41.23% of

the total grassland area in Gujarat (GEER and GUIDE, 2011). Apart from being part of every ecosystem types in Kachchh, there are two major unique grassland ecosystems in Kachchh, viz. Banni and Naliya. Banni, once referred as Asia's finest grasslands cover an area of 2,617.72 km² constituting 51.56% grassland area in Kachchh whereas Naliya grassland covers 654 km² (12.89%) (Devi Dayal *et al.*, 2015). Rangelands covered ~5.5 million ha in western Rajasthan (Kar *et al.*, 2009) and a major source of forage supply. The majority of rangelands of the region are in a highly degraded state, especially due to unrestricted grazing by a large number of livestock, fuelwood collection (Kar *et al.*, 2009), wind erosion and land degradation (Singh and Singh, 2010). Tewari and Arya (2004) gave a detailed account of degradation of rangelands in arid regions of Thar desert. The grazing pressure was 0.87 ACU ha⁻¹ in 1981 against the optimum desirable density of 0.2 ACU ha⁻¹ for permanent pasture and other grazing lands of the arid zone of Rajasthan (Gupta, 2000). Estimates indicated that the pressure increased to 0.96 ACU ha⁻¹ in 1995 and 1.02 ACU ha⁻¹ in 2001. Further, rangelands in hot arid region face natural constraints like low and erratic rainfall, extreme temperatures, poor soil fertility, erosion hazards and depleted vegetation cover. Rangelands are in degradation

*E-mail: jai.singh@icar.gov.in

stage due to a combination of factors, viz. large livestock population, free range grazing, lack of management practices, clearing of browse shrubs etc. (Singh *et al.*, 2015a). Conversion of rangelands in arid regions to arable lands and developmental activities also affected the livestock productivity in rangeland based animal husbandry system.

Halophytes

Plant growth is affected by an array of climatic (temperature, precipitation, light, humidity, evaporation), edaphic (availability of moisture and nutrients, soil reaction, microbes, texture, structure, pollutants) and biotic factors. Near optimal conditions of these factors are rare in nature, hence plants suffer from one or other abiotic and biotic stresses during their life cycle. Salinity is one of the common abiotic stresses faced by plants, particularly in semi-arid and arid regions of the world, where annual evaporation exceeds precipitation. To survive under high salt concentration, some plant species evolved well- adapted morphological and physiological characteristics allowing them to proliferate under saline environment (Khan and Duke, 2001). Though the salt tolerance as a trait in plants has been recognized for >200 years (Flowers *et al.*, 1986), there is ambiguity of what constitutes a 'halophyte'.

Plant species show wide range of salt tolerance, for instance salt sensitive genotypes of chickpea showed inhibition of growth at 25 mM NaCl (Flowers *et al.*, 2010a). On the other extreme, *Anthrocnemum macrostachyum* can survive up to 1000 mM NaCl (Khan *et al.*, 2005). The different concentration of salt is used as criteria to divide the plants into halophyte and glycophyte, which results into different definitions, hence the number of halophyte plants species has varied enormously in literature. Aronson (1989) listed ~1550 species as halophyte using the salt concentration of 80 mM NaCl as criteria for grouping plant species into halophyte and glycophytes (salt sensitive plants). Menzel and Lieth (2003) reported ~2600 species as salt tolerant using the same criteria. Flowers and Colmer (2008) choose salt concentration of 200 mM for the purpose. Flower and Colmer (2015) described halophytes as plants that can tolerate salt concentrations ranging from 500 mM NaCl to 1000 mM NaCl. Flowers *et al.* (2010b) reported ~350 species as

halophyte applying the definition to Arnonson's (1989) database considering plants that survive to complete their life cycle in at least 200 mM salt. Number of halophyte species varied from as low as 350 (Flowers and Colmer (2008) to ~6000 (Le Houerou, 1996) due to use of different approaches in defining halophytes.

Though halophytes constitute a small fraction of total plant species, they represent a wide diversity in terms of plant forms and habitats. They have immense significance in context of expanding salinity problems and decreasing freshwater supply for agriculture. Halophytes seem to be an attractive option to produce fodder, food, fiber, oilseeds and biofuels on salt affected lands and by use of saline water. During last three decades the uses of halophytes are gaining momentum as a source of fodder (El-Shaer, 2003; Masters *et al.*, 2007; Mathur *et al.*, 2007, Singh *et al.*, 2009), oilseeds (Ruan *et al.*, 2008; Webber *et al.*, 2007; Reddy *et al.*, 2008), alkaloids (Gibbons *et al.*, 2000, Hussain *et al.*, 2008), biofuel (Qadir *et al.*, 2008), biomass for renewable energy (Dagar, 1995). Apart from direct use as various produce, they are also used for phytoremediation of salt affected soils (Qadir and Oster, 2002; 2004), decontamination of heavy metal polluted soils (Weis and Weis, 2004; Lewis and Devereux, 2009), lowering water table (Barnett-Lennand, 2002), restoration of overgrazed pastures (Peacock *et al.*, 2003), improving soil fertility (Qadir *et al.*, 2008), and carbon sequestration (Glenn *et al.*, 1993; Geesing *et al.*, 2000).

