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Review article

Bioactive compounds and health potentials of halophytes

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ABSTRACT

Salt tolerance is indeed an agronomically essential trait that has significant implications for agriculture worldwide. Halophytes are the inimitable set of plants that adapted to thrive in highly saline environments that stand for 2% of the terrestrial plant variety. They can withstand a NaCl-rich environment due to their specialized mechanism for salt tolerance and osmoregulation and therefore may be regarded as a resource for new crops. They are commonly found in families such as Chenopodiaceae, Poaceae, Fabaceae, and Asteraceae. Halophytic plants are traditionally used for food and fuel production in certain regions and also offer several medicinal benefits. Halophytes represent rich sources of various types of biologically active phytoconstituents such as terpenes, phenols, alkaloids, flavonoids, glycosides, essential oil, and fatty oil; and responsible for the potential of biological activities such as antioxidant, anti-inflammatory, anti-diabetic, anti-cancer, cardioprotective, and neuroprotective. Various aspects of the bioactive compounds and health potential of halophytes are discussed in the present review.

INTRODUCTION

There are 400,000 known plant species worldwide, of which it is estimated that more than 50,000 are edible. However, not all edible plant species are used extensively for human consumption. A small proportion of edible plant species are grown on a large scale for food production. This is primarily due to various factors including agricultural practices, market demand and economic feasibility. Large-scale cultivation requires a significant amount of resources (El-Seedi et al., 2021), and certain plant species have been selected and cultivated for centuries for their nutritional value, ease of cultivation, and wide-ranging adaptability (Gruber, 2017; Lughadha et al., 2016). According to estimates by the United Nations on global population prospects, in 2050 there will be 9.7 billion people on earth. It is estimated that global food production will need to increase by up to 70% by 2050 to keep pace with population growth (Gustafsson et al., 2013). To achieve this goal, global agriculture must double; there are several hurdles on the way to acceleration, sustainable expansion and food security, such as climate change, which is deteriorating agricultural structures. Salinity refers to the concentration of salt in the soil, and excess salinity can negatively impact plant growth and productivity. This problem occurs in areas where irrigation is used as a means of supplying water to crops (Flowers and Colmer, 2008). Salt tolerance is indeed an agronomically essential trait that has significant implications for agriculture worldwide. Researchers and scientists are actively working to understand the mechanisms of salt tolerance in plants and to develop crop varieties that can withstand high salt concentrations in the soil. This research area includes plant breeding, genetic engineering, and biotechnological approaches to identify and introduce genes associated with salt tolerance into crops. Among the various plant resources that are currently under-exploited, halophytes are relatively rare but are able to tolerate salinity levels in excess of what most plants can handle (Flowers and Muscolo, 2015). Halophytes are the unique group of plants that adapted to thrive in highly saline environment that represent at most 2% of terrestrial plant species. “Halophyte” originates from the Greek word “halo” meaning salt and “phyton” meaning plant. They can withstand in a NaCl-rich environment due to their specialized mechanism for salt tolerance and osmoregulation and thus may be regarded as a source of potential new crops (Flowers and Colmer, 2008).

They are commonly found in families such as Chenopodiaceae, Poaceae (grass family), Fabaceae (legume family), and Asteraceae (daisy family). Many species in these families have adapted in different ways to the saline conditions. Among these families, the Chenopodiaceae, also known as the goosefoot family, is particularly well known for its high proportion of halophytes. The Chenopodiaceae include various salt-tolerant plants such as salt shrubs, sea-bugs and glasswort. It is estimated that about 500 halophytes belong to the Chenopodiaceae family. Halophytes have evolved unique physiological and morphological adaptations that allow them to survive and thrive in saline environments. These adaptations may include specialized salt glands, efficient water uptake and storage mechanisms, and the ability to excrete excess salts through their leaves. Overall, halophytes play an essential role in stabilizing coastal ecosystems as they are well-suited to colonize and thrive in saline habitats where most other plants cannot survive (Aronson, 1989).

CLASSIFICATION OF HALOPHYTES

Halophytes can be classified (Shukla et al., 2023) as follows:

Classification based on the mechanism of tolerance

1. *Salt excluding halophytes:* These halophytes minimize salt uptake by their roots and prevent salt from entering their aboveground tissues.
2. *Salt excreting halophytes:* These halophytes allow salt to enter their root tissues but actively excrete it through salt glands on the surface of their leaves or other above-ground structures.
3. *Salt accumulating halophytes:* These halophytes tolerate high levels of salt by accumulating it in their tissues without suffering significant damage. They store excess salt in vacuoles or special structures such as salt bubbles or salt hairs.

