Ensuring Food Security of Arid Regions through Sustainable Cultivation of Halophytes

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Contents

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Abstract

Scarcity of quality feed in Pakistan is the main cause for the limited growth and decline of livestock that has a significant contribution in the agriculture sector. Different species of halophytes are being grown as fodder in low rainfall and drought-hit areas of many developed countries to overcome the shortage of feed for livestock. A large proportion of saline land on the global scale can be made productive by growing halophytic plants which could be used as food, fodder, and forage. Soil salinity has destroyed most of the irrigated agricultural lands worldwide because salt-sensitive crops cannot survive in such conditions; however, halophytes can survive and reproduce in highly diverse saline habitats, because of their ability to survive in extreme and diverse saline conditions by evolving different adaptive mechanisms. There is a need to explore the potential of halophytes as forage and fodder for livestock. Many dicot and monocot species, particularly halophytic grasses and many members of Chenopodiaceae and Cyperaceae, are excellent candidate crops for food and fodder production; however, their yield depends on the nature of plant and soil.

Keywords

Food scarcity · Food security · Sustainability · Grasses

1 Introduction

Human activities have a great impact on the global climate in the form of weather anomalies, drought spells, and floods. In future, farmers will face more challenges to cope with this difficult situation due to environmental pollution, global warming, and a number of other threats to agriculture. Uncertainties for agricultural production will increase due to weather extremities including more intense and frequent floods and droughts. A large area covered by crops, forests, and grasslands in Asia and other continents had been degraded due to such a tremendous increase in environmental constraints. Soil erosion is another important factor, adversely affecting the productivity of fertile agricultural lands. In many countries, deserts are expanding and area under cultivation is shrinking due to land degradation. This resulted in a gradual decline of crop output to as much as 40% that would further escalate in the next 50 years. Abiotic stresses (i.e., drought and salinity) have become major challenges around the globe for food security and sustainable agriculture resulting in the loss of soil productivity (Murdiyarso 2000).

Globally, about 7–10% of the land is highly saline. Salinity had affected arid and semi-arid areas to a greater extent than did by humid regions. About 20% of the irrigated agricultural land worldwide had been degraded due to increasing salinity, resulting in a significant reduction in crop yield. In some cases, a yield reduction of up to 70% has been recorded in crops grown in saline soils. Food and livestock population is substantially declining because many crops cannot either survive or show very less yield sometimes even when exposed to low salt concentrations.

However, halophytes have a potential to survive and can grow and reproduce in highly salt-affected lands (Colmer et al. 2006). This situation worsens, and conventional agriculture gets damaged in areas particularly with low rainfall and high temperature in summer. Such adverse effects of salinity on crop productivity are contrary to our increasing needs for food. For example, most of the cereals presently under cultivation are salt-sensitive and cannot survive even in low levels of soil salinity (Ventura and Sagi 2013). There is a dire need to combat these issues by implementation of different strategies for sustainable crop production. Halophytes provide an excellent opportunity to be grown as food and forage, because of their inherent potential to survive in such harsh saline environments.

Food security is also threatened by salinity which will have many complex effects. Hence, there is a dire need to resolve the issue of food insecurity. In a broad sense, the food security means to enable the availability of basic food to all people at all times, and they should have sufficient, safe, and nutritious food which fulfill their basic requirement of diet necessary for an active life. According to FAO, stability is needed to make available sufficient quantity of food, and population must have access to adequate food supply (Timmer and Dawe 2007).

Cultivation of halophytes, in arid and semi-arid regions, may be considered as one of the potential strategies to ensure food security. Such areas are confronted with multifarious problems like drought, salinity, nutrient depletion, and soil erosion. As a result of these constraints, the productive potential of these areas is adversely affected. Halophytes have a great potential to promote agriculture and restore the habitat of such areas, and can grow in saline habitat with an ability to tolerate high salts and can survive in extreme conditions, i.e., drought, salinity, and other harsh environmental conditions. They have a prime importance: protecting various habitats and stabilizing ecosystem diversity. They are a source of food, fodder, and forage and provide shelter to a large number of aquatic and terrestrial animal species. Vegetative organs of halophytes have high salts, so their effect can be neutralized by humans and livestock by mixing them with other plants (Norman et al. 2011). However, their seeds have low quantity of salts and can be used as food particularly for oil extraction (Glenn et al. 2013). Halophytes have a great diversity regarding their habit and habitat and can be used for their uses like food, fodder, and forage. They have evolved to various mechanisms to endure highly saline habitats, and these strategies comprise different changes from molecular level to morphological adaptations enabling halophytes to thrive well under highly saline conditions. There is a great diversity of true halophytes belonging to monocot and dicot families present in deserts and areas with high salt concentration (Khan and Qaiser 2006).

