Halophytes: Biology and Economic Potentials

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Abstract: Halophytes are flowering plants which are naturally found in saline habitats such as coastal swamps, coastal dunes, inland salt flats, playas and lands ruined by mal-agricultural practices. They have evolved a number of strategies to survive and reproduce under highly saline conditions where most plants cannot. These strategies range from numerous changes at cellular/molecular level to several morpho-anatomical adaptations. By utilizing combinations of such strategies, halophytes thrive under highly saline conditions and some can even grow better in the presence of salt. A number of these highly salt tolerant plants have several economic utilities and could be cultivated as food, fodder/forage, fuel and medicinal crops on saline lands with the help of salty water irrigation. Several potential crops among local halophytes have been identified and reported by Institute of Sustainable Halophyte Utilization, University of Karachi. However, further research is required to shape these candidate plants as proper crop. In addition research based investment would accelerate this developmental process enormously and make it a highly profitable venture, therefore both government and public sector should be encouraged to play their roles.

Key Words: Halophyte, Salt tolerance, Fodder, Edible oil, Biofuel, Medicine.

INTRODUCTION

Soil salinity is an ever increasing threat to agriculture, which has already destroyed about 20% of the irrigated agricultural lands worldwide [1]. This increasing soil salinization is contrary to the food production for burgeoning human and their livestock populations [2] because most plants including conventional crops cannot withstand even low ($\leq$ 40 mM NaCl) salt concentrations [1]. However, halophytes constitute a small but diverse group of flowering plants which not only survive but also grow and reproduce in highly saline ($\geq$ 200 mM NaCl) environments [3-4]. These plants are distributed in a variety of saline habitats (Fig. **1**), ranging from coastal salt marshes, dunes and mudflats to inland salt deserts/flats and dunes [5] and have evolved a number of mechanisms to meet requirements for survival under such hostile conditions [6-7]. Many of these plant species, called euhalophytes or obligate halophytes, can even grow better under saline conditions and therefore could serve as model organisms to understand mechanisms of high salt tolerance.

Despite high salt tolerance, little attention has been given to halophytes and most studies on salt tolerance involved glycophytes (salt-sensitive plant species) including most crops. However, due to remarkable economic potentials, halophyte biology is gradually gaining momentum and many halophytic plants such as *Thellungiella salsuginea* (described initially as *T. halophila*), *Mesembryanthemum crystallinum* and *Suaeda salsa* [8- 9] have been adopted as models for understanding high salt tolerance. Halophytes may also serve as donor organisms for high salt tolerance genes for the development of salt tolerant transgenic crops in future [10-12]. The objective of this review is to discuss the salt tolerance mechanisms and economic potentials of halophytes with special emphasis on subtropical species, which are in addition high temperature and drought tolerant due to their natural origin in warm/dry subtropical conditions such as prevailing in southern Pakistan.

Salt Effects on Plants

Salinity, the high salt contents of soil, affects plants initially by decreasing soil water potential thereby limiting water uptake by plant roots [13]. Prolonged exposures of plants to soil/water salinity result in excessive entry of Na^+ in to plant body which is toxic and interrupts plant metabolism [13]. These direct effects lead to lower CO_2 fixation than light absorbed by plant photosynthetic machinery, leading to excessive production of reactive oxygen species (ROS) such as superoxide radicals (O_2^{-1}), hydrogen peroxide (H_2O_2) and hydroxyl radicals ($^{\cdot}OH$), which are potentially cyto-toxic [1, 14-15]. Excess ROS are reported to damage important cellular proteins, membrane lipids, chlorophyll and even nucleic acids and if not controlled may cause plant death. Tolerant species such as halophytes employ a number of strategies to address aforementioned problems and can therefore survive under highly saline conditions [3, 16-17].

Salt Tolerance Mechanisms of Halophytes

Salt tolerance of halophytes varies among species [4, 18-19]. For instance *Sporobolus ioclados* barely survived seawater (500 mM NaCl) salinity [20] while extreme halophytes such as *Arthrocnemum macrostachyum* [21-22] and *Suaeda fruticosa* [23] can tolerate as high as 1000 mM