Classification based on ecology

1. *Obligate Halophytes:* These halophytes are highly dependent on high-salt environments and cannot survive in low-salt or freshwater conditions. Eg. glassworts (*Salicornia* spp.), pickleweed (*Sarcocornia* spp.), and saltwort (*Batis maritima*).
2. *Facultative Halophytes:* This can tolerate a wide range of salinity levels, from low to high. They can grow in both saline and non-saline environments but may exhibit better growth and performance in saline conditions Eg. seashore paspalum (*Paspalum vaginatum*) and marsh samphire (*Salicornia europaea*).
3. *Recretohalophytes Halophytes:* This can tolerate high salt concentrations but does not require them for optimal growth. They can grow in both saline and non-saline conditions, but they may exhibit reduced growth and performance in non-saline environments. Eg. mangroves (*Rhizophora* spp.), some species of saltmarsh grasses (*Spartina* spp.), and sea lavender (*Limonium* spp.).
4. *Succulent Halophytes:* Succulent halophytes are characterized by their ability to store water in specialized tissues, such as fleshy leaves or stems. Eg. salt marsh aloe (*Aloe maculata*), and ice plants (*Carpobrotus* spp.).
5. *Xerohalophytes:* These have adapted to arid or desert-like conditions with high salinity. They possess specific adaptations to cope with both water scarcity and salt stress. Eg. Saltbush (*Atriplex* spp.) and desert agave (*Agave deserti*).

Classification based on habitat

1. *Coastal halophytes:* These halophytes are found in coastal areas and are subjected to high salt content due to their proximity to seawater. They often grow in sand dunes, salt marshes, and mangrove forests. Examples include salt marsh grasses (*Spartina* spp.), seashore paspalum (*Paspalum vaginatum*), and mangrove species like *Avicennia marina* and *Rhizophora* spp.
2. *Salt flats and salt pans halophytes:* These halophytes are adapted to grow in areas where salt accumulates due to evaporation, resulting in saline soil surfaces. They can be found in salt flats, salt pans, or saline desert areas. Some examples include saltbush (*Atriplex* spp.), glasswort (*Salicornia* spp.), and pickleweed (*Sarcocornia* spp.).
3. *Saline wetlands halophytes:* These halophytes thrive in wetland environments with high salt concentrations. They can tolerate periods of flooding and water logging. Examples include salt marsh plants such as cordgrasses (*Spartina* spp.), salt meadow rush (*Juncus gerardii*), and salt-tolerant sedges (*Carex* spp.).
4. *Inland saline habitats halophytes:* These halophytes are adapted to grow in saline soils in inland regions away from the coast. They can be found in salt lakes, saline deserts, or alkaline soils. The examples of these halophytes are including salt-tolerant succulents like saltbush (*Atriplex* spp.), saltgrass (*Distichlis* spp.) and halophytic grass (*Sporobolus* spp.).
5. *Halophytic aquatic plants:* These halophytes are adapted to grow in saline or brackish water bodies such as saltwater marshes, estuaries, or coastal lagoons. They can float or submerge in water such as seagrasses (*Zostera* spp. and *Halophila* spp.) and saltwater cord grass (*Spartina alterniflora*).

Classification based on salt tolerance

1. *Mio-halophytes:* Plants that grow in the habitats of low salinity levels.
2. *Euhalophytes:* These are adapted to survive and thrive in high-salt environments, such as saline soils or coastal areas.

Halophytic plants are traditionally used for food and fuel production in certain regions and also offer several medicinal benefits. These plants often contain compounds with medicinal properties that are effective in treating various diseases. For example, *Ipomoea pes-caprae* is used to treat fatigue, overexertion, arthritis, rheumatism and menorrhagia. Wild halophytes contain more nutrients and bioactive chemicals and have a taste comparable to regular lettuce plants, which are believed to be key mediators of their multiple health effects (Ruiz-Rodríguez et al., 2011). The medicinal properties of different types of halophytes have been confirmed for the treatment and prophylaxis of various chronic diseases such as heart problems, diabetes, cancers and ageing (Ksouri et al., 2012). Therefore, it is of paramount importance to propose alternative crop species that can adapt to the harsh conditions of salt cultivation and are potential food and medicinal crops. Various aspects of the bioactive compounds and health potential of halophytes are discussed in the present review.