2 Economic Potential of Halophytes

Due to gradual changes in climate, there are many limitations for cultivation of conventional crops in water-scarce and saline areas, where the above-cited issues are more challenging (Slama et al. 2015). Therefore, it is necessary to plan the cultivation of alternative crops that have the ability to grow under harsh conditions, i.e., drought and salinity. The sustainable cultivation of these crops may be promoted as cash food crops in future (Panta et al. 2014).

Halophytes are economically very important, as they could be grown successfully in saline soils (Aronsen 1989). There is a promising potential in some halophytes to be used as food, fodder, forage, and for commercial and medicinal purposes (Aronsen 1989). In coastal areas, halophytes are not only very diverse, but they also play a key role to prevent soil erosion, and as a source of fodder for cattle, and shelter for a number of terrestrial and aquatic animal species. Halophytes can help produce fodder for livestock especially in areas where livestock is very limited because of fodder shortage and is directly linked to human survival. Natural resources are facing a continuous decline because of population explosion. Under current situation, those natural resources neglected for long time, such as halophytes, should be re-assessed for future utilization. Perennial halophytic grasses like *Desmostachya bipinnata*, *Panicum antidotale*, and *Panicum turgidum* have potential to be used as fodder crops in areas facing drought and salinity (Khan 2003). Different animals prefer to consume different halophytic plant species. For example, sheep and goats prefer to eat *Alhagi maurorum* and *Atriplex leucoclada*, while camels prefer to eat *Salicornia fruticosa* (Glenn et al. 1999).

In the arid regions of the world, cultivation of halophytic fodder crops may be helpful to compensate the shortage of conventional crops. Salt-affected soils limit and suppress the crop growth resulting in decreases yield. Thus, successful cultivation of halophytes depends on the nature of the plant species and the degree of soil salinity (Koyro et al. 2013). For example, Kallar grass (*Leptochloa fusca* L.) has the ability to grow in extreme alkaline soils and has a potential to give maximum yield in the form of green fodder for forage (FAO 2008). There are many other halophytic species which can be utilized as food, forage, or fodder, and their leaves are browsed by camels and used as cattle feed. Many monocotyledonous and dicotyledonous species are common in saline areas and are being used as forage (Dagar 1995) (Figs. 1 and 2).

3 Palatability and Feeding Value of Halophytes

Halophytes have a great variation in their quality as forage that is affected due to various factors, i.e., palatability, nutrient composition, quantity of plant secondary metabolites, feeding value, voluntary animal feeding, and nutrient digestibility. The quality of forage and its suitability for cattle can be determined by analyzing nutrient contents and its chemical composition (Duncan et al. 2000).

Palatability may be due to some other factors such as water content of some plant species having more relative abundance on the rangeland. Additionally, some animal factors and chemical composition may also contribute to the palatability of halophytic forages. For example, if the forage has more crude fiber, it will be preferred by livestock especially the cows and buffaloes as compared to sheep and goats. The palatability and feeding values of some halophytes are very high, while some halophytic species have zero palatability, so in almost all forage populations, palatability may vary from one plant species to the other. Animal factors, i.e., type and nature of animal species, age, physiological, and health status as well as feeding habits, also determine the palatability of the halophyte forages in addition to plant

Fig. 1 Some dicotyledonous halophytes/salt-tolerant plants used for edible purpose in arid regions

internal factors. Palatability of halophytic forages is also affected by the chemical composition of halophytes. For example, if a halophytic forage has more crude fiber percentage, then there is more chance of its selection by livestock because cattle, i.e., cows and buffalos, usually prefer forages with high-fiber contents. Mineral contents and ash percentage are also critical factors for palatability (Glenn et al. 1999).

Halophytic plant species exhibit significant variations regarding their chemical composition, nutritive value, and palatability. Nutritional value of any animal feed is determined by its chemical composition. So, the first indicator of nutritive value of any forage species is its nutrient concentration. The variations in chemical composition and nutrient contents of halophytic forages may be related to the variations in plant growth-controlling factors, e.g., soil fertility, salt concentration in soil, and environmental factors like rainfall and temperature (Koyro et al. 2013).

