# Biodiversity and Possible Utilization of Halophytes in Qatar

Fedae A. Alhaddad, Khaznah N. H. ALrajhei, and
Mohammed H. Abu-Dieyeh

## Contents



**Abstract**

Climate change, nature destruction, food security, and accessibility to fresh water are all the most concerning world issues facing humanities. There are many solutions to minimize the adverse effects of such environmental problems. One of these solutions is to evaluate and study the native plants of each region that are adapted to withstand various environmental stresses such as heat, drought, and salinity. Qatar is located in the Arabian Gulf area that is characterized of having

F. A. Alhaddad · K. N. H. ALrajhei · M. H. Abu-Dieyeh (✉)
Department of Biological and Environmental Sciences, College of Arts and Sciences, Qatar University, Doha, Qatar
e-mail: dandelion@qu.edu.qa



M.-N. Grigore (ed.), *Handbook of Halophytes*,
https://doi.org/10.1007/978-3-030-57635-6_109

high temperature and low precipitation. Qatar has a vision to sustain its own development and protect the natural environment. The Government of Qatar is trying to resolve the environmental problems by implementing modern technology and encouraging the researchers in environmental sector to overcome environmental stresses. Investigation of the wild plant in Qatar is essential due to the ability of these plants to cope with harsh conditions. The flora of Qatar contains about 400 species. Out of 400 species inhabited in the state of Qatar, there are about 49 species that are considered halophytes. Halophytes of Qatar are belonging to different genera like *Avicennia*, *Atriplex*, *Arthrocnemum*, *Anabasis*, *Halocnemum*, *Salsola*, *Suaeda*, *Limonium*, *Seidlitzia*, and *Halopeplis*, and they occur near the coastline or inland areas.

**Keywords**

Halophytes · Qatar · Applications · Sustainability · Diversity · Arabian Gulf

## 1 Introduction

Through various studies, it was revealed that halophytes are significant plants that are economically potential and can be of various applications: as food for both human beings and animals, herbal medicine, vegetable and cooking oil, animal fat, and various things that are helpful to the human existence in this world. It also takes a share in the restoration of the environment as well as the evolution of salt tolerance for enhancing a productive soil. Almost 70% of the global surface is said to be covered by saline waters, while 41.3% of the Earth's land surface is either an arid or semiarid according to the UNDDD (2010).

Arid and semiarid regions are facing a serious environmental problem that affects its vegetation, which is called soil salinization. Soil salinization plays a role in changing the properties of the soil and moreover participates in reducing its productivity (Wang and Li 2013). According to Ghassemi et al. (1995), approximately 955 million ha of land all over the world is salt-affected. Therefore, more effort should be done to improve the productivity of the land and overcome soil salinity. Soil salinization is a critical issue humanity faces where the concentration of salt might change the fertile lands into a barren one, which can lead to reduction of crop production and loss of its biodiversity. Rains et al. (1980) clarified that all plants when exposed to high saline condition are facing three complications: maintaining the adequate water content, coping the adverse effects of toxic ions, and obtaining the essential nutrients in spite of the presence of other ions in the soil. Common crop plants are affected negatively when the electrical conductivity of the saturated soil paste equals or exceeds 4 $dS.m^{-1}$. Therefore, plants are classified based on their salt tolerance into sensitive, moderate, and resistant plants. Agricultural productivity has been reduced due to main abiotic stress factors, salinity being one of them (Bartels and Dinakar 2013). Under such status, the importance of salt-tolerant plants is obvious. Plants that can complete their life cycle in saline habitat, which have equal or more than 200 mM of salt in soil, are referred to as halophytes (Flowers and Yeo 1986). Ecologists, plant physiologists, and molecular biologists are all interested in exploring and investigating the effects of salinity on plants to improve and sustain the economically important crops for both human and animal benefits. As the world population increases and the strain on freshwater sources increases, the problem is only going to worsen. The evolutionary ability of halophytes to adapt to extreme environments makes them at top for utilization in several different economic, environmental, and commercial ways. Besides the conceivable commercial benefits, such as extraction of compounds for cosmetics, antimicrobial agents, and generation of timber, halophytes are also being considered for their possible medicinal benefits. Qasim et al. (2011) looked after of 45 species of halophytes and concluded substantial relief of chronic ailments like constipation, diarrhea, toothache, wounds, burns, asthma, and other bronchial infections, among several other disorders. This is especially of importance to Qatar, considering 6% of their land is saline (Abulfatih et al. 2002).

## 2 General Ecological Description of the State of Qatar

The state of Qatar is a country located in southwestern of Asia. Qatar is a peninsula that extended from the northeastern of the Arabian Peninsula. Geographically, Qatar is located in between latitude 24° 27′ and 26°10′ (N) and longitude 50°45′ and 51° 40′ (E), and so it is located midway along the western coast of the Arabian Gulf (Fig. 1). The length of the peninsula from south to north is about 187 Km. Qatar is one of the Gulf Cooperation Council (GCC) countries that is characterized by having an arid or semiarid desert. Qatar is one of the Arabian Peninsula countries in which saline soil cover almost 6% of its territory, especially in the wet areas, salty flats in the inland, as well as coastal places (Abulfatih et al. 2002). Qatar has a long hot climate in summer (May–September) with an average temperature higher than 35 ° C in daytime and moderate winter (November–April) with an average temperature 20 ° C in daytime (Norton et al. 2009). Its annual average rainfall recorded around 88 millimeters. The high rate of evaporation due to high temperature and the shortage of precipitation throughout the year participate in making the land dry and more saline. Living in this extreme environment is challenging for all biotic components. The plants are facing harsh environmental conditions to grow and survive salinity and drought. The natural vegetation in Qatar is scattered and limited to certain areas (Abdel-Bary 2012). The soil of Qatar in general is sandy calcareous loam that covers the rocky bed. Its landscape is considered flat of rocky desert, with some depressions and salt marshes. The fauna and flora biodiversity are affected by such environment. The flora of Qatar involved few tress, dwarf shrubs, and herbaceous plants. Since the soil is shallow and poor in nutrients and contains high concentration of salt, so the biodiversity of fauna and flora is highly affected. The native plants are facing environmental challenges to survive under harsh conditions such as scarcity of water and salty soil. These plants are adapted to withstand and tolerate the chemical and physical aspects of Qatar. In fact, the living organisms (animals, insects, and


**Fig. 1** A map of the state of Qatar. (Source: Qatar GIS Net)

microorganisms) that are associated with soil and plants are also affected by these adaptations.

The plant kingdom comprises of the nonflowering plants (bryophytes, ferns, and gymnosperms) and the flowering plants. There are around three species of the nonflowering plants in Qatar and around 400 species of flowering plants (Abdel-Bary 2012). Out of 400 species inhabited in the state of Qatar, there are around 270 species that are mostly native to Qatar (Norton et al. 2009). The flowering plants are subdivided into two groups: the dicotyledons and the monocotyledons. This is based on the number of the seed leaves inside the seed coat that appears during germination process (Abdel-Bary 2012). According to Abulfatih et al. (2002), there are around seven common halophytic communities found in Qatar: the inland wetland, the inland salt flat, the coastal mangrove, the coastal low marsh, the coastal high marsh, the coastal sandy shore, and the coastal sandy-rocky shore halophytes. Several different halophytic communities are ubiquitous in coastal regions, salt flats, and wetlands across Qatar, and monitoring their growth can help us improve their yield. Böer and Al-Hajiri (2002) have identified a total number of 49 species of halophytes that is present in Qatar. Halophytes and semi-halophytes form an integral part of Qatari flora in the coastal and sabkha ecosystems. These halophytes can prove to be of great relevance for environmental management, as well as restoration (Böer and Al-Hajiri 2002).

## 3 General Classification of Halophytes

The growth in the halophytes responses differently in the presence of salinity. In general, halophytes can withstand and survive in environments that have a salt concentration of approximately 200 mM or have more sodium chloride that include about 1% of the flora around world (Flowers and Colmer 2008). Glenn et al. (1999) demonstrated that there are only 2% of halophytes among the terrestrial plants and around half of the families of higher plants have a polyphyletic in origin. Approximately 37 orders of plants have halophytic species (Flowers et al. 2010). The following are some families that have halophyte species: Poaceae (or Graminae), Cyperaceae, Fabaceae, Plumbaginaceae, Amaranthaceae, and Asteraceae (Aslam et al. 2011). Amaranthaceae (formerly Chenopodiaceae) have the most diverse halophyte species, and it includes around 550 halophytic species (Aronson and Whitehead 1989; Grigore 2012). There are different means of classification of halophytes (Grigore and Toma 2017).