TRADITIONAL AND MODERN USES

Because of its potential as an edible oil source and its therapeutic properties, the seed of *Haloxylon stocksii* (Boiss.), a member of the Chenopodiaceae family commonly found in South Asia and the Middle East, is an important crop (Abbas et al., 2022). Medicinally this plant is used to treat burns, cuts, internal ulcers, insect stings, and urinary problems. Antimicrobial, anti-inflammatory, analgesic, hypoglycaemic, and hypo-lipidemic have been reported (Baber et al., 2018; Zafar et al., 2020). Important bioactive compounds isolated from various parts of *Haloxylon stocksii* (Boiss) are furfural (Yi and Kim, 1982); 4H-pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl (Teoh and Don, 2015); 2-furan carboxaldehyde (Praveena et al., 2010); 5-(hydroxyl-methyl); 2-furancarboxaldehyde; 5-(hydroxymethyl); 1,6-anhydro-D-glucopyranose (Do Nascimento et al., 2022); phthalic acid; bis (7-ethyloctyl) ester; di-n-octyl phthalate (Sivasubramanian and Brindha, 2013); phenol; 2,20-methylenebis[6-(1, 1-dimethylethyl)-4-(1-methylpropyl); and β–sitosterol (Dilshad et al., 2022). These compounds belong to the different classes, such as furans, aldehydes, pyrones, anhydrohexose, and fatty acid esters.

A member of the Plumbaginaceae family, *Armeria maritime* (Mill.) Wild, commonly known as cliff rose or sea rose, is an evergreen perennial plant that grows on cliffs and rocky shores in Iceland, the Atlantic coast of Europe and the western region of the Baltic Sea (Woodell and Dale, 1993). It has a phenolic acid and flavonoid-based antioxidant system that allows it to grow in saline habitats. Proline, an amino acid, is the main component of the plant (Stewart and Lee, 1974), other bioactive compounds are β-alanine betaine, glycine betaine and choline-o-sulphate (Sánchez-Hernández et al., 2023); gallic acid, caffeic acid, p-hydroxybenzoic acid present as phenolic acids. Flavonoids such as quercetin and kaempferol are present (Gourguillon et al., 2015). Hexadecanoic acid, 9-octadecenoic acid, octadecenoic acid, 3-(3,4- dihydroxy-phenyl)-acrylic acid ethyl ester, and benzaldehyde are some bioactive compounds identified in *Armeria maritime*. The dried flower has antibacterial properties and has traditionally been used to treat bladder infections (Sánchez-Hernández et al., 2023).

Capparis spinosa L. (Caper, Kabbar, Alcaparro) is well known perennial xerophytic plant of the Capparidaceae family in the Mediterranean regions of Great Sahara in North Africa and the dry regions of Western and Central Asia. It is widely used for numerous ailments including liver and kidney problems; recognized as an antioxidant, antimicrobial, anticancer, antidiabetic, anti-inflammatory and many others. It is a very good source of biologically active chemical groups including steroids, alkaloids, aliphatic and triterpenic alcohols, carotenoids, tocopherols, saponin, and phenolic compounds (Tlili et al., 2017).

Salicornia ramosissima J. Woods, member of the Chenopodiaceae family; is known in England as "purple samphire" and in Portugal and Spain as "erva-salada" and is considered a gourmet product for human consumption, is widespread in the salt marshes and salt flats of the Ria de Aveiro (Portugal) and also occurs in many salt marshes of the Iberian Peninsula off the peninsula, western France and in Serbia (Isca et al., 2014a). *S. ramosissima* is a good source of minerals such as sodium, magnesium, potassium and calcium, as well as proteins, amino acids and vitamins, which are eaten fresh or cooked in northern European countries (Lima et al., 2020); it has been used in folk medicine for disorders such as constipation, obesity and diabetes. Biologically it showed immunomodulatory, anti-inflammatory, anti-hyperlipidemic, antidiabetic, cytotoxic and antioxidant activities (Ferreira et al., 2013).