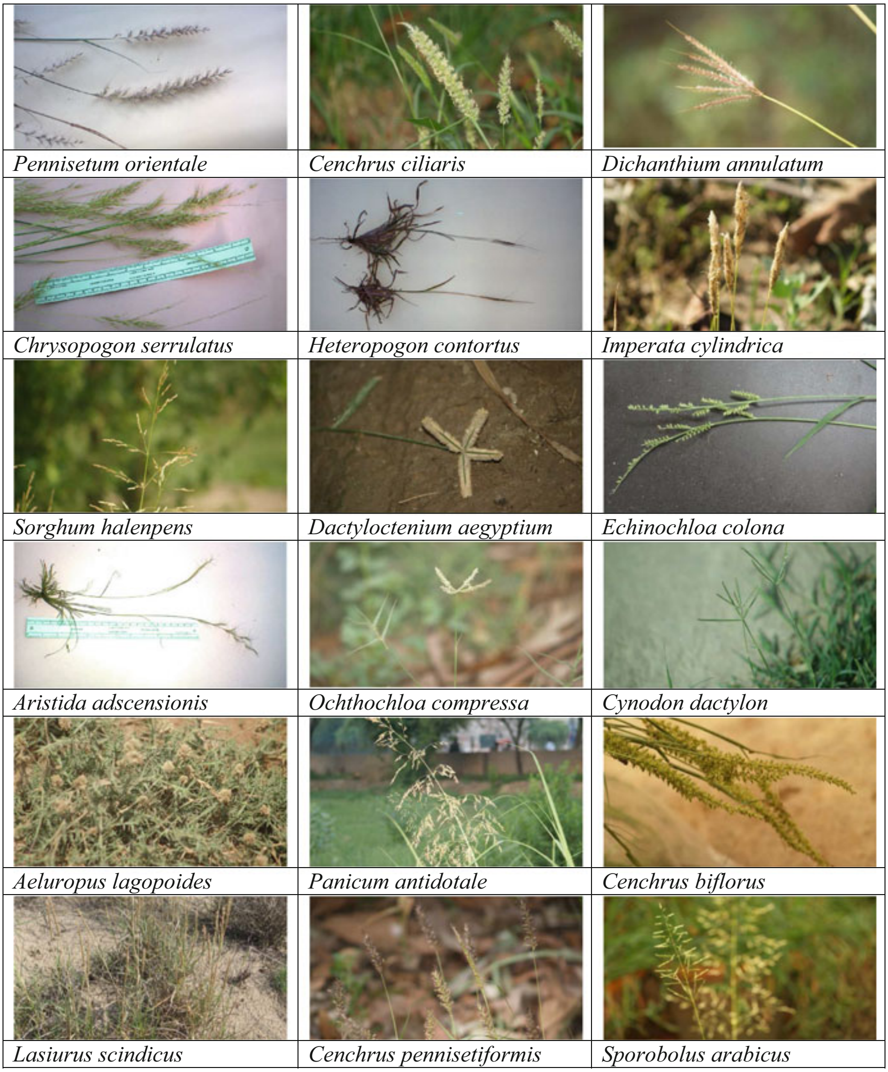

Fig. 2 Some halophytic/salt-tolerant grasses used for edible purpose in arid regions

4 Halophytes as a Source of Food, Fodder, and Forage

In this section, the description of the most important edible halophytes is presented. Different plant parts, i.e., young leaves and shoots of different plant species, are used as food and have also been used as vegetables and salads. These plant species have high salt tolerance and potential to grow in saline and dry and rain-fed areas.

4.1 Amaranth (*Amaranthus*)

The genus *Amaranthus* (L.), belonging to Amaranthaceae family, comprises several members that are able to grow in diverse environments (Mlakar et al. 2010). Amaranth has a very fast growth rate and shows tolerance to extreme conditions. It has a remarkable potential to grow under a wide range of temperature and light conditions. Because it can tolerate drought and salinity, so it has a potential to be used as an important food crop in arid and semi-arid regions (Myers 1996). *Amaranthus retroflexus*, *Amaranthus hybridus*, *Amaranthus powellii*, *Amaranthus spinosus*, and *Amaranthus viridis* are the weeds with worldwide distribution, and cultivated species are their derivatives (Pavlik 2012).

Many civilizations have cultivated the amaranth for use as beverages, sauces mixed with maize flour and for medicinal purpose, and also for religious practices. Amaranth has nutritional and economic value because it is enriched with high-quality proteins. It is a pseudo-cereal with more protein than important cereals, contributing to more than 50% of the total protein on a global level. The protein content is 14.0–16.5%, and lysine, dietary fiber, calcium, and iron are present in significant quantity in grains (Venskutonis and Kraujalis 2013). The amaranth plant species are being cultivated in different regions of the world due to high nutritive value. This crop is of prime importance and has a great potential to grow in arid and semi-arid regions to overcome food scarcity.

4.2 *Beta vulgaris* subsp. *maritima* (L.) Arcang. (Sugar Beet)

Sea or wild beet (*Beta vulgaris* subsp. *maritima* (L.) Arcang.) belongs to the family of Chenopodiaceae. It grows in salt marshes, exhibits high salt-stress tolerance, and can endure harsh conditions (Ribeiro et al. 2016). Its leaves and stem are used as food after cooking or raw greens in different regions (Turner et al. 2011). They also have antioxidative and medicinal properties as they are enriched with vitamin E, phenolics, and flavonoids, while the juice and leaves are used as carminative, purgative, and laxative (Morales et al. 2014), and have a significant amount of α-linolenic acid, linoleic acid, and palmitic acid (Zardi-Bergaoui et al. 2017). Regarding the medicinal properties, essential oil from wild beet has strong antioxidants (Zardi-Bergaoui et al. 2017), and cooked leaves and stem are used for stomach problems (González-Tejero et al. 2008), for healing wounds, and for the treatment of respiratory tract infections (Guarrera and Savo 2013).