Some classification is based on the morphology of the halophytes. In this type of classification, halophytes are divided into either excretive (excrete excess salt toward outside the plant body (Marschner 1995)) or succulents (storing large amount of water to minimize salt toxicity (Weber 2008)). Another classification is based on salt demand of halophytes. This is further divided into three groups: obligate, facultative, and habit-indifferent halophytes. Obligate halophytes grow in saline soil only, while facultative halophytes are able to grow in saline environments, but they are optimum in a saline-free or low salt environment. For habitat-indifferent halophytes, these plants are able to survive in naturally saline soil. Nevertheless, they live on soils free of salt (Sabovljević and Sabovljević 2007). Also, another way of classification is based on the ability of halophytes to minimize the building up of salt ions inside the plant body: (a) excluder, which can be achieved by limiting salt buildup in the plant tissue, or (b) includer, which allows salt to pass for certain limits (Marschner 1995). Böer and Al-Hajiri (2002) indicate that there are around 49 halophyte species in Qatar. Ranging from species that can tolerate high salt concentration (seawater concentration) like *Halodule uninervis* (Forssk.) Asch to species that complete their life cycle in slight salty concentration like *Phragmites australis* (Cav.) Trin. ex Steud., halophytes occur near the coast in the coastline zone, or around inland sabkha, in areas between the inland sabkha and gravel lands, or in any area where accumulation of salts is present.

## 4 Mechanisms of Salinity Resistance

Halophytes react to salt pressure at three basic levels: at cellular, at tissue, and at whole-plant level (Aslam et al. 2011). There are several mechanisms that are used by halophytes to cope against high salt concentration. So it is important to gather this information to have a clear view for the mechanisms. Hasegawa et al. (2000) indicated that as the saline concentrations in the soil are increased, the amount of water in the soil is decreased, causing decline of the water potential leading to the scarcity of water accessible to the plants. Flowers and Yeo (1986) indicated that most of halophytes utilize the basic mechanisms in using the inorganic ions to balance their internal osmosis with external salinity. Yet, halophytes differ as to what degree they can accumulate and tolerate ions (Glenn et al. 1996). Halophytes have special characteristics to tolerate salty environment (Abdel-Bari et al. 2007). In general, there are two main mechanisms that help halophytes to resist salinity: (1) avoidance mechanisms and (2) tolerance mechanisms.

### 4.1 Avoidance Mechanisms

Some halophytes have special physiological features that help resist salt stress. The following mechanisms participate to help the plants to avoid the salt (Yasseen and Al-Thani 2013):

#### 4.1.1 Exclusion Mechanisms

Plants with these mechanisms show impermeability to the salts that is present in high concentration. The roots have the ability to prevent absorption of salty compounds like sodium chloride. Large amount of sodium ions absorbed by roots is retained and accumulated in the vacuoles of the cells of the root, or the root could retain the sodium ions outside the cells by active transport (Wyn Jones and Gorham 2002). Chlorine ions are also excluded either by preventing the translocation of the salt by the root or by preventing the absorption from the root surface (Waisel et al. 1986; Yasseen and Al-Thani 2013). Tomlinson (1986) suggested that around 99% of the salts are excluded by the roots of mangroves. Some plants may use organic solutes like proline to lower the solute potential as well as water potential of leaves; by this way, the salt excludes from the shoot (Flowers et al. 1977; Greenway and Munns 1980; Morgan 1984).

### 4.1.2 Extrusion Mechanisms

Many halophytes prevent a huge accumulation of salt ions in their tissues by three main excretion methods (Waisel et al. 1986):

1. Shedding of older leaves – Ayoub (1975) suggested that the accumulation of salt in older leaves may participate in leaves to fall.
2. Extrusion mechanism through salt glands which excrete salt solutions toward outside of the leaves (Weber 2008) – Some crystals of salt can be clearly seen by the eye, and salt may remain on the leaf surface and later may blow away through either wind or rain (Lipscshitz et al. 1974). The density of salt gland may increase in the halophytes as the salinity is increased in the area (Rozema et al. 1981).
3. Having an epidermal bladders or hairs, so that excess ions like Na+, K+, and Cl − accumulated in the bladder without being secreted to the outside (Yasseen and Al-Thani 2013) – Adam (1993) showed that the bladder may die when it reaches the maximum volume.

### 4.1.3 Dilution (Succulence) Mechanism

Some halophytes have the ability to dilute high concentrated salt either by growth or by increasing succulence (Flowers and Yeo 1986). Dilution by growth is done by absorbing enough amounts of water to prevent to have a concentrated ion solution (Abdel-Bari et al. 2007). The growth of mesophyll cells explained the leaf blade thickening during salinity (Drennan and Pammenter 1982). The leaves of succulent relatively have more mitochondria because large amount of energy is needed for the salt excretion and compartmentalization (Siew and Klein 1969).

## 4.2 Tolerance Mechanisms

These mechanisms involve some physiological adaptations to tolerate salt. There are around four mechanisms to tolerate salt (Abdel-Bari et al. 2007):

1. Osmoregulation achieved by accumulation of salt ions such as Na+, Cl-, etc. or by synthesis organic solutes such as proline. This mechanism can be either by dehydration avoidance or by dehydration tolerance (Hasegawa et al. 2000).
2. Tolerance to nutrient deficiency. As it is shown by various studies, the presence of the salt in the root areas could affect the absorption (increasing or decreasing) of some major elements, such as P, K, N, Mg, and Ca (Levitt 1980; Yasseen and Al-Thani 2013).
3. Tolerance to primary indirect stresses due to the ability of plant to metabolize toxins such as amine accumulation, maintaining growth inhibition by osmoregulation, and enzyme tolerance. Alternatively, it could be due to the enzyme tolerance to such salt stress (Levitt 1980; Hasegawa et al. 2000).
4. Tolerance of primary direct stresses due to salt shock that is related to the plasma membrane properties. The membrane transports ions, and the metabolism of membrane lipids are also affected in case of salinity (Abdel-Bari et al. 2007).

Flowers and Colmer (2008) concluded that approximately all halophytes need to regulate cellular ion concentration (Na+, Cl−, and K+) to adjust the external water potential. The effects of increasing salinities on halophytes are diverse among plant species. Some halophytes stimulated as the salt concentration increases, while other inhibited by increasing salinity concentration (Flowers and Colmer 2008).

## 5 Description for Selected Qatari Halophyte Species

The plant species displayed in this chapter have shown a noticeable internal and external modification to cope salinity and shortage of water contents in the soil. These plants have special properties to withstand extreme salinity conditions. The following descriptions include the citation, the synonym, the vernacular name, the form of vegetation, the habitat and distribution in Qatar, and the available information about their uses. This information was provided mainly from four references (Batanouny 1981; El Amin 1983; Norton et al. 2009; and Abdel-Bary 2012).

**Family: Amaranthaceae**

**Subfamily: Salsoloideae**

***Scientific name: Salsola setifera*** (Moq.) Akhani (Fig. 2)

Synonym: *Anabasis setifera* Moq. Chenop. Monogr. Enum. 164 (1840)

Vernacular names: Hamd al arnab, Sha'ran حمض الأرنب، شعيران

**Description**: Undershrub with erect stem, 20–60 high. Fleshy branches, four-angled. The fleshy (succulent) leaves opposite oblong. Flowers in cluster, yellow or green. Flowering from August to January. Fruit perigonium, five-winged (Batanouny 1981)

**Distribution**: It is distributed all around the coasts slightly elevated above sea level. *Salsola setifera* is inhabited many moist saline soil (Abdel-Bary 2012).

**Uses**: The plant is known as a good food by camel and by other animals (El Amin 1983). Abdou et al. (2013) extracted new anti-inflammatory (triterpenoid saponin) from flowering dried aerial parts of *S. setifera*.

**Subfamily: Salicornioideae**

***Scientific name: Halopeplis perfoliata*** (Forssk.) Bunge. ex Asch. & Schweinf., Fl. Aethiop. (Fig. 2)

Synonym: *Salicornia perfoliata* Forssk., Fl.

Vernacular names: Inab al Bahr, Khureiz عنب البحر ، خريز

**Description**: Undershrub succulent perennial plant. The branches reach up to 40 cm high. The leaves are globose and enclosing the stem as joints, alternate. The color is green and may become reddish or yellowish. The flower pale reddish in color with yellowish stamens. Flowering in March

**Distribution**: *Halopeplis* occurs in salt marshes and in sabkhas and has a wide range of salt tolerance (Abdel-Bary 2012). It forms a community near to the coastline.