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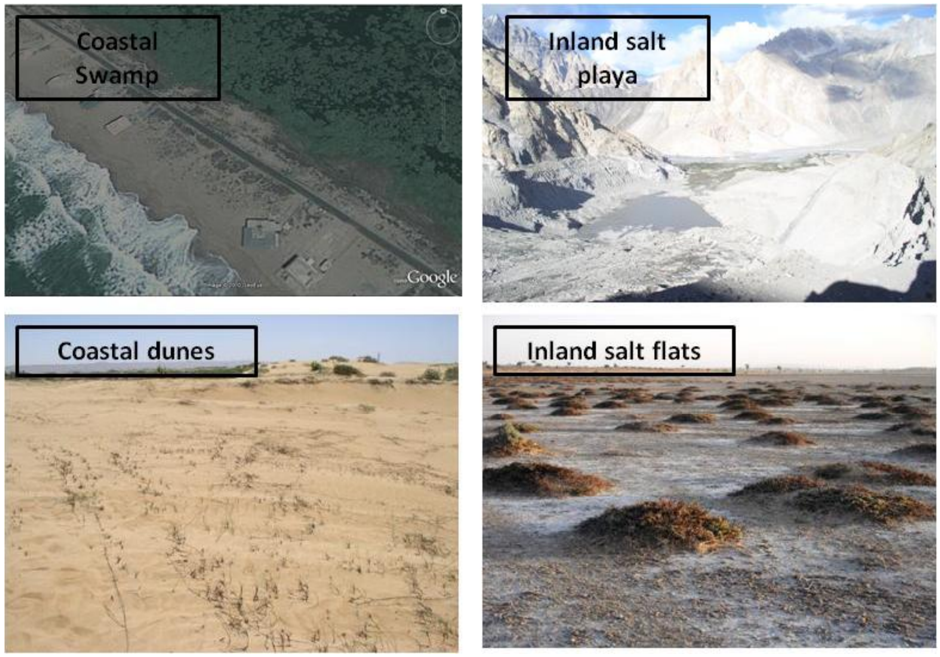

Fig. (1). Some typical halophyte habitats.

NaCl. Salt tolerance of halophytes also varies among different stages of a plant's life cycle and seed germination is generally considered as more sensitive to salt than the mature plant growth for a given species [19]. For instance, *Suaeda fruticosa* a leaf-succulent halophyte can tolerate only 500 mM NaCl at germination stage [24] while mature plants can withstand about 1000 mM NaCl in the growing medium [23]. Despite these differences, many dicotyledonous halophytes are reported to grow optimally in NaCl concentrations ranging from 50 to 250 mMNaCl while monocotyledonous halophytes grow optimally in absence of salinity or sometimes in low ($\leq$50 mM) concentration of NaCl [3]. Mechanisms underlying this growth stimulation by salt are not well understood and could be related to increase in succulence (to dilute accumulated Na^+) and/or dry weight (by accumulating protective compounds) of the plant tissues. Furthermore salt tolerance is a highly complex phenomenon that involves a number of processes at cellular/molecular as well as whole plant levels [3]. In general we can divide plant salt tolerance mechanisms in to 1) osmotic adjustment, 2) ion homeostasis and 3) oxidative stress management.

Osmotic adjustment by accumulation of osmolytes is an important adaptation of halophytes to counter physiological drought imposed by salinity [3]. Halophytes are reported to accumulate organic osmolytes such as proline, glycine-betaine and sugars mainly in cytoplasm for osmotic adjustment without impairing metabolic activities [23, 25-26]. Accumulation of these organic osmolytes in cytoplasm along with Na^+ compartmentalization in the vacuole contributes significantly in overall water relations of halophytes to obtain water from saline soils [3].

Ion homeostasis by keeping tissue Na^+ to low/tolerable ranges and selective uptake of essential nutrients like K^+ and Ca^{++} is another important aspect of salt tolerance [3]. At cellular level Na^+ regulation is achieved by its exclusion from the cell by plasma membrane-bound $Na^{+/}H^+$antiporters (SOS pathway) and sequestering it in vacuoles through tonoplast $Na^{+/}H^+$antiporters [27-28]. In addition some other proteins such as HKT-type transporters, non- selective cation channels (NSCCs), glutamate receptors (GLRs), cyclic-nucleotide gated channels (CNGCs) and McNhaD have also been reported as part of Na^+ regulation machinery [17, 29]. While at whole plant level, halophytes utilize a number of adaptive strategies (Fig. **2**) such as high leaf/stem succulence (to dilute tissue Na^+; e.g. *Suaeda* and *Arthrocnemum* species), salt-secretion through glands/hairs (to get rid of excess Na^+; e.g. coastal grasses and many mangroves), salt exclusion at root (preventing Na^+ from entering to photosynthetic tissues; e.g. *Phragmites karka* and *Panicum turgidum*), dumping salt in old leaves (removing excess Na^+ from body, e.g. many *Atriplex* species) and growth reduction (low Na^+ uptake at the expense of growth, e.g. *Panicum turgidum*) [4, 23]. Furthermore, most halophytes show high selectivity for the uptake of essential nutrients such as K^+ and Ca^{++} in presence of high Na^+ in soil/water with the help of many membrane bound carrier proteins [3, 23, 30-31].