This paper is an attempt to describe the diversity and significances of halophytes of the hot arid region of India.

Diversity of Halophytes

The phylogenetically heterogeneous groups of plants which are native of saline habitats and can cope with or even require high salinity for optimal growth are halophytes. More than 2600 species of halophytes representing half of the plant families distributed globally have been reported (Panta *et al.*, 2014; Flowers and Colmer, 2015). Halophytes are generally classified into two categories, euhalophytes (most tolerant species, which require salt for optimal growth and have the ability to grow at concentrations up to 500 mM NaCl), and miohalophytes (less salt tolerant, which do not

show salt-induced growth stimulation (Brown *et al.*, 2014).

Sen *et al.* (1982) classified halophytes into three categories i.e. true, facultative and glycophytes (transitional halophytes). True halophytes are those species, which grow on saline soil (above 0.5% NaCl) and resist extreme saline conditions, e.g. *Salsola baryosma*, *Suaeda fruticosa*, *S. nudiflora*, *Haloxylon recurvum*, *Sporobolus helvolus*. The plant species which can grow and achieve optimal growth either in saline and non-saline soils or in saline soils upto 0.5% NaCl level e.g. *Salvadora persica*, *Tamarix aphylla*, *Portulaca oleracea*, *Chloris virgata* etc. are categorized as facultative halophytes. Glycophytes are those plant species which grow in the transition zone between saline and non-saline conditions and achieve optimal growth at non-saline niches of the salt basin, i.e. *Haloxylon salicornicum*, *Acacia jacquemontii*, *Gisekia pharnacioides*, *Boerhavia diffusa*, *Dactyloctenium scindicum*, *Ochthochloa compressa*.

We have employed the criteria followed by Dagar and Singh (2007) to delineate the diversity of halophytes in hot arid region and according to this criteria about 350 species of western Rajasthan (constituting >50% of the hot arid region) are salt tolerant. Out of the total salt tolerant plant species about 4, 24 and 72% are obligate, facultative and transitional halophytes, respectively. These salt tolerant species possess enormous taxonomical, plant forms and habitat diversity. Taxonomically, the species belonging to Poaceae, Cyperaceae, Chenopodiaceae and Asteraceae families constitute a major share in salt tolerant species of north-western hot arid regions of India. In herbaceous plant group, Poaceae is most abundant.

In case of woody perennial species of Chenopodiaceae, Tamaricaceae and Salvadoraceae families are important. The dominant herbaceous genera with the highest number of taxa are: *Sporobolus*, *Sesuvium* in true halophyte, *Cyperus*, *Heliotropium*, *Eragrostis*, *Pulicaria*, *Portulaca* in facultative halophyte and *Trianthema*, *Euphorbia*, *Indigofera*, *Aristida*, *Cenchrus*, *Corchorus* and *Tribulus* in glycophytes categories. *Haloxylon*, *Suaeda*, *Tamarix*, *Salvadora* and *Prosopis* are important salt-tolerant genera of shrub/trees.

The salt tolerant species of hot arid region exhibit considerable variability in plant forms.

Among the all three categories of salt tolerant species, herbs constitute $\frac{1}{2}$ to $\frac{3}{4}$ share followed by shrub. Trees in all three categories of salt tolerant groups constitute <10%. The important plants species of the region in three categories of salt-tolerant species are:

True halophytes

Grasses and herbs: *Aeluropus lagopoides* (Fig. 1A), *Sporobolus helvolus*, *S. ioclados* (Syn. *S. marginatus*), *Urochondra setulosa* (Fig. 1B), *Atriplex stocksii*, *Cressa cretica* (Fig. 1C), *Heliotropium curassavicum*, *Sesuvium portulacastrum*, *S. sesuvioides*.

Under-shrubs, shrubs and trees: *Haloxylon recurvum* (Fig. 1D), *Salsola baryosma* (Fig. 1E), *Suaeda fruticosa*. (Fig. 1F), *Suaeda nudiflora*, *Tamarix dioica*, *T. ericoides*, *Tamarix indica*.

Facultative halophyte species

Grasses and herbs: *Brachiaria ramosa*, *Chloris barbata*, *C. virgata*, *Dactyloctenium aegypticum*, *Digitaria ciliaris* (syn. *D. adscendens*, *D. pennata*, *Echinochloa colona*, *Eragrostis ciliaris*, *E. pilosa*, *E. tenella*, *E. tremula*, *Sporobolus coromandelianus*, *S. diander*, *S. maderaspatanus*, *S. tremulus*, *Cyperus bulbosus*, *C. compressus*, *C. conglomeratus*, *C. iria*, *C. rotundus*, *C. tuberosus*, *Kyllinga bulbosa* (syn. *Cyperus triceps*), *Pycnus flavidus* (syn. *Cyperus flavidus*), *Schoenoplectus grossus* (syn. *Scripus grosus*), *Cassia italica*, *Chenopodium album*, *C. ambrosioides*, *Chrozophora prostrata*, *Cleome brachycarpa*, *Convolvulus prostratus*, *Fagonia indica*, *Heliotropium bacciferum*, *H. marifolium*, *H. supinum*, *Portulaca oleracea*, *P. quadrifida*, *P. pilosa* (syn. *P. tuberosa*), *Pulicaria crispa*, *P. foliolosa*, *P. rajputanae*, *P. wightiana*, *Sphaeranthus indicus*, *Zygophyllum simplex* etc.