**Subfamily: Salsoloideae**

**Scientific name: *Caroxylon imbricatum*** (Forssk) Moq. Prodr. (Fig. 2)

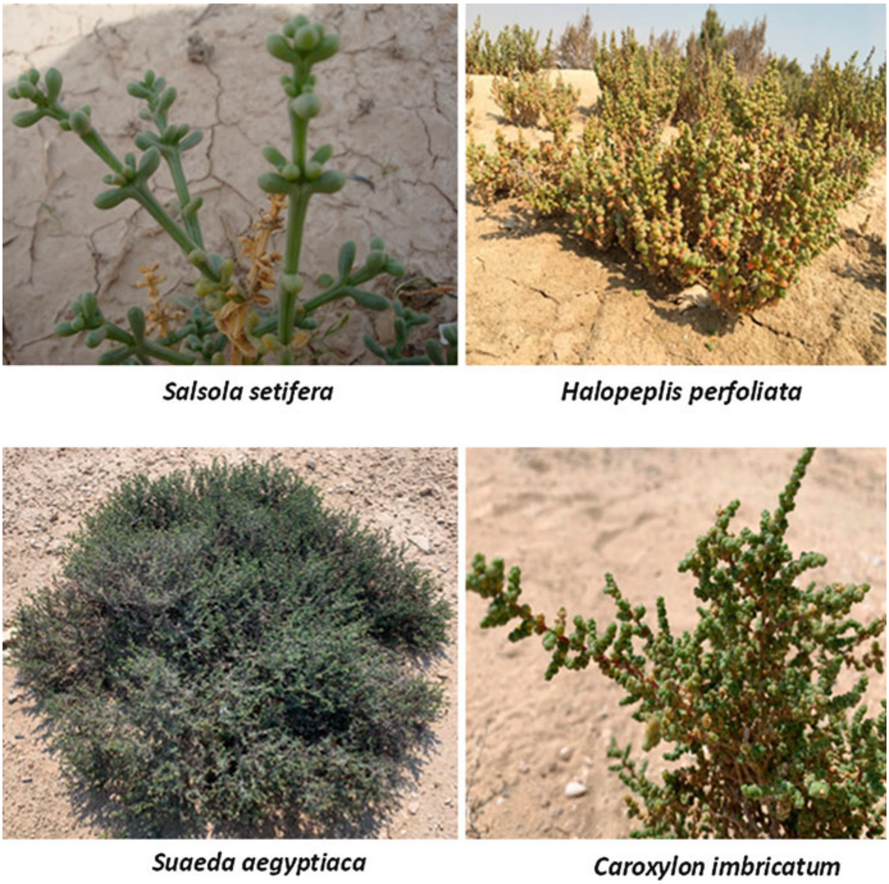


**Fig. 2** Photos of selected halophyte species from the state of Qatar

Synonym: *Salsola baryosma* (Roem. et Schult.) Dandy. *Chenopodium baryosmom* Schult. ex Roem. et Schult. *Salsola foetida* Delile ex Spreng. *Salsola imbricata* Forssk., Fl. Aegypt.-Arab. CVII, CVIII, 57 (1775) (Abdel-Bary 2012)

Vernacular name: Hamdzefer حمض زفر

**Description**: Most common succulent undershrub or small shrub up to 60 cm high. The newly growth leaves clustered with rudimentary laminas and base grasps. The branches are encircling with bare old branches. The inflorescences arrange in the form of spicate. The fruit appears as white flower. The dispersal of the enclosed fruit is by wind blow. Flowering period from June to September

**Distribution**: *Caroxylon imbricatum* distributed approximately in all cities of Qatar (Batanouny 1981). It occurs on coastal saline areas. *Caroxylon* widespread in sabkhas, in moist habitats, and around agricultural fields (Batanouny 1981)

**Uses**: The flowers may be used as an anti-inflammatory and diuretic. *Caroxylon* used for producing alkali, camels feed on it. Oleic acid and linolenic acid have been extracted from *Caroxylon imbricatum* and are usually associated with reducing risks in the cardiovascular system (Ramadan et al. 2009). The plant has distinct fishy taste and odor (Abdel-Bary 2012).

**Subfamily: Suaedoideae**

***Scientific name: Suaeda aegyptiaca*** (Hasselq.) Zohary, J. Linn. Soc. London, Bot. 55:635 (1957). (Fig. 2)

Synonym: *Suaeda hortensis* Forssk., Fl. Aegypt.-Arab. 71 (1775) nom. Inval.; *Chenopodium aegyptiacum* Hasselq., Iter Palaest. 460 (1757); *Schanginia baccata* (Forssk. ex J.F. Gmel.), Syst. Nat., ed. 13, 2: 503 (1791); *Schanginia aegyptiaca* (Hasselq.)

Vernacular name: Al-Ikreet, Hatallus, Suweid الإخريط، حتلس، سويد

**Description**: Shrub glossy green succulent. The leaves slightly curved like claw. It reaches around 2 cm long. The terminal of inflorescences has kind of long spikes in shape and the sessile flower colors reddish purple or green.

**Distribution**: *Suaeda* occurs on coastal sabkhas or on any salinity soil (Abdel-Bary 2012).

**Uses:** The fresh leaves could be used in salads. Furthermore, the stems and leaves could be used to treat tooth from gum infections (El Amin 1983: Abdel-Bary 2012).

**Family: Acanthaceae**

**Subfamily: Avicennioideae**

**Scientific name: *Avicennia marina*** (Forssk.) Vierh., Denkschr. Kaiserl. Akad. Wiss., Wien. Math.- Naturwiss. Kl. Lxxi.435 (1907). Subsp. marina (Fig. 3)

Synonym: *Sceura marina* Forssk., Fl. Aegypt.-Arab. 37 (1775).

Vernacular Names: Shoura, Garam, قرم, شوره

**Description**: Evergreen trees or shrubs with respiratory roots (pneumatophores). Leaves are dark green in color, the above leaves are glabrous, while the below leaves are scaly and hairy. Flowers small yellow to orange color. Seeds germinating on the mother plants in fruit

**Distribution**: Mangrove forests located at northeastern coastline especially in Al Dhakhira, Al Reweis, and Fewairet (Abdel-Bary 2012)

**Uses:** Camel fodder and as source of wood in the past

**Family: Plumbaginaceae**

**Scientific name: *Limonium axillare*** (Forssk.) Kuntze, Revis. Gen. Pl. 1:395 (1891). (Fig. 3)

Synonym *Statice axillaris* Forssk., Fl. Aegypt.-Arab. 58 (1775).

Vernacular name: Qataf, Shelail قطف، شليل

**Description**: Woody shrub. Leaves are fleshy oblanceolate. Leaves large with salt glands. The branched inflorescences have tiered-pagoda pattern. The flowers appear pink or rose. Flowering period December to May

**Distribution**: Common on sabkhas ecosystem and coastal lines with saline shelly soil (Abdel-Bary 2012)

**Uses:** The whole plant could be used in case of diarrhea and as astringent (Ghazanfar 1994).

**Family: Zygophyllaceae**

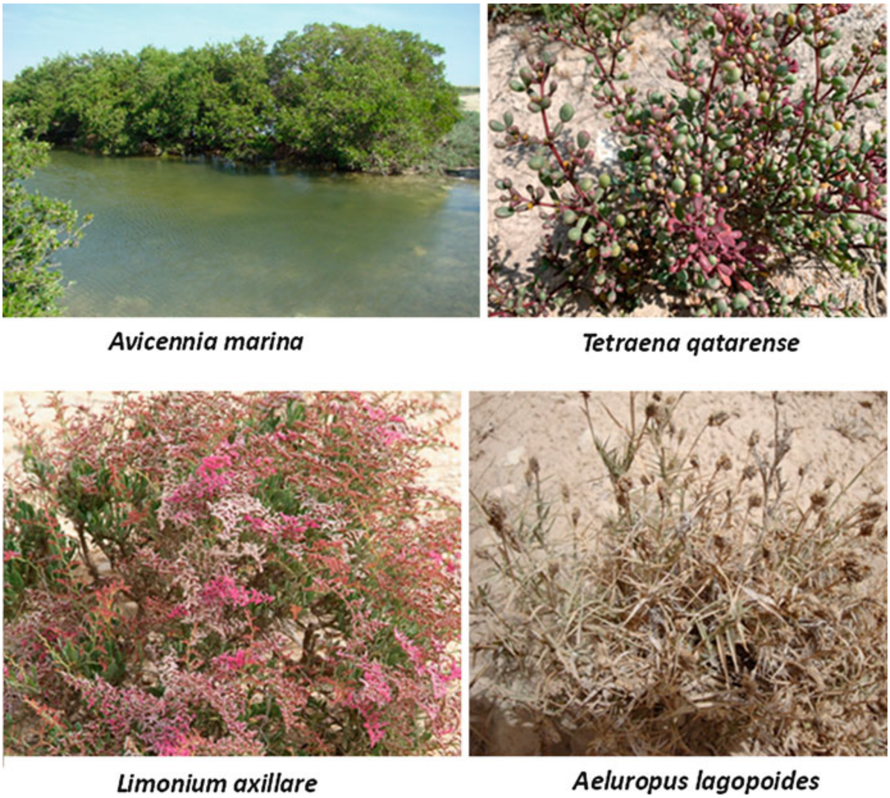


**Fig. 3** Halophyte species from the state of Qatar

**Scientific name: *Tetraena qatarense*** (Hadidi) Beier and Thulin Pl. Syst. Evol. 240 (1–4):36 (2003). (Fig. 3)

Synonym: *Zygophyllum qatarense* Hadidi in Boul., Webb. 32, 2:394 (1978)