4.3 *Capparis spinosa* L. (Caper Bush)

Caper (*Capparis spinosa* L.) belonging to Capparaceae family is a xerophytic plant (Chedraoui and Rajjou 2017). Its leaves, buds, flowers, and fruit are edible and are used for culinary purposes and traditional medicines (Chedraoui and Rajjou 2017).

Caper contains key bioactive molecules such as alkaloids, saponins, terpenes, phenolic compounds, glucosinolates, lipids, and liposoluble compounds (Aichi-Yousfi et al. 2016; Akkari et al. 2016; Mansour et al. 2016). *Capparis spinosa* also acts as a strong antioxidant (Mansour et al. 2016) and is used to cure a number of diseases such as hyperglycemia, liver and kidney problems, stomach, and respiratory disorders (Anwar et al. 2016). The species can grow under drought and salinity conditions in arid and semi-arid regions and has a potential to survive in dry lands and mountain slopes, with an ability to absorb water more efficiently, due to its extended root system (Mahmood et al. 2013).

4.4 *Chenopodium album* L. (Bacon Weed)

White goose foot (*Chenopodium album* L., Chenopodiaceae) is a salt-tolerant weed, growing in drought and saline areas, and its young vegetative organs are used as food, salad, or in cooked form (Panta et al. 2014). It is a vegetable with green foliage, very beneficial for human health. It is enriched with important vitamins, minerals, fiber, and essential amino acids and is a cheap food source especially in the developing countries where the daily diet is full of starch. There are many wild vegetables in the world which are never utilized by people because their nutritional potential is not exposed due to the lack of scientific knowledge and information. *Chenopodium album* is one of the underexploited vegetables which have many nutritional benefits (Ksouri et al. 2012).

Chenopodium album is rich in high lysine and methionine contents. Recently, *C. album* has got importance because of its potential to grow under stressful conditions like low rainfall, high temperature, and high altitude. It has high nutritional value, as its leaves are used as raw in salads or cooked, and is part of the human diet in many developing countries. *Chenopodium album* leaves are an important source of calcium and vitamins and can be used in different food products to enhance their nutritional value (Poonia and Upadhayay 2015). *Chenopodium album* has a high content of vitamin C (155 mg/100 g), carotenoids (12.5 mg/100 g), and fibers (4–6 g/100 g) and higher iron contents in the leaves than those in commonly consumed spinach and cabbage, but lower than those in *Amaranth* leaves (Sangeetha and Baskaran 2010).

It is also an important medicinal plant with high antioxidant activity and is used as diuretic, laxative, sedative, and hepato-protective. Increased awareness and more use of this plant will not only prevent diseases, i.e., cancer and cardiovascular disorders, but also will be highly beneficial to the rural community (Ksouri et al. 2012).

4.5 *Chenopodium quinoa* Willd. (Quinoa)

Quinoa (*Chenopodium quinoa* Willd.) is a facultative halophyte belonging to the Chenopodiaceae family. It is an important commercial crop in different South American countries, i.e., Peru, Bolivia, and Ecuador. Its cultivation has spread to other places such as the United States, China, and Europe. It is also grown in Canada, as well as in Kenya and South Asia. It has adapted to harsh climatic conditions. Its good growth in a variety of soil types indicates that quinoa has a great potential to adapt to different environments. Quinoa has more nutritional value than conventional cereals and protein content, and their quality is superior to that of common cereal grains (Schoenlechner et al. 2008).

In the current scenario, the water scarcity, i.e., drought, and the increasing salinity are the basic causes of crop loss and low yield worldwide and may become even more severe with the increasing climate change impact. Quinoa can tolerate different environmental conditions which makes it a good candidate crop to combat challenges regarding food security. Today, people are more interested in replacing conventional pseudo-cereals with cereals, i.e., quinoa or amaranth having more nutritional value, or using them as supplement to common cereals to improve or maintain their health (Koziol 1992).

Quinoa is very important because of its great nutritional value, specific composition, and significant amount of minerals, vitamins, and other bioactive components such as saponins and polyphenols (Schoenlechner et al. 2008). The protein content in quinoa is significantly more as compared to common cereals and that of wheat (Taylor and Parker 2002).