A perennial herb with a distinctive fragrance, sea fennel (*Crithmum maritimum* L.) is also known as kritmo in Greece and St. Peter's wort in England. It is found in coastal regions of southern and western European nations, along the Mediterranean Sea shores, in North America, Central Asia, and beyond. Sea fennel has been used as a tonic, carminative, anthelmintic, diuretic, and anti-scurvy since ancient times. It is also used in traditional medicine. Traditionally eaten in salads in most Mediterranean countries, either raw or after scalding in boiling water to soften it; is also eaten as an appetizer with various foods such as bread and olive oil or even capers. The hydrophilic (polyphenols, vitamin C) and lipophilic (carotenoids, essential oils, fatty acids) bioactive chemicals found in sea fennel are both abundant. Main constituents of polyphenols are hydroxycinnamic acids, rutin, quercetin, quercetin-3-O-galactoside, luteolin-6, 8-diglucoside (Kraouia et al., 2023); essential oils are sabinene and β–terpinene (Fanouriou et al., 2018); fatty acids are oleic, linoleic, and linolenic, and palmitic acid (Martins-Noguerol et al., 2022). It is a good source of minerals, especially Ca, Mg, and K (Gómez-Bellot et al., 2021).

Haloxylon salicornicum (Moq.) shrub of halophytic species belongs to the Chenopodiaceae family; found in saline areas of the Thar Desert. Different parts of plants are used in folk medicine for antiseptic, anti-inflammatory, and antiulcer effects (Shafi et al., 2001). Biologically anticancer, antidiabetic, anticoagulant (Qasheesh, 2004), hepatoprotective activity; volatile oil present in plant act as antimicrobial especially against *Staphylococcus aureus* and *Bacillus subtilis* (Ahmad et al., 2006; Sathiyamoorthy et al., 1999).

Sesuvium portulacastrum used as a medicine for fever, kidney disorders, and scurvy, and to treat infections in South Africa (Magwa et al., 2006). The essential oil present in plant exhibit antifungal, antioxidant, and antibacterial activity. Methanolic extract showed a positive effect in the treatment of Alzheimer's disease similar to the Donepezil drug (Suganthy et al., 2009).

The high phenolic content of *Arthrocnemum macrostachyum* revealed its antioxidant action. For persons with Alzheimer's disease, coronary heart disease, tumours, arteriosclerosis, and inflammation, FAME and PUFA, which are present in halophytes, are regarded as crucial dietary supplements. The ability of methanol extracts to reduce iron and chelate copper may be used to prevent oxidative stress-related illnesses like Alzheimer's disease (Custódio et al., 2012).

Halocnemum strobilaceum is a terrestrial halophytic plant of the Chenopodiaceae family, growing wildly in Egypt, has traditionally been used in Algeria and Iran as a digestive, stimulant and for treatment of fever and headache although in Egypt no data reported about the traditional uses of this plant (Mabberley, 1997). Phytosterol present in plants can reduce the cholesterol level in the blood (Brauner et al., 2012); antioxidant activity due to flavonoids was reported. Hypoglycemic and hypolipidemic activities were also reported (Narender et al., 2009).

Salsola annua referred to in the Amaranthaceae family is a valuable raw material producing high-quality food ingredients. Biologically plant is useful as anti-inflammatory (Brauner et al., 2012), antidiabetic (Kambouche et al., 2009), germicidal and antiseptic in oral disinfectants, and anaesthetic (Botelho et al., 2007).

A wild, perennial, wild halophytic herb, *Solanum surattense* Burm.f., is widely used in traditional medicine to treat coughs, asthma, bronchitis, and sore throats. The literature reports the presence of bioactive compounds solasonoin, solamargin, campesterol and diosgenin in different parts of plants, as well as pharmacological activities such as hepatoprotective, cardioprotective, anti-asthmatic and mosquito repellent (Tekuri et al., 2019).

Zaleya pentandra (L.) Jeffrey is a perennial xero-halophyte commonly found in Asian and African countries such as Pakistan, Iran, India and Africa that have sandy salt flats along the coast. The plant is traditionally used to cure coughs, stomach ailments and snake bites. According to studies, the methanolic extract of the plant contains phenolic and flavonoid components and has powerful antioxidant properties (Saleem et al., 2019).