Under-shrubs, shrubs and trees: *Alhagi maurorum*, *Barleria acanthoides*, *B. prionitis*, *Withania somnifera*, *Aerva javanica* var. *javanica* (syn. *A. persica*), *Aerva javanica* var. *bovei* (syn. *A. pseudotomentosa*), *Capparis decidua*, *Haloxylon salicornicum*, *Opuntia dillenii*, *O. elatior*, *O. ficus indica*, *Periploca aphylla*, *Tamarix aphylla*, *Ephedra ciliata* (syn. *E. foliata*), *Prosopis chilensis*, *P. juliflora*, *Salvadora oleoides*, *S. persica*, *Tamarix aphylla* (syn. *T. articulata*), etc.

Glycophyte species

Grasses and herbs: *Aristida adscensionis*, *A. funiculata*, *A. hystricula*, *Cenchrus biflorus*, *C.*

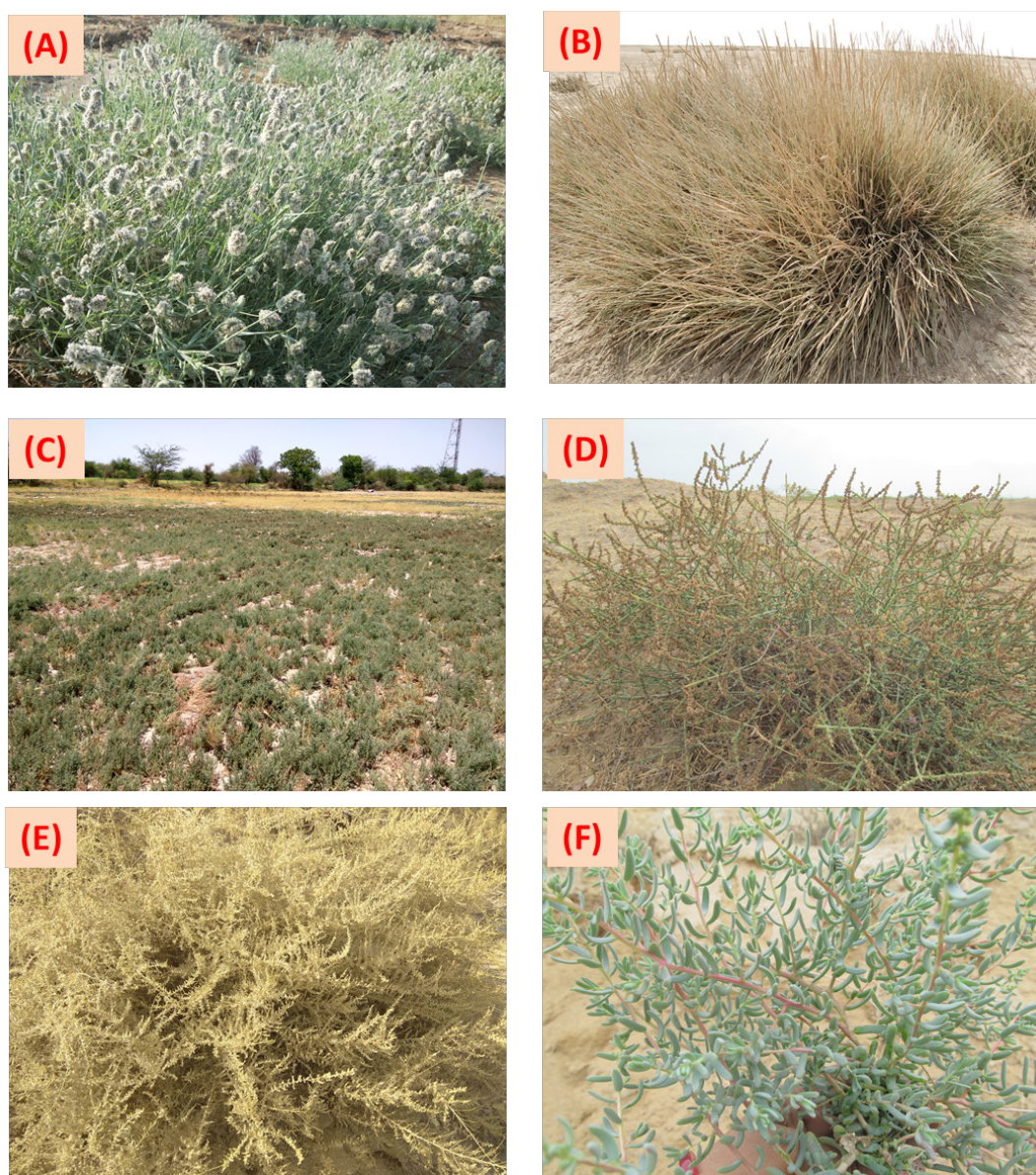


Fig. 1. Halophytes of hot arid region: (A) *Aeluropus lagopoides*, (B) *Urochondra setulosa*, (C) *Cressa critica*, (D) *Haloxylon recurvum*, (E) *Salsola barysoma*, and (F) *Suaeda fruticosa*.