Oxidative stress management by keeping cellular levels of ROS within narrow tolerable ranges is also an important aspect of plant salt tolerance [1]. Halophytes have evolved an efficient antioxidant defense system which consists of enzymes such as superoxide dismutase (SOD), catalase (CAT) and enzymes of Halliwell-Asada pathway and non-enzymes like ascorbic acid (AsA) and glutathione (GSH) [16]. These enzymatic and non-enzymatic antioxidants are found in different cell compartments and prevent oxidative damages to membrane lipids and proteins [16, 32-34]. A

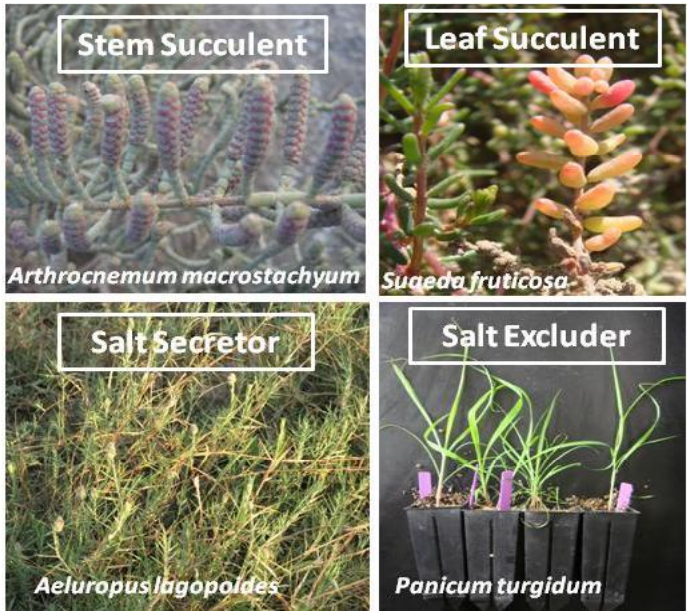

Fig. (2). Some adaptations of halophytes.

direct relation between increased antioxidant defense and salt tolerance has been reported for halophytes [16, 35-36].

Economic Potentials of Halophytes

Despite enormous efforts directed towards improving the salt tolerance of conventional crops, few productive salt-tolerant varieties have been developed yet, because salt tolerance is a complex phenomenon as described above [6]. Therefore cultivation of halophytes on salt-prone wastelands by using saline/brackish water for food, fodder/forage, fuel, fibers, medicines and other purposes appears an instant solution [10]. Use of halophytes as alternate crops would lead to reduce agricultural water consumption and would be ideal for areas with limited water availability such as southern Pakistan [37]. However, in order to improve yield and shape these wild halophytic species as crop plants, further research is required. Institute of Sustainable Halophyte Utilization (ISHU) at University of Karachi is therefore involved in systematic studies on halophytes growing naturally in saline coastal and inland areas of Pakistan to uncover their different economic potentials (Fig. **3**). ISHU is the only institute in the world covering all aspects of halophyte biology from ecosystem to genes, therefore was awarded world's first UNESCO chair in sustainable Halophyte utilization. Researchers at ISHU have discovered a number of candidate crops with following economic potentials:

1. **Fodder/forage**: A systematic screening of halophytes found in the coastal areas of Pakistan was done at ISHU, which revealed two halophytic grasses namely *Panicum turgidum* and *Desmostachya bipinnata* as excellent candidate crops for fodder production [38]. Lately, a cropping system was developed and patented for mass-scale fodder production on saline lands with salty water irrigation [38]. This cropping system can produce about 50-60,000 kg/ha/year of fodder (fresh weight) on saline lands, which is as good as maize and was well-appreciated by world famous research journal "Science" as editor choice of the week (Jan. 2, 2009 Science issue 323: 17).

2. **Edible oil**: Seeds of many halophytes contain appreciable amount of oil [39-40] and may serve as a source of edible oil (Khan, unpublished data). Research conducted at ISHU revealed that the seeds of *Suaeda fruticosa* and *Arthrocnemum macrostachyum* contain about 25% oil, while those of *Halopyrum mucronatum*, *Cressa cretica*, *Haloxylon stocksii* and *Alhaji maurorum* contain 22.7%, 23.3%, 23.2% and 21.9% oil respectively [40]. Contents of unsaturated fatty acids were high (65–74%) in oils derived from halophytes due to the presence of 12 important unsaturated fatty acids. Detailed chemical analyses of halophyte oils are in progress for their feasibility as edible oil.