The Fabaceae family, sometimes known as the Babul family, includes the significant halophytic shrub *Acacia nilotica* (L.), which is found in tropical and subtropical areas of Africa, the Middle East, and the Indian subcontinent. A detailed analysis of the literature found that the main types of phytocomponents in this plant are tannins, flavonoids, alkaloids, fatty acids, and gums. Pharmacology database reports have identified significant anti-inflammatory, antioxidant, anti-diarrheal, anti-hypertensive, antispasmodic, antibacterial, anthelmintic, and anticancer properties.

In wild desert areas of Asia, Africa, and Saudi Arabia, *Capparis decidua*, a plant belonging to the Capparaceae family, flourishes. The plant has various uses in traditional medicine in addition to its nutritional benefits. There have been reports of pharmacological activities including anti-diabetic, antihelmintic, antibacterial, antifungal, analgesic, antinociceptive, antirheumatic, hypolipidemic, anti-atherosclerotic, antitumor, antioxidant, anti-inflammatory, hepatoprotective, and antispasmodic effects. Several phytochemicals, including alkaloids (capparisinin, capparisin, stachydrin, and isocodonocarpine), phenols, flavonoids, sterols, and fatty acids, are responsible for the bioactivity of *Capparis deciduas* (Nazar et al., 2020).

An oil-producing halophytic tree belonging to the Salvadoraceae family, *Salvadora oleoides* Decne., is used in traditional medicine to cure a number of ailments, such as haemorrhoids, tumours, bronchitis, cough rheumatism, fever, conjunctivitis, carminative and alexipharmic agents, etc. Additionally, it has been reported to have anti-microbial, analgesic, hypolipidemic, and antidiabetic properties. Sterols such as β-sitosterol and its glucosides, flavonoids, dihydroisocoumarin, and terpenoids like methoxy-4-vinylphenol and cis-3-hexenyl benzoate are among the plant's primary constituents (Arora et al., 2015).

Cleome brachycarpa Vahl is a perennial herb in the Cleomaceae family used to treat rheumatism, as well as being an anti-inflammatory, antidermatotic, digestive and antiemetic. Chemically, flavonoids, trinortriterpenoid dilactone, deacetoxybrachycarpon, cabralealactone and ursolic acid have been detected in the plant (Afifi et al., 2014).

The most prevalent species in the dry and semi-arid regions of the Indian desert is *Ziziphus nummularia*. Tribes employ various plant parts as traditional medicine to treat ailments like allergies, scabies, eczema, and pyorrhea. Plants have been shown to have pharmacologically anti-diabetic, anti-ulcer, anti-fungal, cytotoxic, and antioxidant actions in the literature. Additionally, it helps with digestive issues. The reported phytocomponents in *Ziziphus nummularia* are polysaccharides, pectin composed of L-rhamnose, D-galacturonic acid, D-galactose, L-arabinose, peptide alkaloids, cyclopeptides, flavonoids, saponins, triterpenoids, fatty acids, ziziphin N, O, P and Q and Dodecaacetylprodelphinidine B3 (Sonia and Singh, 2019).

Citrullus colocynthis (L.) Schrad, a member of the Cucurbitaceae family is common in Pakistan's arid regions, offers medicinal and nutraceutical benefits. The plant is well-known as a traditional remedy for cancer, mastitis, diabetes, jaundice, asthma, and joint discomfort. Plants include a variety of bioactive substances, including glycosides, flavonoids, alkaloids, carbohydrates, fatty acids, and essential oils (Hussain et al., 2014).

Table 1. List of halophytes having health potential

S.No.	Halophyte	Family	Useful part	Medicinal use	Reference
1.	*Arthrocnemum indicum* (Willd.) Moq.	Amaranthaceae	shoots	antitumor	Yang et al., 2010
2.	*Chenopodium album* L.	Amaranthaceae	leaves	anticancer, cytotoxic	Zhao et al., 2016
3.	*Acanthus ilicifolius* Linn.	Acanthaceae	leaves, root	asthma, headache, skin diseases, anticancer	Velmani et al., 2016
4.	*Avicennia marina* (Forssk.) Vierh	Acanthaceae	leaves, stems	rheumatism, smallpox	Huang et al., 2016
5.	*Mesembryanthemum crystallinum* Linn.	Aizoaceae	leaves	liver problems, diabetes	El-Amier et al., 2016
6.	*Sesuvium portulacastrum* L.	Aizoaceae	whole plant	kidney problems, antioxidant	Chintalapani et al., 2018
7.	*Suaeda ruticose* L.	Amaranthaceae	leaves	anticancer	Custodio et al., 2022
8.	*Salicornia europaea* L.	Amaranthaceae	aerial parts	bronchitis, hepatitis, diarrhoea	Isca et al., 2014b