ciliaris, *C. prieurii*, *C. setigerus*, *Dactyloctenium scindicum*, *Ochthochloa compressa* (syn. *Eleusine compressa*), *Panicum antidotale*, *P. turgidum*, *Saccharum spontaneum*, *Arnebia hispidissima*, *Bergia suffruticosa*, *Commicarpus verticillatus* (syn. *Boerhavia verticillata*), *Citrullus colocynthis*, *Corchorus depressus*, *C. tridens*, *Euphorbia granulata*, *E. heyneana* (syn. *E. microphylla*), *Farsetia hamiltonii*, *Indigofera cordifolia*, *I. sessiliflora*, *Peganum harmala*, *Polygala eriocarpa*, *Rhynchosia capitata*, *T. portulacastrum* L., *Tribulus pentandrus* (syn. *T. alatus*), *T. terrestris*, *Zaleya govinda* (syn. *Trianthemagovinda*), *Zaleya radimita* etc.

Under-shrubs, shrubs and trees: *Abutilon bidentatum*, *A. fruticosum*, *Taverneira cuneifolia*, *Abutilon indicum*, *Acacia jacquemontii*, *Calligonum polygonoides*, *Calotropis gigantea*, *C. procera*, *Clerodendrum phlomidis*, *Cordia gharaf*, *Grewia tenax*, *Indigofera oblongifolia*, *Leptadenia pyrotechnica*, *Lycium barbarum*, *Maytenus emarginatus*, *Mimosa hamata*, *Sarcostemma viminalis* (syn. *S. acidum*, *Sericostoma pauciflorum*, *Ziziphus nummularia*, *Cocculus pendulus*, *Maerua oblongifolia*, *Pentatropis spiralis*, *Pergularia daemia*, *Acacia nilotica*, *Prosopis cineraria*, *P. glandulosa*, *Tecomella undulata* etc.

Table 1. Botanical characteristics and usages of important halophytes of hot arid region

Species	Botanical description	Usages
<i>Haloxylon recurvum</i>	Family: Chenopodiaceae It is a leaf succulent, dwarf, branching perennial shrub. Stem is glabrous, pruinose, branches are divaricate, two at a node. Leaves are trigonous or semiterete, ovate-subulate or ellipsoid varying from 0.3 to 0.8 cm in length. Flowers are axillary, forming strict spikes, perianth segments somewhat fleshy, ovate, subobtuse; wing membranous. Seeds are orbicular, flattened having spirally coiled embryo. The perianth is brown light to dark pink. After fruiting on drying, plants turn blackish gray. It develops very deep tap roots.	Production of saji used for making Papad. Fodder for camel, goat. Ash as washing agent. The plant is traditionally used as an external application to treat insect stings. The ash of the plant is used to treat internal ulcers. (Singh <i>et al.</i> , 2005a; Rathore <i>et al.</i> , 2012).
<i>Suaeda fruticosa</i>	Family: Chenopodiaceae Silvery green, erect, much-branched shrub and turns black when dried. It has divaricately branched with glaucous stems. The leaves are blue-green, short petioled, glaucous, variable in size and shape (5-15 mm long and 2-6 mm wide), linear- oblong or obovate. Flowers are axillary, solitary or 2 to 5 together arranged in loose, leafy spike inflorescence. The perianth is parted into five equal green sepals united at the base, with 3 yellow stigmas. The seeds are obliquely ovoid, smooth and shiny black.	Leaves with young shoots used as vegetable, browsed by wild animals and livestock. Also used for low grade saji production. Plant is traditionally used for treating digestive disorders.
<i>Salsola barysoma</i>	Family: Chenopodiaceae It is low to high growing, much branched spreading shrub. The stem is slender and twiggly, new shoots are bright and reddish. Branchlets broadly ovate or orbicular, fleshy as large as the perianth lobes or shorter. The leaves which are triangular and scale-like appear in clusters of small balls. They are minute, alternate, sub-orbicular and fleshy. The flowers form dense cylindrical spikes, solitary in the axil of leaves. Perianth oblong, rounded at the apex; wings horizontal, attached to the middle to the back of perianth, flat, membranous, white shining. Fresh plants give peculiar unpleasant odour of rotting fish when crushed particularly when in flowering stage.	Browsed by animals. Production of low grade saji (Singh <i>et al.</i> , 2005a). Green foliage of <i>Salsola barysoma</i> could be an alternate feed resource to goats during drought in arid region (Mathur <i>et al.</i> , 2007).
<i>Salvadora persica</i>	Family: Salvadoraceae Much branched, large straggling shrub or evergreen small sized tree having spreading or dropping glabrous, more or less glaucous branches. Leaves are opposite, elliptic, lanceolate or ovate, obtuse and often mucronate at apex. Flowers are greenish, yellow in axillary and terminal compound inflorescence. Fruit is berry (6-7 mm diameter), globose smooth, red when ripe. Seeds are 1-4 mm diameter, sub-globose, smooth and brown.	Ripe fruit are eaten fresh. Browsed by animals. Bark extract is used in toothpaste preparation. Stem bark is used in gastric troubles (Jindal <i>et al.</i> , 2005).
<i>Cressa cretica</i>	Family: Convolvulaceae A perennial, erect dwarf branched herb. Roots are horizontal, geminate, with lateral branches. Stem is erect at initial stage and then become decumbent. Leaves are lanceolate, ovate or elliptic- to scale-like, sessile, or shortly petiolate. Flowers are solitary, axillary, 5-8 mm long, sessile or on short peduncles. Fruit is capsular, ovoid, unilocular, 2-4-valved, and generally one-seeded. Seeds are 3-4 mm long, glabrous and smooth, and shining to reticulate, dark brown.	Grazed by animals. Plant is used as anthelmintic, stomachic, tonic and aphrodisiac purposes, enriches the blood, and is useful in constipation, leprosy, asthma, and urinary discharges, in the treatment of diabetes and general debility (Chopra <i>et al.</i> , 1956).