Vernacular name: Harm Qatari هرم قطري

**Description**: Undershrub with fleshy terminal branches; woody and hard bases. Simple succulent leaves. Solitary inflorescences with short peduncles. Pale yellow slender flowers. Fruit split longitudinally. Flowering period March to April

**Distribution**: Most common on sandy and rocky areas. Widespread around coastline and in saline sandy habitat (Abdel-Bary 2012)

**Family: Poaceae (Monocotyledons)**

**Scientific name: *Aeluropus lagopoides*** (L.) Trin. ex Thwaites. (Fig. 3)

Synonym: *Dactylis lagopoides* L., Mant.

Vernacular name: Ikrish, Shirraib. عكرش، شرياب

**Description**: Perennial grass up to 15 cm high

Terminating inflorescences with overlapping spikelets

Distichous leaves with sharp rigid points. Flowering from March to May

**Distribution**: More common in saline habitats, including saltmarsh, sabkha edge, and the edges of wetland areas. Usually dominates on saline flat

**Uses**: This species is a good fodder.

## 6 Halophyte Applications in Agriculture

The world population has increased dramatically leading to extensive use of natural resources to satisfy the human needs. For example, many natural forests or grasslands have been changed for agricultural purposes which in turn led to changes in soil properties and increase in salt content. The call for protection of natural ecosystem has been increased in the past years. Many symposiums and scientific events were done for the issue of conservation as well as for finding out solutions to what we are in. Efforts have been done in many countries, with little concerns in most of the world. Scientists utilize the halophytes to solve salinization problem. Some halophyte species like *Sesuvium portulacastrum*, *Suaeda fruticosa*, and *Atriplex nummularia* accumulate the salts in their tissue as well as reduce the amount of salt in their land which could help in reducing salinization problems (Al-Nasir 2009). The demands on natural resources, such as fresh water and proper land for agriculture, have increased gradually around the world, in the arid land in the Middle East in general and in the Gulf Cooperation Council (GCC) countries in particular (Jammazi and Aloui 2015). This is due to the rapid development and increase in the number of population. Several factors contributed in having a saline soil in the GCC countries, for example, the hot and dry climate of this region with scarcity of fresh water and the human practices in irrigation of agricultural areas. Progress and innovative practices are essentially in need to maintain sustainable food and water supplier in this region. This is why scientists are looking for solutions to deal with saline regions by growing halophytes that can germinate and survive in such condition.

There are many limiting factors that affect the productivity of the agricultural lands, and soil salinity is one of these factors. Soil salinity refers to the increase of soluble salts in soil, which hinder the plant from extraction of water from the soil. As a result, the productivity of agricultural land declines, and the production of economical crops reduces. The are many different salts that generally found in saline soils like sodium chloride, potassium chloride, sodium sulfate, and magnesium sulfate. Sodium chloride is the most common salt among these salts. Soil salinity is build up of some or all of the following factors: (1) irrigation water with high salt, (2) extreme evaporation of water from the surface of the land, (3) intensive use of fertilizer, and (4) poor soil drainage. The accumulation of salts in the soil stressed the plants in several ways like toxicity from the accumulation of high concentration of ions, oxidative stress, nutritional disorder, alternation of metabolic disorder, and water stress that is imposed by water potential of the rooting system. The majority of the economical crops cannot tolerate the high salt concentration in soil, but few plants have adapted to the stress of salts. As a result, the yield reduced with the increase of soil salinity. Salinity problem is an ancient problem that is recognized all over the world. Many scientists and researchers tried different methodologies and techniques to enhance the economical crops for maximum utilization of water in saline soil. In contrast, halophytes have their own specific salt tolerance mechanisms that allow them to grow and survive under saline soil. This is why some halophyte species which have economical benefits were used to reduce the stress of saline soil. Several halophytes like *Aster tripolium*, *Crithmum maritimum*, *Salicornia* spp., and *Portulaca oleracea* have been consumed by humans and are still gathering in Europe. These species have the ability to synthesize secondary metabolites like amino acids, antioxidants, and sugars. Therefore, these metabolites functions as scavengers of reactive oxygen species and osmolytes, which have health-promoting benefits. Several halophytes are being sold on the European market as salad crops and sea vegetables like *Aster tripolium* and *Salicornia spp.* (Böer 2006). *Chenopodium quinoa* (Quinoa) tolerates many abiotic stress factors like salinity, wind, drought, and frost, beside the nutritional value of the seeds, so this crop can help poverty by contributing in the global food security (Adolf et al. 2013). Leaves of *Atriplex hortensis*, a salt-tolerant plant, are edible since ancient times (Wilson et al. 2000). *Atriplex hortensis* has chemical composition similar to spinach; this is why it is recommended to substitute spinach by *A. hortensis* (Carlsson and Clarke 1983).

## 7 Halophyte Importance for Animal Feeding

Halophytes constitute one-third of the 350 total plant families, such as grasses, forbs, and shrubs, which are significant for animals. Obviously, halophytes are scattered in many families of plants, which shows that it is not a hard characteristic that might arise once in evolution and does not refer to the specific areas (Squires and Ayoub 1994). Salt affects around 7–10% of the global land areas and under different climatic situations and spreads more widely in both arid and semiarid places in comparison to humid places (Dudal and Purnell 1986). The general characteristics for a plant to be as good for feed/forage are the plant should be leafy, tasty, edible and contain nutritive value of more than 5% of protein and less than 10% of ash (Badri and Hamed 2000). Halophytes could be used in animal feed but with restriction due to the high amount of salt that could be present in some species (Glenn et al. 1999). The following halophyte species could be a promise as a fodder without any processing, *Dactyloctenium scindicum*, *Phragmites karka*, *Cenchrus ciliaris*, *Sporobolus ioclados*, *Panicum antidotale*, *Kochia scoparia*, and *Dichanthium annulatum*, due to their relatively high protein content and low amount of ash (Gul et al. 2014). Halophyte quality acts as significant factor of responding animal needs. Factors that affect quality include and not only limited to worthiness of feeding, nutrient components, as well as tastiness (Atia-Ismail 2015). Fodder quality analysis can be determined to meet the animal needs through suitable portion supplementation. The use of halophytic fodder acts as difficulty in shaping shares, especially in terms of nonnutritional and nonprotein nitrogen mechanisms (Masters 2015). It was also addressed to the deliciousness factors as important ones for halophytic fodders in understanding how far the animals might accept and consume. Fodder tastiness shares in ensuring the quantity of feeding provided to certain animals on a specific period of time (Glenn et al. 1999). In spite of the above-stated plant internal factors, tastiness of the halophyte fodder is also determined by animal factors, such as feeding habits, age, species, health and physiological conditions, race, and nutrition as well as halophyte fodder chemical components. In terms of the chemical effects, the level of crude fiber and its percentage could be high, and this will contribute a significant role in choosing livestock; i.e., fodder including a high level of fiber could be good for animal use, especially for cattle rather than goats and sheep. Areas receiving low rain fall percentage could encounter critical conditions to fodder tastiness compared to places with high percentage of rain (Atia-Ismail 2015). These might vary as per their chemical components, tastiness, as well as the nutritional worthiness. This is because the chemical components are the first factor that could show animal nutritional value and deliciousness; i.e., it is an indication of the chemical components of the feed plant, which is different from one plant to another in terms of plant growth control, such as its soil salinity, fertility, as well as temperature and rain. Halophytic forage minerals are different due to their level of growth, salinity of soil, as well as seasonality (Atia-Ismail 2015). Accordingly, mineral component concentration of certain halophytic forage can be a source of satisfaction and feeding for animals and, at the same time, can balance the shortage that results from places to depend on grassing ranges, such as coastal or desert places (Atia-Ismail 2015).