9.	*Eryngium maritimum* L.	Apiaceae	roots, shoots	diuretic, diarrhoea, headaches, digestive problems	Pereira et al., 2019
10.	*Crithmum maritimum* L.	Apiaceae	whole plant	stimulating,diuretic	Renna et al., 2017
11.	*Cakile maritima* Scop.	Brassicaceae	aerial parts	diuretic, antiscorbutic, antiproliferative, purgative	Arbelet-Bonnin et al., 2019; Omer et al., 2019
12.	*Calystegia soldanella* (L.) R.	Convolvulaceae	whole plant	rheumatic arthritis, scurvy, anticancer	Lee et al., 2017
13.	*Cymodocea rotundata* Asch. & Schweinf.	Cymodoceaceae	leaf	cytotoxic, antioxidant	Abraham et al., 2017
14.	*Cyperus rotundus* L.	Cyperaceae	rhizomes	stomach disorders	Al-Snafi, 2016
15.	*Alhagi maurorum* Medik.	Fabaceae	aerial parts	gastroenteritis, ulcers, rheumatoid arthritis,	Muhammad et al., 2015
16.	*Glycyrrhiza uralensis* Fisch.	Fabaceae	root	anti-inflammatory, antiviral	Al-Snafi, 2018
17	*Melilotus indicus* L.	Fabaceae	aerial parts	analgesic, cytotoxic	Ahmed and Al-Refai, 2014
18.	*Prosopis juliflora* Sw. DC.	Fabaceae	leaves	eye and digestive disorders, anti-inflammatory	Sathiya and Muthuchelian, 2011
19.	*Sesbania grandiflora* L. Poir.	Fabaceae	fruit, leaves	anti-inflammatory, analgesic, antipyretic, anticancer	Thamboli, 2000
20.	*Juncus acutus* L. Torr. ex Retz.	Juncaceae	leaves	cytotoxic	Rodrigues et al., 2014
21.	*Thespesia populnea* L. Sol. ex	Malvaceae	whole plant	scabies, psoriasis, skin diseases, dysentery, piles, diabetes.	Patil and Nitave, 2021
22.	Limoniastrum guyonianum Durieu ex Boiss.	Plumbaginaceae	leaves	gastric infections	Trabelsi et al., 2012
23.	*Portulaca oleracea* L	Portulacaceae	seeds	antioxidant, anti-carcinogenic	Xu and Deng, 2017
24.	*Bruguiera gymnorhiza* (L.) Lam	Rhizophoraceae	stem bark	cytotoxic	Liao et al., 2011
25.	*Ceriops tagal* (Pers.) C. B. Rob.	Rhizophoraceae	stem bark	cytotoxic	Urashi et al., 2013
26.	*Lycium barbarum* L.	Solanaceae	fruits	anticancer	Tang et al., 2012
27.	*Tamarix aucheriana* (Decne.)	Tamaricaceae	aerial parts	anticancer	Abaza et al., 2013

Table 2. List of chemical constituents present in various halophytes

S.No.	Halophytes	Chemical constituents	References
1.	*Haloxylon salicornicum* (Moq)	Alkaloids (haloxynine, halosaline, haloxine) saponins, tannins, glycosides	Ashraf et al., 2013; El-Shazly et al., 2005
2.	*Sesuvium portulacastrum* L.	Essential oil: o-cymene, α- and β-pinene, *trans*-caryophyllene,1,8-cineole (eucalyptol), limonene, α-terpinene and α-terpinolene, camphene, bornyl acetate, tridecane and alpha-humulene. sterols, flavonoids, alkaloids, organic acids, phenolic compounds	Filipowicz et al., 2003; Al-Azzawi et al., 2012
3.	*Halocnemum strobilaceum* (Pall.) Bieb.	Campesterol, stigmasterol, β-sitosterol, α-amyrin, chrysoeriol, luteolin galactoside, quercetin, scopoletin.	Radwan and Shams, 2007
4.	*Salsola annua* Bunge	Triterpenoids, α-amyrin glucopyranoside, patuletin glucopyranoside, myricitrin, sophradiol glucopyranoside, alkaloids, saponins	Abdou et al., 2013; Kambouche et al., 2009
5.	*Salicornia euro* L.	alkaloids, saponins, flavonoids, phenolic compounds, triterpenoid saponin: oleanolic acid glucoside, chikusetsusaponin methyl ester, calenduloside E and	Yin et al., 2012