Botanical characteristics along with main usages of important halophytic species of hot arid region of India are presented in Table 1.

Evaluation of Diversity in Halophytic Species

Chenopod shrubs (*Haloxylon*, *Salsola* and *Suaeda*) are important halophytic plant species

of hot arid regions. ICAR-CAZRI collected the germplasm and evaluated the diversity of these shrub species. *Haloxylon recurvum*, native of salt deserts and thrives on the saline depressions in western Rajasthan shows considerable diversity in plant form, perianth color and seed weight. Light to dark pink perianth was observed in its natural population. The 100-

seed weight (dehusked seed without perianth) ranged from 0.240-0.256 g. Two plant types of *Salsola baryosma* i.e. tall and short were noticed in natural habitats. Those plants which are collected from the Lunkaransar (Bikaner) and Suratgarh (Sriganganagar) are tall type; while from Phalodi (Jodhpur) was the short one. The 100 seed weight (husked seed with perianth) of *S. baryosma* ranged from 0.038-0.057 g.

Halophytes in Saline Deserts of Kachchh, India

A field survey conducted at saline desert of Great Rann of Kachchh revealed occurrence of 13 grass species and 55 non-grass halophytes during summer months of 2014. Some common plants are: *Aeluropus lagopoides*, *Sporobolus marginatus*, *Suaeda nudiflora*, *Cressa cretica*, *Salvadora persica*, *S. oleoides*, *Cyperus* spp. etc. A unique halophyte of remarkable salinity tolerance observed was *Urochondra setulosa*. The survey conducted at Ranns of Kachchh showed that it is primarily distributed in Great Rann and Little Rann of Kachchh. The studies conducted at Ranns showed that *U. setulosa* grows profusely in soil with electrical conductivity values of 69.7 dS m⁻¹ at surface to 5 cm depth. It is mostly observed as pure stand in extreme saline areas where no other plant species survive. In areas of relatively low salinity in Great Rann it was found to be associated with other halophytes such as *Suaeda nudiflora*, *Aeluropus lagopoides* and *Sporobolus marginatus*. In Kachchh, *A. lagopoides* reported to occur at soil salinity values as high as 27.7 dS m⁻¹, *S. marginatus* upto 83.1 dS m⁻¹. The halophyte *S. nudiflora* was observed at soil salinity values upto 9.9 dS m⁻¹ and *Cressa cretica* upto 27.2 dS m⁻¹ (Mangalassery *et al.*, 2017a and b).

Utilization Potential of Halophytes

Utilization of *Alhagi maurorum* by the Sumerians as a soil ameliorant is the oldest report on the use of halophytes (Khan and Ansari, 2008). In recent times the credit is given to the Israelis for utilization of halophytes with saline water and salt affected lands (Boyko, 1964), subsequently, their utilization gained momentum in other countries also (Khan and Weber, 2006; Yensen 2006; Khan *et al.*, 2006; Glenn *et al.*, 1996; 1999; O'Leary, 1984) etc. The brief description of utilization potential of halophytes is as under:

Fodder and feed: One of the greatest potential of halophytes probably rests in their utilization as forage and fodder (Pasternak, 1990; Khan and Ansari, 2008). This is particularly relevant to arid and semi-arid regions where the halophytes are most abundant and livestock population is high. Rathore *et al.* (2011) demonstrated economic significances of halophytic shrub species. *Haloxylon* spp. and *Kochia* spp. are used as forage in many parts of the world. In Iran, *Spartina* and *Salicornia bigelovii* in USA, *Atriplex* spp. in Argentina and Australia. The planting of halophytes for fodder supply is recognized as an attractive and accepted option in low rainfall saline areas of Australia and the countries of North Africa (Glenn *et al.*, 1996; Malcolm, 1996; O'Leary, 1984). The halophytes are grazed and browsed, and thus contribute directly to the pastoral value of rangelands of the hot arid region of India. The grasses like species of *Sporobolus*, *Aeluropus*, *Chloris* etc. are grazed by animals. The Chenopod shrubs like *Haloxylon recurvum*, *S. salicornicum*, *Salsola baryosma*, *Suaeda fruticosa*, *S. nudiflora* are important source of fodder for camels. *Salvadora oleoides* and *S. persica* used as forage for cattle, goat and camel. *Haloxylon recurvum* is a potential fodder during the summer period in the region. It contains 13.3% crude protein, 20.7% crude fibre, 62.9% total carbohydrate and 58.2% neutral detergent fibre NDF (Mondal *et al.*, 2005). Feeding experiment conducted at ICAR-CAZRI, RRS, Bikaner revealed that it could be fed to goat by mixing with other palatable roughage (Mondal *et al.*, 2005). Seeds of *H. salicornicum* can be used as an alternative concentrate feeds to cattle and camel (Singh *et al.*, 2009). In coastal areas *Avicennia*, *Aegiceras*, *Cerops*, *Rhizophora* spp. are consumed extensively as forage by camels (Dagar, 1995, Khan and Aziz, 2001). Considering the acute shortage of fodder in the region, the role of halophytes to augment fodder availability is enormous.

Food: Wild salt tolerant plant species are used as a food/vegetable in the region. A number of herbs like *Sesuvium portulacastrum*, *Portulaca oleracea*, *P. quadrifida*, are used as vegetable in the region. The green shoots of *Suaeda fruticosa* are also used as vegetable in the Salsette Island in Maharashtra and sold in the market (Shah, 1984). The seeds of *Haloxylon salicornicum* are used for making *Chapaties* (breads)

with pearl millet. Various species of halophytes, viz. *Chenopodium*, *Salicornia* and *Suaeda* are also used as salads and vegetables worldwide (Panta *et al.*, 2014).

Oil and waxes: Halophytes are used as a source of oils, both for human consumption and industrial uses. Examples of halophytes as the potential oilseed crops are *Kosteletzkya virginica* (Ruan *et al.*, 2008); *Salicornia bigelovii* (Glenn *et al.*, 1991) and *Salvadora persica* (Reddy *et al.*, 2008). Webber *et al.* (2007) examined the potential of seeds of *Arthrocnemum indicum*, *Alhagi maurorum*, *Cressa cretica*, *Halopyrum mucronatum*, *Haloxylon stocksii* and *Suaeda fruticosa* as a source of edible oil and these species contain 22 to 25% oil with 65-74% of unsaturated fatty acids. They suggest that the seeds of these halophytes particularly *S. fruticosa* could be used as a source of oil for human consumption. Seeds of the *Salvadora oleoides* and *S. persica* contain 40-50% fat and are good source of lauric acid. Seeds of *S. persica* are rich in protein (15-18%) and potential species for oil production in salt-affected lands of arid regions.

Medicine: Wild salt tolerant species are traditionally used to cure diseases and ailments. *Cressa cretica* is one of the important medicinal herbs used in numerous indigenous medicines as anthelmintic, stomachic, tonic, aphrodisiac, and also in leprosy, asthma and urinary disorders (Kirtikar and Basu, 1935). Woody perennial (shrub/trees) salt-tolerant species like *Haloxylon recurvum*, *Salsola baryosma*, *Salvadora oleoides*, *S. persica*, *Tamarix* spp., *Alhagi maurorum*, etc. have been used for curing disease and disorders. *S. persica* is widely used in toothpaste preparation (Jindal and Singh, 2005). Plant ash of *Haloxylon recurvum* is traditionally used in skin diseases, wounds, burns, itches, etc. and also used to cure ulcers (Bhandari, 1990; Gilani and Shaheen, 1994). *Alhagi maurorum* is considered to be the source of 'Manna' of the Bible (Paris and Dillemann, 1960), but other authorities, however, are more inclined to favor lichen i.e. *Leconora esculenta* or the excretions of *Tamarix mannifera* as 'Manna'. *Alhagi manna* is one of the principal laxative and purgatives in the compendium of Persian remedies. Tender shoots of *Suaeda fruticosa* are used as vegetable to cure indigestion and flatulence. *Salsola baryosma* is used as a vermifuge (Kirtikar and Basu, 1935). Salsoline obtained from *Salsola*

have hypotensive property similar to papaverin (Paris and Dillemann, 1960). Salsolic acid, a new oleanane type triterpene has been isolated from *S. baryosma*. The compounds showed inhibitory activity against the enzyme butyrylcholinesterase (Ahmad *et al.*, 2007). Ahmad *et al.* (2008) reported that Salsolins A and B along with 2- α , 3 β , 23, 24-tetrahydroxyurs-12-en-28-oic acid compounds showed significant antioxidant activity.