Quinoa has a great potential to be grown as an oilseed crop because it has fatty acid profile, the same as that of maize and soybean oil. Quinoa seeds are enriched with unsaturated fatty acids like wheat seeds, and its mineral contents are also more than those in other cereals. High amounts of calcium, magnesium, iron, and zinc are present compared with those in wheat or barley (Schoenlechner et al. 2008). Quinoa seems to be an important crop to be cultivated with common cereals to ensure food security in water-scarce, arid, and semi- arid areas.

4.6 *Cichorium spinosum* L. (Spiny Chicory)

Spiny chicory (*Cichorium spinosum* L.) belonging to the Asteraceae family is common in coastal and mountainous areas and is found in Australia, Algeria, Egypt, Tunisia, the Philippines, Senegal, Thailand, Sudan, Kenya, Nepal, Zambia, Afghanistan, and India. It is of halophytic nature and could be grown in saline soils, as well as in the arid areas as a leafy vegetable on commercial scale. It is used as a summer vegetable due to its good taste and is used fresh or dry. In recent studies, the beneficial health effects of this plant species have been explored. In many countries and different regions, it is commonly used as staple food (Klados and Tzortzakis 2014).

It has more nutritional value as compared to that in spinach and is a good source of carotenoids, vitamin C, vitamin E, glutathione, and minerals, so it may be an important component of human diet. Furthermore, phenolic content and antioxidant activity may contribute to human health. This species has considerable antioxidant activity as high amounts of tocopherols and phenolic compounds are present in its leaves (Petropoulos et al. 2017).

4.7 *Crithmum maritimum* L. (Sea Fennel)

Sea fennel (*Crithmum maritimum* L.), a member of family Apiaceae, is a perennial, facultative halophytic plant and is commonly found in different European countries (Jallali et al. 2012; Pereira et al. 2017). It is commonly found near coastal areas, rocky mountains, and sandy tracts (Renna and Gonnella 2012). In different regions of the world, sea fennel is used as an important food ingredient for different recipes. It has high essential oil contents, and its leaves and seeds are a rich source of essential fatty acids. It is used as food and is commonly used in different food dishes in different regions. Its leaves are used in the form of salad or pickled; dried leaves are used as a coloring agent, and flower tops are used as herbal tea (Siracusa et al. 2011), while all aerial parts can be used in beverages (Pereira et al. 2017). Seeds contain a significant amount of oils, with the same composition as that of olive and canola oil (Atia et al. 2010).

Sea fennel has also medicinal value and can be used as a diuretic, digestive, laxative, and purgative. Sea fennel has high content of phenolic compounds, so it has a strong antioxidant activity (Meot-Duros et al. 2010). Sea fennel is a promising crop and can be cultivated on saline and water-deficit soils for sustainable agriculture, but currently it is underutilized for commercial cultivation. It is a halophyte with a great potential to adapt to different habitats, so it can be considered as an alternative crop to ensure food security in arid regions.

4.8 *Cynara cardunculus* L. (Artichoke Thistle)

Cardoon (*Cynara cardunculus* L.) also known as artichoke thistle belonging to the Asteraceae family is a species that has gradually adapted to saline and water-deficit areas (Ceccarelli et al. 2010). It is cultivated on a large scale in Italy followed by Spain, France, and Greece (Lattanzio et al. 2009). It is produced commercially by vegetative propagation. Artichoke is of prime importance in human nutrition (Lattanzio et al. 2009). Artichoke has a significant contribution in agricultural economy of different European countries where its production is more than half of the total world production. Immature inflorescences or buds of wild and cultivated species are used as a supplement in different food dishes, while the whole plant may be used for cheese production, in the food industry. Flower heads are enriched with minerals, vitamin C, and dietary fibers (Ceccarelli et al. 2010). In seeds crude protein and crude fiber are 21.6% and 17.1%, respectively, while high contents of polyphenolic compounds, inulin, fiber, and minerals are found in foliar and flower parts. Apart from its consumption as food, some cardoon varieties have also medicinal value due to rich bioactive compounds (Lattanzio et al. 2009). Leaves and stem of cardoon are rich in nutrients, and the forage has a very high digestibility for organic matter, while ensilage is the most appropriate way for preserving it for long periods. As this species is well adapted to drought, it is recommended to be grown in arid areas to assist food crops to ensure food security (Fernandez et al. 2006).

4.9 *Eryngium maritimum* L. (Sea Holly)

Sea holly (*Eryngium maritimum* L.) belonging to family Apiaceae is a perennial halophytic shrub, which shows better growth in nitrogen-deficit soil and in saline conditions (Clausing et al. 2000). The species grows usually in sandy soil and can be found along the coasts in Europe and in North Africa (Tlili and Khaldi 2017). The leaves and roots of this plant species are edible and have medicinal value and are used for treatment of different diseases (Lajnef et al. 2017). Sea holly has a significant quantity of phenolic acids in roots and aerial parts, i.e., leaf and stem (Mejri et al. 2017). Seeds of *Eryngium maritimum* are rich in oil contents, and its roots also contain essential oils (Darriet et al. 2014).