		calenduloside E 6'-methyl ester, dihydroxyoleanenoic acid glucopyranosyl ester	
6.	*Suaeda maritime* (L.) Dumort	Triterpenoids, alkaloids, tannins and steroids	Bandaranayake, 2002
7.	*Avicennia marina* (Forssk.) Vierh.	fatty acids, steroids, tannins, triterpenoids, betulinic acid, taraxerol, taraxerone,	Bandaranayake, 2002
8.	*Tetraena qatarense* (Hadidi) Beier & Thulin	alkaloids, sterols, coumarins	Taha and Alsayed, 2000
9.	*Lycium shawii* Roem. & Schult.	Orientin, 3,6,2',4'- tetrahydroxyflavone, 5-O-methyl-visamminol, azukisaponin III, 9,10,11-trihydroxy-(12Z)-12- octadecenoic acid, apigenin-7-O-glucoside, alatanin	Mohammed et al., 2021
10.	*Anabasis articulate* (Forssk.) Moq.	Quercetin-3,7-dirhamnosyl, 3-Gluco-7-rhamnosyl quercetin, hyperoside, kaempferol 3-neohesperidoside, 5-o-methylvisamminol, acetylcaranine, azukisaponin III, tricoumaroyl spermidine	Mohammed et al., 2021
11.	*Zilla spinosa* (L.) Prantl	Orientin, quercetin-3,7-dirhamnosyl, 3-gluco-7-rhamnosyl, quercetin, kaempferol 3-neohesperidoside, 5-o-methylvisamminol, acetylcaranine, azukisaponin III, tricoumaroyl spermidine, tricoumaroyl spermidine	Mohammed et al., 2021
12.	*Rumex vesicarius* L.	Sorbitol, galabiose, chlorogenic acid, quercetin-3,7-dirhamnosyl, luteolin, kaempferol, kaempferol-3-O-glucoside	Mohammed et al., 2021
13.	*Anabasis ehrenbergii* Schweinf. ex Boiss.	Carbohydrate: xylose, ribose, rhamnose; phenolic compound: rutin, naringenin, gallic acid, chlorogenic acid; amino acid: leucine, methionine, phenylalanine, aspartic acid, carbohydrate: galactose, glucose	Hawas et al., 2022
14.	*Suaeda aegyptiaca* (Hasselq.) Zohary	Gallic acid, syringic acid, glucose, mannose	Hawas et al., 2022
15.	*Suaeda monoica* Forssk. ex J.F.Gmel.	Gallic acid, coumaric acid, naringenin, glucose	Hawas et al., 2022
16.	*Zygophyllum album* L.F.	Naringenin, rutin, arabinose, glucose	Hawas et al., 2022
17.	*Atriplex halimus* L.	Flavonoids, tannins, alkaloids, saponins, 3′,5′-dimethoxymyricetin-3-O-β-D-xylopyranosyl-7-O-fucopyranosyl-(1 → 3)-β-D-glucopyranoside, 3′-methoxyquercetin-7-O-β-D-fucopyranosyl-(1 → 3)-β-D-glucopyranosyl-3-O-β-xylopyranosyl-(1 → 4)-β-xylopyranoside, 3′-methoxyquercetin-7-O-α-L-rhamnopyranosyl-3-O-α-arabinofuranosyl-(1 → 6)-β-D-glucopyranoside, 3′,5′-dimethoxymyricetin-7-O-fucopyranosyl-(1 → 3)-β-D-glucopyranoside	Benhammou et al., 2009; Clauser et al., 2013
18.	*Atriplex gmelinii* L.	3,5-dicaffeoyl-epi-quinic acid	Oh et al., 2018
19.	*Atriplex littoralis* L.	Atriplexins, spinacetin, arbutin , 4-hydroxybenzyl-β-d-glucopyranoside	Gođevac et al., 2015
20.	*Avicennia alba* Blume	Neophytadiene, hexadecanoic acid, catechol borane	Eswaraiah et al., 2020
21.	*Avicennia marina* (Forssk.) Vierh	6' -O-(n-butanol) ilekudinoside B ester	Yang et al., 2018
22.	*Echinochloa. crus-galli* (L.) P. Beauv.	5,7-dihydroxy3'4'5' -trimethoxy flavones	El Molla et al., 2016
23.	*Plantago lanceolata* L.	Rutin, myricetin, quercetin, kaempferol, O-cumaric,	Alsaraf et al., 2019
24.	*Suaeda fruticosa* (L.) Forssk.	Monoterpenes: dihydrojasmone, jasmolone, terpinene-4-ol, Diterpenes: pimaric acid, steviol, momilactone B, phenolic compounds: quercinol, zingerone, zingerol, neovaflan	Saleh et al., 2020
25.	*Tamarix aucheriana* (Decne.) Baum	Methyl ferulate, syringic acid	Bahramsoltani et al., 2020
26.	*Lycium barbarum* L.	Scopoletin, 2-O-β-D-glucopyranosyl-L-ascorbic acid	Tang et al., 2012
27.	*Portulaca oleracea* L.	Portulacerebroside A, portulacanones B, C & D, 2,2' -dihydroxy-4',6'-dimethoxychalcone	Zhou et al., 2015; Zheng et al., 2014
28.	*Juncus acutus* L.	Juncunol	Rodrigues et al., 2014
29.	*Cynodon dactylon* L. Pers	Delphinidin-3-O-acetylglucoside	Khlifi et al., 2013
30.	*Limbarda crithmoides* (L.) Dumort	10-Acetoxy-9Z-chloro-8,9-dehydrothymol, 10-acetoxy-8,9-epoxythymol tiglate	Adorisio et al., 2020