Fuel wood: Fuel wood is a major source of energy in hot arid region. Halophyte species like *Tamarix*, *Salvadora* are important source of fuel wood. Dagar and Singh (2007) reported that *Tamarix aphylla* can produce 87 t ha⁻¹ biomass on soil having pH 10 or more and advocated the species as a source of biomass energy on highly alkaline soils. The systematic planning of vast salt affected lands for biomass energy plantation is suitable option to overcome the fuel wood deficiency in the hot arid region.

Biofuel: Use of halophytes as biofuel crops on marginal agricultural land would help to counter the concern that biofuel industry reduces the amount of land available for food production (Qadir *et al.*, 2008). *Euphorbia antisiphilitica* is one of the potential biofuel plant species that can be grown successfully in salt-affected lands with saline water irrigation (Dagar and Singh, 2007).

Bioactive compounds: *Salsola baryosma* is the source of bioactive compounds. Singh *et al.* (2015b) gave a detailed account of bioactive phytochemical obtained from *H. salicornicum*. Gibbons *et al.* (2000) and El-Shazly *et al.* (2005) isolated alkaloids from *H. salicornicum*. Ferheen *et al.* (2005) obtained hypoxigenase inhibiting glycosides and naphthene derivatives from *H. salicornicum*. Recursterol A and B and C-24 alkylated sterols isolated from *H. recurvum* (Hussain *et al.*, 2008). *In vitro* anti-tuberculosis activities of the constituents isolated from *H. salicornicum* from Pakistan is reported (Bibi *et al.*, 2010). *Haloxylon recurvum* showed anti-fungal properties and inhibited growth of *Alternaria solani* (Gehlot and Bohra, 1997). The isolation of bioactive compounds having different uses expands economic potential of halophytes.

Industrial products: Halophytes like *Haloxylon recurvum*, *Salsola baryosma* and *Suaeda fruticosa* have been used for producing 'saji', which is a mixture of sodium and potassium bicarbonate

and extensively use in local *papad* industry (Singh *et al.*, 2005a; Rathore *et al.*, 2012). The saline wastelands unsuitable for crop cultivation can be utilized for growing *H. recurvum* (Rathore *et al.*, 2008), which gives remunerative returns to the farmers of the region. Purified fat obtained from seeds of *Salvadora oleoides* and *S. persica* is used for making soap and candles and considered potential substitute of coconut oil in soap industry.

Ecological Significance of Halophytes

Apart from direct use of halophytes, this group of plants is also being targeted for environment restoration purpose. The ecological significance of halophytes is as under:

Restoration of degraded land: The potential of halophytes in bioremediation is well illustrated by Qadir and Oster (2004) who compared results of 14 experiments with gypsum application versus vegetative reclamation of sodic soils. Yunusa and Newton (2003) also advocated the use of halophytes for improvement of saline soils as compared to chemical amendments. They found that bioremediation reduced sodicity throughout the root zone where gypsum was effective only in the layer where it was applied. Furthermore, phytoremediation improved soil structure and formed macro-pores enhancing air and water infiltration. Qadir and Oster (2002) advocated phytoremediation of salt-affected soils due to low initial capital input, more uniform and greater zone of reclamation, promotion of soil aggregate stability and creation of macro pores, and financial benefits from plants grown during reclamation. In natural habitats of hot arid region, the soil under canopy of *H. recurvum* showed lower pH (8.8), EC_2 (1.01 dS m^{-1}) and higher carbon (0.28%) as compared to soil in open area having pH 9.1, EC_2 1.21 dS m^{-1} and organic carbon 0.16%. These results show that the species has ability to reduce the pH, salinity and is thus a potential species for phytoremediation of salt-affected soils.

Desertification is one of the main types of land degradation in arid and semi-arid areas. Numerous studies have shown that the shrub plantation improves soil properties and microclimatic conditions beneath their canopies compared to open spaces, particularly and may act as 'resource islands' for understory herbaceous plants in arid and semi-arid areas

(Reynolds *et al.*, 1999). These 'resource islands' are of great importance for the rehabilitation of desertified lands because they can act as a starting point for natural succession by facilitating the growth of other plants (Gomez-Aparicio *et al.*, 2004). Results of ICAR-CAZRI indicated that establishment of *H. salicornicum* increased silt + clay content, enhanced water holding capacity, organic carbon, available nitrogen, available phosphorus, and electrical conductivity; and decreased pH, and bulk density. Compared to open area, the surface soils (0-5 cm) under its canopies had 69, 47, and 41% higher organic carbon, available nitrogen, and available phosphorus, respectively. Furthermore, density and biomass of herbaceous plants in alleys of *H. salicornicum* was 1.2 and 1.6 fold greater than open area (Rathore *et al.*, 2015).

Decontamination of heavy metal from soil: Rapid industrialization since mid-20th century has led to an enormous increase of production, use and release of trace heavy metals into the environment, and these pose serious threats to human health and biodiversity. There are evidences that showed that halophytes are capable of extracting heavy metals from sediments and accumulate them in tissues (Weis and Weis, 2004; Cambrolle *et al.*, 2008; Lewis and Devereux, 2009). Chenopod halophytic shrubs can be used as bioindicators of heavy metals. Al-Khateeb and Leilah (2005) reported that *Haloxylon salicornicum* and *Salsola baryosma* accumulated Mn. Zn concentration was also high in *S. baryosma*.