## 8 Biofuel Significance of Halophytes

In addition to what is stated above, these plants also have an essential role in the process of production of sources of energy, which can be categorized as renewable and nonrenewable (Noorollahi et al. 2015). The current issues of increasing energy demand and decline of its production reserves as well as the global warming created international movements to look for alternative ways to obtain sources of renewable energy. Accordingly, bioenergy might become an alternative to the earlier sources of energy due to its advantages of low environmental effects, especially in terms of gas emissions and greenhouse, and be used for power as well as heat production (Yokoyama and Masumura 2008). Biomass can be obtained from various plants, biological materials of animal wastes, and urban and agricultural wastes. For example, biodiesel can be extracted from biomass materials of cooking oil, fats of animals, and vegetable oil (Hull 2011). It was found that oilseed is a type of halophyte plant which is a salt-tolerant enjoying a high likely biomass which can be generated from liquid biofuels and at the same time having a strong resistant of saline soil (Crockett et al. 2006). Through this study, it was revealed that some oilseed halophytes such as *Salicornia bigelovii* take rarely fatty acids that can be applied in industrial areas as biofuel liquid (Garcia 2010). Therefore, obtaining a proper place to plant oil crop is a good thing to have a sustainable crop generation of biofuels.

## 9 Halophyte Plant Applications in Medicine

Some plant species are used as medicines because of their capacity to treat several diseases like cough, fever, headache, and rheumatism. Approximately around 7500 medicinal plant species are used in India against various diseases (Kala and Sajwan

2007). Ksouri et al. (2009) indicated that the species *Tamarix gallica* which is used traditionally for liver disease treatment has bioactive compounds, for example, tannins, glycosides, steroids, alkaloids, phenols, flavonoids, and saponins. It is also revealed that halophytes act as economically potential factors which share the medicine applications as well as restoration of environmental issues (Qasim et al. 2011). It was revealed on various studies that, especially in Pakistan, almost 631.5 tons of medicinal herbs are extracted from these plants with a total amount of Rs. 1.5 billion per year. Almost 90% of this herbal medicine is imported from Asian countries such as China, India, and Sri Lanka which generate heavy revenue of foreign exchange (Hussain et al. 2003). In another study conducted by group of scholars, it was highlighted that halophytes are significant for medical applications, food, and nutraceuticals as well as encourage health biomolecules (Ksouri et al. 2011).

The unfriendly environmental situations of plants such as production growth constraints and reactive oxygen species create a sense scene process, metabolic disorders, and cellular damages (Menezes-Benavente et al. 2004). Halophytes are known for their capability of resistance and quench of toxics resulted from reaction of oxygen species, because they have strong antioxidant systems (Ben Amor et al. 2007; Jaleel et al. 2009; Ksouri et al. 2008, 2010). These antioxidant groups can hinder the oxidation of lipids or of other molecules by preventing the initiation or propagation of oxidative chain reaction (Tepe et al. 2006). In the same token, antioxidant constituents in halophytes show a strong biological activity and can exceed many traditional antioxidants from synthetic antioxidants or medicinal glycophyte which are restricted because of their potential carcinogenetic properties (Suhaj 2006). These antioxidants showed promising options in terms of security and economic side due to the applicability in the areas of food industry as well as preventive medicine to replace synthetic antioxidants (Tadhani et al. 2007). There is an exciting growth of revealing among halophyte species those with high antioxidant constituent for their application in the pharmaceutical, cosmetic, and agri-food industries. These plants are traditional salt-tolerant plants that have potential medicinal and nutraceutical properties that can be a source of food dietary functional components, polyunsaturated fatty acids and vitamins, as well as high molecular tannins and flavonoids (Ksouri et al. 2009; Bouftira et al. 2007; Ksouri et al. 2008; Meot-Duros et al. 2008; Meot-Duros and Magne 2009; Falleh et al. 2011).

## 10 Halophyte for Oil Production Applications and Commercial Products

Salinization affected developed countries as well as developing countries (Panta et al. 2014). In Australia, around two million hectares of agricultural land have shown sign of salinity in the year 2002, and around 820,000 hectares of land are considered as non-good for crop production commercially (Australian Bureau of Statistics 2004). Halophytes have their special physiological, morphological, anatomical, and special characteristics that all together participated in survival and germination of such plants in saline environments (Flowers and Colmer 2008;

Shabala and Mackay 2011). Around 90% of human food is provided by almost 30 plant species (Khan et al. 2006). The great value of having halophytes comes from the idea in farming areas that had saline soil and limited amount of fresh water. These plants are also widely used for vegetable oil production purposes as it has high promising capabilities of producing oil with high poly-unsaturation equal to the traditional oil seed crops such as sunflower and canola (Khan and Qaiser 2006). Several studies had been conducted to determine the quantity of oil that could be extracted from the seeds of halophytes. For example, *Salicornia bigelovii* seed has 30% oil content and around 35% protein content (Ho and Cummins 2009). *Suaeda fruticosa* seed contain 74% unsaturated fatty acid and could be used by human as edible oil (Weber et al. 2007). It consists also of seeds of different types of halophytes including *S. brachiata*, *Salicornia bigelovii*, *Suaeda fruticosa*, *Halogeton glomeratus*, *Arthrocnemum macrostachyum*, *Haloxylon stocksii*, and *Kochia scoparia* which have enough quantity of high-quality appetizing oil with unsaturation ranging from 70% to 80% (Weber et al. 2001). These types of plants are used for pickles, salads, as well as vegetables in various parts of Pakistan. In the same token, fuel wood is also mainly extracted from the perennials of the salt-tolerant species including *Kochia*, *Tamarix*, *Capparis*, *Suaeda*, and *Prosopis* (Dagar 1995).

## 11 Halophytes for Desalination, Phytoremediation, and Biofuel

Some halophytes have the ability of accumulation of sodium chloride in their tissues, and this could be a promise way in removing access amount of salt from salt-affected lands. Panta et al. (2014) mentioned that the amount of salt that could be removed from salt-affected land could be ranged from 2 to 6 tons of salt per hectare per year. Shabala (2013) indicated that the use of halophytes in desalination units not always gave the same biomass, because of other environmental issues that the scientist should put into consideration. Some elements, like Cd and Pb, accumulated in soil and water which in turn can affect the human health (Khan et al. 2010). So the need for a sustainable strategy to remove such contaminants is needed. This is why scientist look for plants that have the ability to extract these elements from the soil and condense them in their tissues in a process known as phytoremediation. Using halophytes could be much effective in already saline soil. Some salt march plants and seagrasses can be used to extract heavy metals and accumulate them into their tissues (Lewis and Devereux 2009). Usman et al. (2019) demonstrate that *Tetraena qataranse*, the most common undershrub desert plant that naturally found in the rocky and high saline soil in Qatar environment, can accumulate some heavy metal contaminants, like Cr, Cu, Cd, and Ni, into their roots. Therefore, *T. qataranse* could be a promising candidate for phytostabilization of the toxic metals (Usman et al. 2019).

In energy sector, the production of biofuel from biomass gain more interest recently. As the fossil fuel prices raised and the amount of reservoir declined, the demand for renewable resources increased. Bioethanol can be produced from food crops like corn and sugarcane. Since these crops are important source of food for human, so the scientists were looking for other sources that are not in competition with the food sources. Halophytes can be a vital part on future energy sector by providing bioethanol and biodiesel (Panta et al. 2014). Abideen et al. (2011) represented that some halophytic plants from Pakistan can be a good source of bioethanol production, such as *Phragmites karka*, *Desmostachya bipinnata*, and *Typha domingensis.* Smichi et al. (2016) indicated that the halophyte specie *Juncus maritimus* could be a good source of ethanol production especially if it is pretreated by freezing and thawing of biomass treatment. In China, the seeds of *Suaeda salsa* were used to extract edible oil, and around 46.6 g of total reducing sugar was obtained from around 100 g of *S. salsa* sample, so *Suaeda salsa* could possibly be an important feedstock for bioethanol production (Li et al. 2013).