4.10 *Inula crithmoides* L. (Golden Samphire)

Golden samphire (*Inula crithmoides* L., syn. *Limbarda crithmoides* (L.) Dumort.) belonging to family Asteraceae is a succulent commonly present in Europe. It shows potential to be grown in severe arid climatic conditions, i.e., in drought and salinity. Its young leaves are used as food and have medicinal value (Zurayk and Baalbaki 1996). Aerial parts of the plant have antioxidant activity and used as traditional medicine for treatment of bronchitis, tuberculosis, and anemia (Malash et al. 2015).

4.11 *Plantago coronopus* (Buck's-Horn Plantain)

Plantain (*Plantago* spp.) belonging to Plantaginaceae family is common in dry and arid environments. Leaves and flowers of *P. coronopus* are of medicinal value and have a great use in European pharmaceutical industries, while leaves of other *Plantago* species can be used in food industry and as supplement for making different food dishes (Pereira et al. 2017).

Plantago coronopus is a halophyte with a wide variety of ethnomedicinal uses. The leaf, stem, and roots of the plant have medicinal uses and have anticancer, antimicrobial, antiviral, anti-inflammatory, analgesic, and astringent properties (Jdey et al. 2017). *Plantago* species are high in primary and secondary metabolites, namely, phenolic, flavonoids, lignin, glycosides, triterpenes, and polysaccharides (Jdey et al. 2017). Its roots have the highest phenolic content and a variety of phenolic compounds, followed by flowers and leaves. Moreover, this species is also a valuable source of amino acids and minerals, which may be a used in human nutrition on a large scale (Pereira et al. 2017).

4.12 *Portulaca oleracea* L. (Common Purslane)

Common purslane (*Portulaca oleracea* L.) belongs to the Portulacaceae family. It is an important cosmopolitan plant (Karkanis and Petropoulos 2017). Its vegetative parts are used as salad and vegetable. It has omega-3 fatty acids in significant amount. This species has a medicinal importance in curing various diseases (Ramadan and Tolba 2017).

In addition to omega-3 fatty acids, common purslane is enriched with several other fatty acids (Uddin et al. 2014). Oxalic acid and minerals are found in significant quantity (Alam et al. 2014), while different types of alkaloids, mucilage, pectin, flavonoids, and phenolic acids have also been reported (Erkan 2012). These phenolic compounds are used to improve heart functioning and blood circulation, reducing human cancer. It also acts as anti-inflammatory agent (Ramadan and Tolba 2017). *Portulaca oleracea* is a widely distributed halophyte present in diverse habitats, so it has a great potential to grow in different regions of the world, as food and for medicinal purpose (Alam et al. 2014).

4.13 *Salicornia herbacea* L. (Glasswort)

Glasswort (*Salicornia herbacea* L.) belonging to family Amaranthaceae is a halophytic plant species commonly grown in saline soils and salt marshes (Kim et al. 2017) and coastal areas, flood areas, and saline lakes (Anwar et al. 2016). This plant is used as food and medicine in seashore areas of different countries. The leaves, stem, and flowers of the plant are used and eaten as vegetable in many European countries as these are enriched in sodium, potassium, and calcium and other minerals. Their major amino acids include glutamic acid, leucine, isoleucine, and aspartic acid (Ksouri et al. 2012), while ground dried powder is used for vinegar production that has anti-fatigue properties (Zhao et al. 2014).

Salicornia herbacea has several bioactive compounds that have medicinal importance and used as laxative and purgative, to reduce body fats, and as anti-diabetic and anti-carcinogenic (Ksouri et al. 2012).

4.14 *Salsola soda* L. (Saltwort)

Saltwort (*Salsola soda* L.) belonging to family Amaranthaceae is an annual halophytic succulent shrub (Polat and Satıl 2012). It can be used for reclamation of saline soils and can be grown in association with conventional crops. In some parts of Europe, saltwort is grown along with other crops, i.e., tomato and pepper, in saline soils. It is found that pepper and tomato show maximum yield when grown together with *S. soda*, but less production was recorded when grown alone. The higher yield of these plant species is due to the ability of the halophytic plant to accumulate Na, thus reducing its impact on pepper and tomato (Tundis et al. 2009).

It is cultivated in Italy and is being introduced as a commercial cash crop due to its value products. Its leaves are used as raw or cooked as vegetables. Saltwort has various bioactive compounds including flavonoids, alkaloids, and minerals (Centofanti and Bañuelos 2015).

Salsola soda is medicinally very important, as it is used for the treatment of diabetes. Its aerial parts show a marked antioxidant activity. Due to a rapid change in climate, salinization and drought problems are expanding worldwide, resulting in a gradual decline in crop yield. Cultivation of halophytes in saline and drought-hit areas is highly recommended to address food security challenges. Therefore, *S. soda* has a promising potential to be grown as a commercial cash crop in addition to conventional cereals and food crops (Tundis et al. 2009).