Biofence: Biofence is an integral component of traditional farming systems of the arid region. Besides providing protection to crops against wild and stray animals, it provides economic products and promotes biodiversity and helps in minimizing wind induced soil erosion. The salt tolerant woody species like *Salvadora persica*, *Tamarix* spp., can be utilized as biofence.

Wind break/Shelterbelt plantation and Sand dune stabilization: The vegetative belts protect the soils from wind erosion and minimize the adverse effects of hot winds on agricultural crops in arid regions. The salt tolerant species like *Tamarix aphylla* are suitable species for wind break/shelter belt plantations. Some halophytic taxa like *H. recurvum*, *H. salicornicum* can be used in erosion control in sand dune areas, interdunal

plains because of their spreading canopy and deep root systems.

Carbon sequestration: The rapid increase in atmospheric CO₂, an important greenhouse gas has aroused concern about its role in climate change. Sequestering carbon in the biomass could help to mitigate the adverse effect of anticipated climate change. It has been suggested (Ayoub and Malcolm, 1993; Glenn *et al.*, 1993) to use halophytes for capturing and long-term sequestering of atmospheric CO₂, to alleviate the greenhouse effect. Saline lands provide an opportunity to use halophytes for this purpose in hot arid region. Here it is worth mentioning that halophyte biomass decomposes slowly in dry land, favoring the long-term sequestration of captured carbon.

Other Significances

Landscaping/Amenity plantation: Natural habitat of halophyte species can be preserved for their aesthetic beauty. Salt tolerant species of hot arid region like *Haloxylon recurvum*, *H. salicornicum*, *Suaeda frutioca*, *Salsola baryosma* have attractive floral shoots at fruiting stage, which can be utilized for decorations. Diversity of perianth colour in *Haloxylon recurvum* can also be utilized for ornamental purpose. In *H. salicornicum*, a variety of colors in perianth, viz., white, creamy white, pink, light pink, light pinkish white etc. were observed in different accessions. A wide variation in the plant types among and within accessions was noticed and some of them exhibited ornamental look during both vegetative and flowering stages. Therefore, research attention is required to explore and improve the ornamental value of this species (Singh *et al.*, 2005 b). Moreover, due to less water requirement as compared to other conventional ornamental species, halophyte shrubs can be utilized for landscaping of saline patches and also in areas of saline irrigation water.

Gene bank for salt tolerance: Khan and Duke (2001) opined that halophyte has enormous potential to serve as an essential gene bank from which economically viable cash crops could be developed. In order to realize this goal, the ecology and physiology of these plants must be thoroughly investigated. Although there are many aspects of the physiology of salt tolerance that are not yet understood. Compartmenting of ions for osmotic adjustment,

the synthesis of compatible solutes, the ability to accumulate essential nutrients in presence of high concentration of the ions generating salinity, the ability to continue to regulate transpiration in presence of high concentration of Na⁺ and Cl⁻ (Flowers and Colmer, 2008) are some of the traits that alone or in combination imparts tolerance. Furthermore, salt tolerance is often part of multi-faceted syndrome that may include, for example, flooding (Colmer and Voesenek, 2009) and drought. Indeed, physiological response to salinity is often similar to responses to other environmental stresses (Munns and Tester, 2008) and may rely on common stress-tolerance pathways (Tuteja, 2007). The identification of trait associated with salt tolerance in halophytes and their transfer to other crops for enhancing salt tolerance through modern biotechnological and genetic engineering techniques are of great importance more so in view of expanding salinity problems and declining fresh water availability for agriculture in the future.

Conclusions

Rangelands of hot arid regions of India are endowed with rich diversity of salt tolerant plant species. These species vary considerably with respect to taxonomy, plant forms, salt tolerance and habitat. The halophytes besides providing a variety of economic products, performs vital ecological functions and thus helps to maintain ecological stability of the fragile arid ecosystem. The use of halophytes as alternate fodder and feed has special significance for the arid region, because animal husbandry is the mainstay of the agrarian economy of the region and fodder deficit is the most important constraint of sustainable livestock production of the region. The results of several feeding experiments to utilize the halophyte as alternative fodder are encouraging, and there is a need to work out the feeding value, optimum mixing ratio of these species to be used for fodder supply.

The economic potential of halophytes as a source of *saji*, oil, wax, biofuel and bioactive compounds requires attention. There is need to identify the suitable habitat, fine tune management practices, product extraction techniques along with effective marketing of economic products. Species of *Salvadora* are important in arid regions as valuable multi-purpose species to alleviate soil degradation

and desertification, which can be used for food, fodder, oils, soap and candle making and climatic protection, and hence deserves special attention.

As other plant communities, halophyte vegetation is also facing threats due to over-exploitation, invasion of alien species and impacts of climate change. In view of the socioeconomic and ecological role of halophyte species in the hot arid fragile ecosystem, it is imperative to preserve their natural habitats and conserve, collect and evaluate the available germplasm of salt tolerant species for ensuring sustainability and also to mitigate the impacts of climate change.

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