## 12 Halophytes and the Role of the Associated Microorganisms

Abundant microscopic organisms living in the soil include fungi, bacteria, protozoa, and algae. Many organisms like fungi and bacteria play a vital role in maintaining the ecosystem processes. As an example, fungi retain the nutrient to the soil by breaking down the decay plants, while mycorrhizae and nitrogen-fixing bacteria help the plant by aiding the roots in absorption of minerals and water, improving the soil structure and soil stabilization, and promoting the growth of the plant.

### 12.1 Applications that Can be Produced and Investigated from Endophytes

Endophytes are referring to group of organisms (bacteria or fungi) that live in the host (e.g., plants). *Agrobacterium* and *Pseudomonas* are some isolated genera. Initially endophytes were characterized as contamination, but later scientists identify the important roles that the endophytes played against plant pathogens as discussed by Hallmann et al. (1997). Various studies believed that the presence of endophytes helps the plant to become healthier compared to the plant without them, as reviewed by Martinez-Klimova et al. (2016). This might be due to the metabolites that are produced by endophytes which participate in enhancing the plant growth and nutrient uptake or due to its participation in defending the plant against pathogens and pest (Martinez-Klimova et al. 2016). Human from this valuable interaction of endophytes and plants can use many benefits. For example, it helps the plant to have better growth under stress environment of salt or heat conditions and then produces economical compounds that could be used in medicine.

Inoculum delivery methods, which are both practical and reliable, must be developed to be able to use endophytes in practical production. Many methods have been developed to be able to use endophytes in different applications, such as seed treatments, bacteria suspensions, foliar spray, and soil drenches (Fahey et al. 1991). Seed inoculation technique has been developed by the application of differential pressure to infuse the suspension of bacteria into seeds to meet certain shelf-life requirements (Fahey et al. 1991). Another possible application is the inoculation of bacteria into the cell suspensions of plant to ensure the early colonization of plant by endophytes. Spraying of bacterial suspensions can also be used to flowers and foliage as biocontrol agents (Knudsen and Dandurand 2014). Endophytes with different delivery methods can be used depending on the requirements of the stage of development of a particular crop. Recently some applications have been related to phytoremediation. Here the scientist believed that endophytes participated in enhancing toxin uptake from the environment (Khan and Doty 2011). Finally, endophyte application in seed treatment provides practical, inexpensive, rapid, and reliable way to enhance the overall benefits along with soil drench and/or leaf application through increasing endophyte colonization.

### 12.2 Efficiency of Using Endophyte-Plant Relation in the Phytoremediation of Organic Waste in Soil

Removing organic contaminant from soil by endophytes is a promising area for future phytoremediation. Many strategies are discussed in the literature to enhance phytoremediation, biostimulation being one of them. Adams et al. (2015) proposed that biostimulation could be performed by changing some parameters, physical or chemical, to stimulate plant and the endophyte to produce enzymes that degrade the pollutant. Another method is by adding nutrients that promote metabolic activity. Another strategy is by bioaugmentation, which is the inoculation with the endophyte (strain) that has the ability to improve contaminant removal. Third strategy is through genetic modification by genetic engineering of either the host (plant) or the endophytes (bacteria) to enhance the removal of organic pollutant (Doty 2008).

## 13 Conclusion

In the race of development, Qatar shades light on its rapid economic growth that changes the social, the cultural, the infrastructural, the demographical, and the economical face of Qatar. Nowadays, the accelerated rate of expanding infrastructure beside the urbanization and the construction of advanced road system, new highways, and numerous buildings all together participate in changing the natural habitat. Qatar is located in an area that is characterized of having high temperature and limited sources of fresh water. The natural environmental and anthropogenic factors contribute to the changes and disturbances of the natural habitat that is inhabited with numerous types of plants and animals. The country planners and policy-makers are facing challenges to ensure sustainable development in the entire country. The flora of Qatar is rich in numerous plants that were used by human in ancient times. Halophytes have the ability to withstand the harsh condition of high temperature, poor soil in nutrients, and limited sources of water. This chapter displays our current knowledge for the status of halophytes in the state of Qatar. Since halophyte can adapt to survive in harsh condition and they have different applications in many ways, so it is highly recommended to restore vegetation and manage the ecosystem by planting halophytes in unused regions in the entire state of Qatar.

**Acknowledgments** We would like to thank Mrs. Muneera Ali Al-Mesaifri for providing us with few pictures for Qatari halophytes and for her efforts in field trips. This chapter was supported by Qatar University Internal Grant No. QUCG-CAS-20/21-3. The findings achieved herein are solely the responsibility of the author(s).

## References


Abdel-Bari, E. M., Yasseen, B. T., & Al-Thani, R. F. (2007). *Halophytes in the state of Qatar*. Doha: Environmental Studies Center, University of Qatar.

Abdel-Bary, E. M. (2012). *The Flora of Qatar Volume 1: Dicotyledons*. Doha: Environmental Studies Center, University of Qatar.

Abdou, A. M., Abdallah, H. M., Mohamed, M. A., Fawzy, G. A., & Abdel-Naim, A. B. (2013). A new anti-inflammatory triterpene saponin isolated from Anabasis setifera. *Archives of pharmacal research, 36*(6), 715–722.

Abideen, Z., Ansari, R., & Khan, M. A. (2011). Halophytes: Potential source of ligno-cellulosic biomass for ethanol production. *Biomass and Bioenergy, 35*(5), 1818–1822.

Abulfatih, H. A., Abdel Bari, E. M., Alsubaey, A., & Ibrahim, Y. M. (2002). Halophytes and soil salinity in Qatar. *Qatar University Science Journal, 22*, 119–135.

Adam, P. (1993). *Saltmarsh ecology*. Cambridge University Press.

Adams, G. O., Fufeyin, P. T., Okoro, S. E., & Ehinomen, I. (2015). Bioremediation, biostimulation and bioaugmentation: A review. *International Journal of Bioremediation & Biodegradation, 3*, 28–39.

Adolf, V. I., Jacobsen, S. E., & Shabala, S. (2013). Salt tolerance mechanisms in quinoa (*Chenopodium quinoa* Willd.). *Environmental and Experimental Botany, 92*, 43–54.

Al-Nasir, F. (2009). Bioreclamation of a saline sodic soil in a semiarid region/Jordan. American-Eurasian. *Journal of Agricultural and Environmental Science, 5*(5), 701–706.

Aronson, J. A., & Whitehead, E. E. (1989). *HALOPH: A data base of salt tolerant plants of the world*. Tucson: Office of Arid Lands Studies, University of Arizona.

Aslam, R., Bostan, N., Nabgha-e-Amen, M. M., & Safdar, W. (2011). A critical review on halophytes: Salt tolerant plants. *Journal of Medicinal Plants Research, 5*(33), 7108–7118.

Atia-Ismail, S. A. (2015). Plant secondary metabolites of halophytes and salt tolerant plants. In El Shaer & V. Squires (Eds.), *Halophytic and salt tolerant feedstuffs: Impacts on nutrition. Physiology and Reproduction of Livestock* (Vol. 127, p. 142). CRC Press.

Australian Bureau of Statistics. (2004). *Year Book Australia*. Belconnen: ACT, 1301.0.

Ayoub, A. T. (1975). Sodium and cation accumulation by senna (*Cassia acutifolia*). *Journal of Experimental Botany*, 891–896.

Badri, M. A., & Hamed, A. I. (2000). Nutrient value of plants in an extremely arid environment (Wadi Allaqi biosphere reserve, Egypt). *Journal of Arid Environments, 44*(3), 347–356.

Bartels, D., & Dinakar, C. (2013). Balancing salinity stress responses in halophytes and non-halophytes: A comparison between Thellungiella and *Arabidopsis thaliana*. *Functional Plant Biology, 40*(9), 819–831.

Batanouny, K. H. (1981). *Ecology and Flora of Qatar*. Centre for scientific and applied Research, University of Qatar.

Ben Amor, N., Jimenez, A., Megdiche, W., Lundqvist, M., Sevilla, F., & Abdelly, C. (2007). Kinetics of the anti-oxidant response to salinity in the halophyte *Cakile Maritima*. *Journal of Integrative Plant Biology, 49*(7), 1024–1034.

Böer, B. (2006). Halophyte research and development: What needs to be done next? In M. A. Khan & D. J. Weber (Eds.), *Ecophysiology of high salinity tolerant plants* (pp. 397–399). Berlin: Springer Verlag.

Böer, B., & Al-Hajiri, S. (2002). The coastal and Sabkha Flora of Qatar: An introduction. In *Sabkha ecosystems: Volume I: The Arabian peninsula and adjacent countries, 1*. Kluwer: Publications. Netherlands.