3. **Biofuel**: Biofuels – bioethanol and biodiesel from halophytes could be a technically feasible alternative to conventional gasoline. The biggest advantage of using halophytes as biofuel crops is that they don't compete with food crops for good quality agricultural lands and water as they would be grown on saline soil and water resources which are considered as waste. In addition, their use as fuel would be less harmful to environment than the gasoline, as they would emit the same amount of CO_2 during combustion which would have been fixed during photosynthesis. Halophytic grasses such as *Desmostachya bipinnata, Phragmites karka, Halopyrum mucronatum, Panicum turgidum* and *Typha domingensis* appear to be suitable candidates for bioethanol

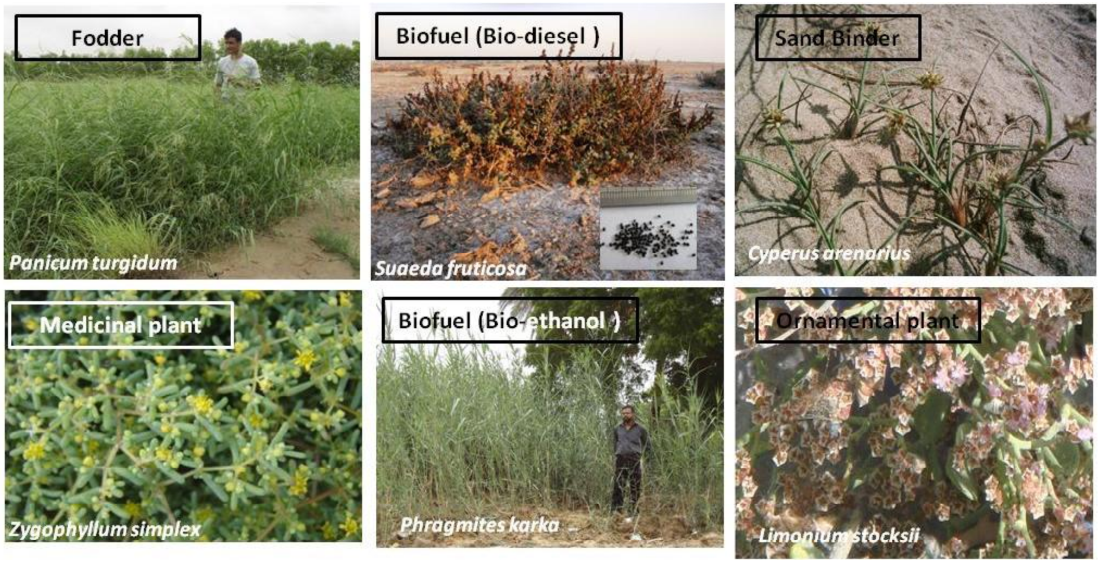

Fig. (3). Some potential halophytic crops for the future.

production on the basis of preliminary examination conducted at ISHU [41]. They have faster growth rate therefore are even better than the conventionally used fuel crops. Besides their massive biomass, these halophytes have relatively low lignin content (<10%) which can make them more efficient for bioethanol production. The potential of using halophytes as a source of biodiesel is also under investigation. Fatty acid methyl esters from halophytes appear a promising source for biodiesel production and can be used in conventional diesel engines without significant modification.

4. **Medicines**: Ethno-botanical studies on coastal halophytes have been conducted, which revealed about 50 plant species with different medicinal properties [42]. Different plant parts of these plants are used to treat 12 disease conditions however, the use of leaves was highest followed by whole plants. At present different chemical analyses such antioxidant properties, anti-microbial properties and anti-cancer properties etc. are in progress. Proper identification of bioactive compounds responsible to cure different diseases may not only help in uplift of local pharma-industry but also the socio-economic status of the people.

CONCLUSIONS

Halophytes, the natural flora of saline habitats, constitute a small but diverse group of plants with potential to revolutionize the future. These remarkable plants can fulfill almost every requirement of human beings especially those related to food, fodder, fuel and medicines. With a little government/private sector support, the cultivation and conservation of such natural resources would result in sustainable maintenance and utilization of this plant wealth in development of many local industries and also the uplift of socio-economic status of the poor people. It is therefore recommended that both the government and private sector should be encouraged to invest in this venture to make halophytes as a resource for future.

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