BIOACTIVE COMPOUNDS FROM HALOPHYTES

Bioactive compounds are naturally occurring or synthetic chemical substances found in various living organisms including plants, animals, fungi and microorganisms. These compounds are known for their biological activity and have the potential to interact with living organisms and affect their functions. They play an essential role in various physiological processes and can have a positive effect on human health. Examples of bioactive compounds are polyphenols (e.g. flavonoids, resveratrol), alkaloids (e.g. caffeine, morphine), terpenoids (e.g. carotenoids, essential oils), peptides, enzymes and various vitamins and minerals. These compounds are of great interest to researchers and the pharmaceutical industry because of their promise for drug development, functional foods and nutraceuticals, and for improving health and well-being. However, it is important to note that while many bioactive compounds offer health benefits, some may also have negative effects or interact with medications. Therefore, their use should be approached with caution and proper guidance (Bernhoft, 2010). Halophytes represent rich sources of various types of biologically active compounds, such as terpenes, phenols, alkaloids, flavonoids, glycosides, essential oil, and fatty oil; and are responsible for numerous pharmacological activities. These compounds also have the potential to be used as medicines (Arya et al., 2019). Table 2 presented a detailed list of chemical constituents of various halophytes.

CONCLUSION

Indeed, domesticating novel crops from the wild, especially halophytes, can play a crucial role in ensuring food security and adapting to changing environmental conditions. The salinization of arable land and freshwater areas has posed a significant challenge to traditional agriculture, making it essential to explore alternative options for increasing food production and diversification. Halophytes, which are plants adapted to grow in saline environments, offer a promising solution. By utilizing these plants for cultivation on saline land, we can potentially increase productivity and reduce the pressure on conventional arable land and freshwater resources. Furthermore, halophytes may provide unique health benefits beyond the staple diet, as they contain various bioactive compounds with several advantageous properties. The bioactive compounds found in halophytes include phenols, flavonoids and flavanones, saponins, sterols, diterpenoids, phthalic acid, tocopherol, and terpenes. These compounds have been identified and isolated, and they are known for their diverse health benefits. Some of the notable health properties associated with these bioactive compounds include antioxidant, anti-inflammatory, anti-diabetic, anti-cancer, cardioprotective, and neuroprotective effects. Due to these potential health benefits, halophytes have attracted consumer attention as a possible addition to the diet. However, it's crucial to highlight that more research is still needed to fully understand and harness the potential of halophytes as a food source. Both preclinical and clinical studies are necessary to explore the effects of these bioactive compounds on human health. Additionally, further investigations at the cellular and tissue levels are urgently required to unravel the biomolecular mechanisms underlying the health-promoting properties of these compounds.

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DECLARATION

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