4.15 *Sesuvium portulacastrum* L. (Glasswort)

Sesuvium portulacastrum is a herbaceous perennial halophyte of family Aizoaceae. This species has a wide distributional range, and it usually grows in coastal and warmer areas and is an important source of nutritious food and fodder. Glasswort has salty taste and fleshy, cultivated on a large scale, because of its great food value as a vegetable for cooking purpose (Lokhande et al. 2009). It has economical as well as medicinal importance and is used in the perfumery and food industries (Ramani et al. 2006).

It is the plant with high nutritional value because proteins, carbohydrates, and crude fiber are present in significant quantity. It can be grown in the arid and semi-arid regions as an alternative source of food and fodder for domestic animals (Magawa et al. 2006).

The organic compost of these halophytes, i.e., *S. portulacastrum*, *Suaeda maritima*, and *Ipomoea pes-caprae*, can be used as an alternative source of chemical fertilizers to improve the soil fertility and crop yield. Soil fertility in the arid and semi-arid regions has decreased due to the excessive use of toxic chemical fertilizers, so the organic mixture of these halophytes could become an important source of fertilizer in future for sustainable agriculture (Balakrishnan et al. 2010).

4.16 *Suaeda fruticosa* Forssk. (Shrubby Sea Blight)

Shrubby sea blight (*Suaeda fruticosa* Forssk.) is a halophyte belonging to Amaranthaceae family, and it commonly occurs in areas with high salt concentration. Its seeds have significant quantity of oil used by humans for different purposes, while foliage is used as food or forage (Devi et al. 2016).

Shrubby sea blight has fatty acids, such as linoleic and oleic acids, palmitic and stearic acids (Ozcan 2014), and different minerals (Towhidi et al. 2011). It has a significant quantity of phenols, flavonoids, tannins, carotenoids, alkaloids, and saponins (Oueslati et al. 2012; Qasim et al. 2017), which depict medicinal potential of the species. *Suaeda fruticosa* has high concentration of phenolic compounds and shows bioactive activity (Qasim et al. 2017). It is also used in traditional medicine against diabetes and for effective lipid metabolism (Benwahhoud et al. 2001).

4.17 *Tribulus terrestris* L. (Puncture Vine)

Puncture vine or devil's thorn (*Tribulus terrestris* L.) belonging to family Zygophyllaceae is commonly found in sandy tracts, and arid regions of the world and is considered moderately salt tolerant. It has a wide distributional range and has ethno-medicinal value (Hammoda et al. 2013).

After the rainy season, *Tribulus terrestris* is widely grazed by cattle, sheep, and goats. Animal production can be increased by harvesting this plant and drying it during the wet season and then feeding it as a protein supplement during the dry season. However, the excessive use of the leaves of *T. terrestris* as fodder can be toxic for livestock, especially sheep (Šalamon et al. 2016).

5 Forage and Fodder Potential of Halophytes

Vast areas of salt-affected soils are occupied by naturally adapted halophytes, and it is a common practice for a long time that they are grazed or browsed by cattle, i.e., sheep, goats, buffalos, and cows. Scarcity of feed for livestock is a major constraint; thus their production capabilities cannot be fully exploited. The problem can be tackled by increasing the availability of livestock feed. Halophytic grasses, shrubs, and trees are all potential sources of fodder, but the greatest potential of halophytes is their utilization as forage and fodder. The leaves of *Atriplex* spp., *Salsola* spp., and *Puccinellia* spp. are used as cattle feed. Many species of *Salicornia* spp., *Chenopodium* spp., *Suaeda* spp., and *Kochia* spp. are examples of common fodders that are found to be a good fodder for domestic cattle (Khan 2003).

Many halophytes provide a valuable feed for grazing animals particularly under arid conditions or during interruption of feed supply caused by seasonal changes. The value of certain halophytic species has been recognized by their incorporation in pasture improvement programs in many saline regions throughout the world. Moreover, species can be selected on the basis of biomass percentage and protein levels as well as their adaptability to diverse environmental conditions including salinity. Different chenopods, i.e., *Atriplex* species, *Beta vulgaris*, *Halocaris hispida*, different species of *Haloxylon*, *Salicornia* spp., and *Suaeda fruticosa* can be used as fodder. Members belonging to Cyperaceae, i.e., *Bolboschoenus affinis*, *B. glaucus*, and *Carex divisa*, have also a potential to be grown in arid, water-deficit, and saline soils. It can be used as a good source of fodder for cattle (Khan and Qaiser 2006).