Bouftira, I., Abdelly, C., & Sfar, S. (2007). Identification of a naturally occurring 2,6-bis (I,I,-dimethylethyl)-4-methylphenol from purple leaves of the halophyte plant *Mesembryanthemum crystallinum*. *African Journal of Biotechnology, 6*, 1136–1139.

Carlsson, R., & Clarke, E. M. W. (1983). *Atriplex hortensis* L. as a leafy vegetable, and as a leaf protein concentrate plant. *Qualitas Plantarum Plant Foods for Human Nutrition, 33*, 127–133.

Crockett, C. L., Peterson, P., & Mann. (2006). *Feasibility study for commercial production of biodiesel in the Treasure Valley of Idaho*. University of Idaho, College of Biological & Agricultural Engineering.

Dagar, J. C. (1995). Characteristics of halophytic vegetation in India. In M. A. Khan & I. A. Ungar (Eds.), *Biology of salt tolerant plants* (pp. 255–276). Karchi: University of Karchi, p. 476.

Doty, S. L. (2008). Enhancing phytoremediation through the use of transgenics and endophytes. *The New Phytologist, 179*, 318–333.

Drennan, P., & Pammenter, N. W. (1982). Physiology of salt excretion in the mangrove *Avicennia marina* (Forsk.) Vierh. *New Phytologist, 91*(4), 597–606.

Dudal, R., & Purnell, M.F. (1986). Land resources: Sale affected soils. *Reclamation and Revegetation Research.*

El Amin, H. M. (1983). *Wild plants of Qatar. Khartoum: Arab Organization for Agricultural Development, for the Ministry of Industry and Agriculture*, Qatar xiv, 161p. illus., col. illus., maps. En Icones. Geog, 2.

Fahey, J. W., Dimock, M. B., Tomasino, S. F., Taylor, J. M., & Carlson, P. S. (1991). Genetically engineered endophytes as biocontrol agents: A case study from ~industry. In J. H. Andrews & S. S. Hirano (Eds.), *Microbial ecology of leaves* (pp. 401–411). Berlin: Springer.

Falleh, H., Oueslati, S., Guyot, S., Ben Dali, A., Magne, C., Abdelly, C., & Ksouri, R. (2011). L/CESI-MS/MS characterization of procyanidins and properlargonidins responsible for the strong antioxidant activity of the edible halophyte *Mesembryanthemum edule*. *Industrial Crops and Products, 34*, 1066–1071.

Flowers, T. J., & Colmer, T. D. (2008). Salinity tolerance in halophytes. *New Phytologist, 179*(4), 945–963.

Flowers, T., & Yeo, A. R. (1986). Ion relations of plants under drought and salinity. *Functional Plant Biology, 13*(1), 75–91.

Flowers, T. J., Troke, P. F., & Yeo, A. R. (1977). The mechanism of salt tolerance in halophytes. *Annual Review of Plant Physiology, 28*, 89–121.

Flowers, T. J., Galal, H. K., & Bromham, L. (2010). Evolution of halophytes: Multiple origins of salt tolerance in land plants. *Functional Plant Biology, 37*(7), 604–612.

Garcia, R. M. (2010). *Physiological studies of the halophyte Salicornia bigelovii: A potential food and biofuel crop for integrated aquaculture-agricultural systems*. The University of Arizona.

Ghassemi, F., Jakeman, A. J., & Nix, H. A. (1995). *Salinisation of land and water resources: Human causes, extent, management and case studies*. CAB International.

Ghazanfar, S. A. (1994). Handbook of Arabian medicinal plants. Springer, New York.

Glenn, E., Pfister, R., Brown, J. J., Thompson, T. L., & O'Leary, J. (1996). Na and K accumulation and salt tolerance of *Atriplex canescens* (Chenopodiaceae) genotypes. *American Journal of Botany*, 997–1005.

Glenn, E. P., Brown, J. J., & Blumwald, E. (1999). Salt tolerance and crop potential of halophytes. *Critical Reviews in Plant Sciences, 18*(2), 227–255.

Greenway, H., & Munns, R. (1980). Mechanisms of salt tolerance in nonhalophytes. *Annual Review of Plant Physiology, 31*(1), 149–190.

Grigore, M. N. (2012). *Romanian salt tolerant plants: Taxonomy and ecology*. Pim: Iasi.

Grigore, M. N., & Toma, C. (2017). *Anatomical adaptations of halophytes. A review of classic literature and recent findings*. Cham: Springer International Publishing.

Gul, B., Ansari, R., Ali, H., Adnan, M. Y., Weber, D. J., Nielsen, B. L., & Khan, M. A. (2014). The sustainable utilization of saline resources for livestock feed production in arid and semi-arid regions: A model from Pakistan. *Emirates Journal of Food and Agriculture, 26*(12).

Hallmann, J., Quadt-Hallmann, A., Mahaffee, W. F., & Kloepper, J. W. (1997). Bacterial endophytes in agricultural crops. *Canadian Journal of Microbiology, 43*(10), 895–914.

Hasegawa, P. M., Bressan, R. A., Zhu, J. K., & Bohnert, H. J. (2000). Plant cellular and molecular responses to high salinity. *Annual Review of Plant Biology, 51*(1), 463–499.

Ho, M. W., & Cummins, J. (2009). Saline agriculture to feed and fuel the world. *Navigation, 1*(2), 3.

Hull, S. (2011). Wisconsin sustainable planting and harvesting guidelines for no forest biomass. *Wisconsin Bioenergy Council*.

Hussain, N. A., Naseem, G. R, Sarwar, F., Mujeeb & Jamil, M. (2003). Domestication/cultivation scope of medicinal crops on salt-affected soils. *Conservation and Sustainable uses of medicinal and aromatic plants of Pakistan, 2–4*, pp. 37–43.

Jaleel, C. A., Ksouri, R., Gopi, P., Manivannan, J., Ines, H., Al-Juburi, Z., Chang-Xing, S., Hong-Bo, S., & Panneerselvam, R. (2009). Antioxidant defense responses: Physiological plasticity in higher plants under abiotic constraints. *Acta Physiology Plant, 31*, 427–436.

Jammazi, R., & Aloui, C. (2015). Environment degradation, economic growth and energy consumption nexus: A wavelet-windowed cross correlation approach. *Physica A: Statistical Mechanics and its Applications, 436*, 110–125.

Kala, C. P., & Sajwan, B. S. (2007). Revitalizing Indian systems of herbal medicine by the National Medicinal Plants Board through institutional networking and capacity building. *Current Science Bangalore, 93*(6), 797.

Khan, Z., & Doty, S. (2011). Endophyte-assisted phytoremediation. *Plant Biology, 12*, 97–105.

Khan, M. A., & Qaiser, M. (2006). Halophytes of Pakistan: Characteristics, distribution and potential economic usages. In *Sabkha ecosystems* (pp. 129–153). Dordrecht: Springer.

Khan, M. A., Ansari, R., Gul, B., & Qadir, M. (2006). Crop diversification through halophyte production on salt-prone land resources. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 1*, 048.

Khan, S., Hesham, A. E. L., Qiao, M., Rehman, S., & He, J. Z. (2010). Effects of Cd and Pb on soil microbial community structure and activities. *Environmental Science and Pollution Research, 17*(2), 288–296.

Knudsen, G. R., & Dandurand, L. M. C. (2014). Ecological complexity and the success of fungal biological control agents. *Advances in Agriculture, 2014*, 1.

Ksouri, R., Megdiche, W., Falleh, H., Trabels, N., Boulaaba, M., Smaoul, A., & Abdelly, C. (2008). Influence of biological, environmental and technical factors on phenolic content and antioxidant activities of Tunisian halophytes. *Comptes Rendus Biologies, 333*, 865–873.

Ksouri, R., Falleh, H., Megdiche, W., Trabelsi, N., Mhamdi, B., Chaieb, K., . . . & Abdelly, C. (2009). Antioxidant and antimicrobial activities of the edible medicinal halophyte *Tamarix gallica* L. and related polyphenolic constituents. *Food and Chemical Toxicology, 47*(8), 2083–2091.

Ksouri, R., Megdiche, W., Koyro, H.-W., & Abdelly, C. (2010). Responses of halophytes to environmental stresses with special emphasis to salinity. *Advances in Botanical Research, 53*, 117–145.

Ksouri, R., Ksouri, M. K., Jallali, I., Debez, A., Magne, C., Hiroko, I., & Abdelly, C. (2011). Medicinal halophytes: Potent source of health promoting biomolecules with medical, nutraceutical and food applications. *Critical Reviews in Biotechnology, 32*(4), 289–326.