6 Grasses as Forage and Fodder

Mostly grasses are found in diverse habitats and are a permanent source of fodder and forage in arid and semi-arid regions of the world. Grasses found in saline and alkaline areas are also used as fodder and forage. *Brachiaria distachya*, *Pennisetum orientale*, and *Cenchrus ciliaris* are the main species for cultivation, being a source of fodder in arid regions. *Dichanthium annulatum*, *Chrysopogon serrulatus*, *Heteropogon contortus*, *Imperata cylindrica* and *Sorghum halepens*, and *Desmostachya bipinnata* cover the major portion of the Salt Range of Pakistan that serve for grazing animals. These species are collected in the growing season and are stored for winter use; hence these grass species are a permanent source of fodder. Grasses like *Acrachne racemosa*, *Enneapogon persicus*, *Dactyloctenium aegyptium*, *Echinochloa colona*, *Aristida adscensionis*, *Ochthochloa compressa*, *Cynodon dactylon*, *Panicum antidotale* and *Tragus roxburghii*, and *Dichanthium annulatum* are considered as good fodder grasses (Ahmad et al. 2009). *Cynodon dactylon* (Bermuda grass) is also used as a fresh fodder, and it shows maximum resistance to grazing compared with all other fodder species. It has a potential to grow in all types of soils and diverse habitats. *Dactyloctenium aegyptium* is a drought-resistant fodder grass species, adapted to different types of soils with a diverse texture, and it has fast growth rate in rain-fed areas after rainfall of short duration (Skerman and Riveros 1990). *Chrysopogon serrulatus*, a common grass species in the mountains of arid areas sprouting in summer season, is liked by cattle as a fodder (Ahmad et al. 2009).

Two halophytic grasses, namely, *Panicum antidotale* and *Desmostachya bipinnata*, can be cultivated as alternate of conventional fodder crops. *Panicum antidotale* is also a good candidate to be used as a substitute for maize, but it may also be used as hay after drying. Minerals and fibers are in good quantity in *Panicum antidotale* as required by the animals, either in green or dry hay form. It is a perennial grass and can be harvested several times without reseeding, thus saving considerable time and resources. *Panicum antidotale* has a good nutritional value with higher yield when irrigated with brackish water (10–15 dS/m). In addition, the use of proper fertilizers (NPK 120 kg/ha) and organic manures increase its yield and improve its nutritional property by lowering the salt contents and harmful secondary metabolites (Ali et al. 2014).

Desmostachya bipinnata is a common perennial grass species growing on wastelands. It is used as an alternate for wheat straw and as a source of dry fodder. It has the potential to colonize in saline and arid areas with low rainfall. Cattle prefer to graze young leaves of *D. bipinnata*, but avoid to eat older ones because hard fiber and sharp margins may injure the mouth of the animals; however, when used in dry form, it proves to be an excellent fodder. Animal nutritionists are of the view that ash in feed ranging from 8% to 10% is beneficial for animals (Badri and Hamed 2000). *Panicum antidotale*, with 11% ash, falls within the recommended limit; however *D. bipinnata* has quite higher ash contents (14%) and hence needs cautious approach. Identification of halophytes with low salt concentration in leaves can be done and be used as a replacement of traditional green fodder; however, the plants with high salt concentration in their foliage can be better utilized by chopping the leaves in small pieces and washing with water to reduce internal salts (Le Houerou 1992). Many undesirable volatile components can be removed by drying the plants (Lieth and Masoom 1993). In conclusion, *P. antidotale* appears to be an alternate source of green and dry fodder in the replacement of maize and wheat straw, respectively, whereas dry chopped leaves of *D. bipinnata* can be mixed with green leaves and other vegetative parts and may be a good replacement of wheat straw as a dry fodder.

According to Khan and Qaiser (2006), *Aeluropus lagopoides*, *Desmostachya bipinnata*, *Aristida mutabilis*, *Aristida adscensionis*, *Lasiurus scindicus*, *Cenchrus biflorus*, *C. ciliaris*, *C. pennisetiformis*, *Ochthochloa compressa*, *Cynodon dactylon*, *Sporobolus arabicus*, and *Sporobolus helvolus* are the halophytic grasses that can be used as fodder or forage.

7 Conclusion

It is concluded that wild halophytic species have a great potential to adapt to severe environmental conditions such as salinity and drought that could be used as alternative cash crops in a saline and arid agricultural regime and are considered as a valuable genetic source. Moreover, due to varying and increased bioactive compounds, these species are of prime importance in food industries for manufacturing different health-promoting food products, such as beverages, leafy salads, food additives, antimicrobial agents, etc. Therefore, saline and arid wastelands could be made productive by the cultivation of halophytes for human use and for livestock. The use of halophytes as alternate crops would not only reduce water demand for agriculture, but it will also promote and improve agriculture and crop production in areas with low rainfall. However, further research is required, in order to improve yield and recommend these wild halophytic species as crop plants.

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