Levitt, J. (1980). *Water, radiation, salt, and other stresses* (Vol. 2). Elsevier. Levitt, J. (1980). Response of plants to environmental stresses, Vol. 2 *Water radiation salt and other stresses*. New York: Academic Press. 607 pp.

Lewis, M. A., & Devereux, R. (2009). Nonnutrient anthropogenic chemicals in seagrass ecosystems: Fate and effects. *Environmental Toxicology and Chemistry, 28*(3), 644–661.

Li, S., Li, J., Hu, X., Li, M., Yan, Z., Li, S., & Fan, C. (2013). Study on enzymatic saccharification of Suaeda salsa as a new potential feedstock for bio-ethanol production. *Journal of the Taiwan Institute of Chemical Engineers, 44*(6), 904–910.

Lipscshitz, N., Shomer-llan, A., Eshel, A., & Waisel, Y. (1974). Salt glands on leaves of Rhodes grass (*Chloris gayana* Knuth). *Annals of Botany, 38*, 459–462.

Marschner, H. (1995). *Mineral nutrition of plants* (2nd ed.). Boston: Academic.

Martinez-Klimova, E., Rodríguez-Peña, K., & Sánchez, S. (2016). Endophytes as sources of antibiotics. *Biochemical Pharmacology.*

Masters, D. G. (2015). Assessing the feeding value of halophytes. In El Shaer & V. Squires (Eds.), *Halophytic and salt tolerant feedstuffs: Impacts on nutrition. Physiology and Reproduction of Livestock*. New York: CRC Press.

Menezes-Benavente, L., Kernodle, S. P., Margis-Pinheiro, M., & Scandalios, J. G. (2004). Salt-induced antioxidant metabolism defenses in maize (*Zea mays* L.) seedlings. *Redox Report, 9*, 29–36. https://doi.org/10.1179/135100004225003888.

Meot-Duros, I., & Magne, C. (2009). Antioxidant activity and pheno content of Crithmum maritimum I., leaves. *Plant Physiology Biochemistry, 47*, 37–41.

Meot-Duros, I., Le Floch, G., & Magne, C. (2008). Radical scavenging, antioxidant and antimicrobial activities of halophyte species. *Journal of Ethnopharmacology, 116*, 258–262.

Morgan, J. M. (1984). Osmoregulation and water stress in higher plants. *Annual Review of Plant Physiology, 35*(1), 299–319.

Noorollahi, Y., Sokhansefat, S., Sokansefat, T., Rahmani, K., & Jalilinasrabady, S. (2015). Biodiesel resources assessment and evaluation of the production capacity from Salicornia plant in Golestan Province, North-East Iran. *International Journal of Renewable Energy Research, 5*(3).

Norton, J., Majid, S. A., Allan, D., & Al Safran, M. (2009). *An illustrated checklist of the flora of Qatar*. Gosport: Browndown Publications.

Panta, S., Flowers, T., Lane, P., Doyle, R., Haros, G., & Shabala, S. (2014). Halophyte agriculture: Success stories. *Environmental and Experimental Botany, 107*, 71–83.

Qasim, M., Gulzar, S., & Khan, M. A. (2011). Halophytes as medicinal plants. In *NAM Meeting in Denizli*. Turkey.

Rains, D. W., Croughan, T. P., & Stavarek, S. J. (1980). Selection of salt-tolerant plants using tissue culture. In D. W. Rains, R. C. Valentine, & A. Hollaender (Eds.), *Genetic engineering of osmoregulation: Impact on plant production for food, chemical and energy* (pp. 279–292). New York: Plenum Press.

Ramadan, M. F., Amer, M. M. A., Mansour, H. T., Wahdan, K. M., El-Sayed, R. M., El-Sanhoty, S., & El-Gleel, W. A. (2009). Bioactive lipids and antioxidant properties of wild Egyptian Pulicaria incise, Diplotaxis harra, and Avicennia marina. Journal für Verbraucherschutz und Lebensmittelsicherheit, 4(3–4), 239– 245.

Rozema, J., Gude, H., & Pollak, G. (1981). An ecophysiological study of the salt secretion of four halophytes. *New Phytologist, 89*(2), 201–217.

Sabovljević, M., & Sabovljević, A. (2007). Contribution to the coastal bryophytes of the Northern Mediterranean: Are there halophytes among bryophytes. *Phytologia Balcanica, 13*, 131–135.

Shabala, S. (2013). Learning from halophytes: Physiological basis and strategies to improve abiotic stress tolerance in crops. *Annals of Botany, 112*, 1209–1221.

Shabala, S. N., & Mackay, A. S. (2011). Ion transport in halophytes. *Advances in Botanical Research, 57*, 151–187.

Siew, P., & Klein, C. R. (1969). The effect of NaCl on some metabolic and fine structural changes during the greening of etiolated leaves. *The Journal of Cell Biology, 37*, 590–596.

Smichi, N., Messaoudi, Y., Moujahed, N., & Gargouri, M. (2016). Ethanol production from halophyte *Juncus maritimus* using freezing and thawing biomass pretreatment. *Renewable Energy, 85*, 1357–1361.

Squires, V. R., & Ayoub, A. T. (1994). Halophytes as a resource for livestock and for rehabilitation of degraded land. In *Tasks in vegetation Science series*. The Netherlands: Kluwer Academic Press.
Suhaj, M. (2006). Spice antioxidants isolation and their antiradical activity: A review. *Journal of Food Composition and Analysis, 19*, 531–537.
Tadhani, M. B., Patel, V. H., & Subhash, R. (2007). In vitro antioxidant activities of *Stevia rebaudiana* leaves and callus. *Journal of Food Composition and Analysis, 20*, 323–329.
Tepe, B., Sokemen, M., Akpulat, H. A., Yumrutas, O., & Sokmen, A. (2006). Screening of antioxidative properties of the methanolic extracts of Pelargonium endlicherianum Fenzl., Verbascum Wiedemanniamnum Fisch, and amEY., Sideritis Libanotica Labdill and Hieracium cappadocicum Freyn from Turkish Flora. *Food Chemistry, 98*, 9–13.
Tomlinson, P. B. (1986). *The Botany of Mangroves* (Vol. 21, p. 413). Cambridge/London: Cambridge University Press.
UNDDD (United Nations Decade for Deserts and the Fight against Desertification). (2010). (Online) Cited 28 December 2019. Available at https://www.un.org/en/events/desertification_decade/whynow.shtml
Usman, K., Al-Ghouti, M. A., & Abu-Dieyeh, M. H. (2019). The assessment of cadmium, chromium, copper, and nickel tolerance and bioaccumulation by shrub plant Tetraena qataranse. *Scientific Reports, 9*(1), 1–11.
Waisel, Y., Eshel, A., & Agami, M. (1986). Salt balance of leaves of the mangrove *Avicennia marina*. *Physiologia Plantarum, 67*(1), 67–72.
Wang, Y., & Li, Y. (2013). Land exploitation resulting in soil salinization in a desert–oasis ecotone. *Catena, 100*, 50–56.
Weber, D. J. (2008). Adaptive mechanisms of halophytes in desert regions. In *Salinity and water stress* (Vol. 44, pp. 179–185). Netherlands: Springer Netherlands.
Weber, D. J., Gul, B., Khan, M. A., Williams, T., Wayman, P., & Warner, S. (2001). Composition of vegetable oil from seeds of native halophytic shrubs. In: McArthur, E., Durant, Fairbank
Weber, D. J., Ansari, R., Gul, B., & Khan, M. A. (2007). Potential of halophytes as source of edible oil. *Journal of Arid Environments, 68*(2), 315–321.
Wilson, C., Lesch, S. M., & Grieve, C. M. (2000). Growth stage modulates salinity tolerance of New Zealand spinach (*Tetragonia tetragonioides*, Pall) and red Orach (*Atriplex hortensis* L.). *Annals of Botany, 85*, 501–509.
Wyn Jones, G., & Gorham, J. (2002). Intra- and inter-cellular compartments ofions. In A. Läuchli & U. Lüttge (Eds.), *Salinity: Environment–plant–molecules* (pp. 159–180). Dordrecht: Kluwer.
Yasseen, B. T., & Al-Thani, R. F. (2013). Ecophysiology of wild plants and conservation perspectives in the State of Qatar. *Agricultural Chemistry, 37*.
Yokoyama, S. H., & Masumura, Y. (2008). *The Asian biomass handbook*. The Japan Institute of Energy.