Halophytes for Future Horticulture

The Case of Small-Scale Farming in the Mediterranean Basin

Rúbia C. G. Corrêa, Francesco Di Gioia, Isabel C. F. R. Ferreira, and Spyridon A. Petropoulos

Contents

R. C. G. Corrêa
Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, Bragança, Portugal

Program of Master in Science, Technology and Food Safety, Cesumar Institute of Science Technology and Innovation (ICETI), University Center of Maringa (UniCesumar), Maringa, Brazil
e-mail: rubia.correa@unicesumar.edu.br; rubiacorrea@ipb.pt

F. Di Gioia
Department of Plant Science, Pennsylvania State University, University Park, PA, USA
e-mail: fxd92@psu.edu

I. C. F. R. Ferreira (✉)
Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, Bragança, Portugal
e-mail: iferreira@ipb.pt; rubiacorrea@ipb.pt

S. A. Petropoulos (✉)
Department of Agriculture, Crop Production and Rural Environment, School of Agricultural Sciences, University of Thessaly, Volos, Greece
e-mail: spetropoulos@uth.gr

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Abstract

Mediterranean agro-ecosystems host also a very rich patrimony of wild edible plants that have always represented an important food source for the rural communities of the Mediterranean area, and several studies have demonstrated their relevant role in the traditional Mediterranean diets. Despite worldwide interest in the so-called health foods or super-foods, only a few of these native species have been incorporated in commercial cultivation systems, whereas most of them are usually gathered by hand from self-seeding wild plants. Moreover, Mediterranean agriculture is characterized by small-scale farms, which are considered to be the backbone of farming sector and crop production in the region and are essential to the preservation and development of rural area economies, especially under the ongoing climate change the world is facing. The present chapter will present the most up-to-date information regarding the chemical composition and bioactive properties of the most important wild halophytes of the Mediterranean basin, case studies of their commercial exploitation, as well as future prospects for further exploitation focusing on preservation of native genetic material and improved management of the natural and agricultural environment.

Keywords

Halophytes · Wild edible species · Small-scale farms · Bioactive properties · Phenolic compounds · Antioxidant activities

1 Introduction

Farming sector is pivotal to the economies of the Mediterranean countries and contributes a high share to gross domestic product (GPD) of the related countries (FAO 2017). However, Mediterranean agriculture is characterized by much smaller farms, in terms of average land and labor units' endowment and, above all, in terms of output, compared to the rest of the EU countries (Guiomar et al. 2018). Therefore, small-scale farms are considered the backbone of farming sector and crop production in the wider Mediterranean region and are essential to the preservation and development of rural area economies. Besides, the ever-increasing population and the continuous land occupation for human activities exert increasing pressure on the farming sector, and thus farms' size becomes even smaller (Hazell et al. 2006). The ongoing climate change has also detrimental impact on the farming sector, and the Mediterranean agriculture is severely affected by limited and highly irregular distribution of rainfalls and increasing incidences of weather extremities which have rendered the use of agricultural land prohibitive or not economically feasible, for many regions, especially for smallholders and family farmers (European Environment Agency 2019). Due to the combination of high evapotranspiration rates and unpredictable precipitation patterns, the production of vegetables in the

Mediterranean area heavily relies upon the availability of groundwater for irrigation. Especially along the coastal areas of the Mediterranean basin, an excessive pumping of groundwater caused the intrusion of seawater, and the use of irrigation water characterized by high salinity levels, sometimes combined with an excess of boron (Vengosh et al. 2004; Di Gioia et al. 2017a, 2018b), is accelerating the process of salinization and land degradation leading to the desertification of these areas. Therefore, the current situation in most regions of the world could be described by severe land fragmentation and degradation, especially in the arid and semi-arid regions of the Mediterranean, where farming is relatively more intensive in terms of both per ha labor and output, but it is undermined by a strong land fragmentation, making farms too small to generate an acceptable family income (EUROSTAT 2020). The problem is more intense in North African countries where farm size is lower than Mediterranean Europe, with the exception of Tunisia (Mekki et al. 2018). The results of this situation are land abandonment and the aging of rural population, since farming sector is not competitive, viable, and attractive to young farmers (Hanrahan 2018).

The intensification of agriculture and the irrational use of agrochemicals have caused degradation of agricultural soils due to the deterioration of physicochemical properties and structure and the dramatic loss of organic matter (Ozturk et al. 2018). Therefore, during the last decades, the farming sector is caught in a vicious circle: the use of gradually degraded soils demands increased agrochemical inputs to achieve the expected yields, which concomitantly increases production cost and shrinks profit margins. Moreover, these practices have a negative environmental impact if they are not properly managed, i.e., increasing nutrient losses by leaching and runoff of nutrients, especially nitrogen (N) and phosphorus (P). Some of the reasons for these problems are the low use efficiency of fertilizers and the continuous long-term use (Ladeiro 2012; Di Gioia et al. 2017c).

Mediterranean agro-ecosystems host a rich patrimony of wild edible plants (WEPs) that have always been an important food source for the rural communities (Morales et al. 2014; Pieroni 2017). However, the consumption of WEPs has substantially decreased due to globalization and a shift from a rural, agriculture-based economy to a market-oriented one in certain areas of the Mediterranean basin. Nowadays, the increasing demand for healthy food and natural antioxidant intake from Central and Northern Europe countries, combined with the development of local cuisine and the search concerning sustainable food, has rekindled the interest for the culinary use of WEPs (Pereira et al. 2011; Sánchez-Mata et al. 2012; Di Gioia et al. 2018b). WEPs represent an extraordinary food source and basic ingredients in the so-called Mediterranean diet that may be used to diversify and enrich modern diet with many colors and flavors, essential nutrients, minerals, fiber, vitamins, essential fatty acids, and health-promoting compounds (Bianco et al. 1998; Bharucha and Pretty 2010; Morales et al. 2013, 2014; Petropoulos et al. 2020). In addition, WEPs are very well-adapted to the local soil and climatic conditions, and their cultivation should demand lower inputs (e.g., water, fertilizers, agrochemicals) than domesticated species (Karkanis et al. 2019). Moreover, Mediterranean flora includes several domesticated horticultural species, which have shown great adaptability under the diverse environment of the region, allowing farmers to produce food products even in arduous environments, including saline environments (Petropoulos et al. 2016a, 2017c). Many wild and/or domesticated species have survived in the Mediterranean conditions because they have been adapted to soils with low level of organic matter and nutrients and limited water availability (Petropoulos et al. 2016a, 2018c; Loconsole et al. 2019b). The ability of these species to resist or tolerate stressful conditions suggests that they could play a pivotal role as alternative farming options in soils and climates where the cultivation of conventional species is difficult or even impossible; such alternative species can also be a viable options for small-scale farmers who are unable to be competitive in the intensive and global horticultural market due to intense labor requirements and high production costs, while the valorization of these species and the implementation of tailor-made farming systems could be an alternative for small-scale farmer against the strong global competition (Nebel and Heinrich 2009; Petropoulos et al. 2018c). Apart from their use as alternative cash crops, halophytes could also be used as model plants to reveal salt-tolerant mechanisms to be integrated in conventional crops through plant breeding (Koyro et al. 2011).

The study of the selected WEPs in regard to be commercially exploited in small farms is highly important, and there is a scarcity of information in the scientific literature relative to their commercial use or cultivation practices, with only a few exceptions concerning information about specific WEPs (Petropoulos et al. 2015, 2016a, b, 2017b, c, 2018a, b) (Di Gioia et al. 2018a). Therefore, the present book chapter will focus on wild edible species with commercial interest, especially halophyte ones which could be cultivated in arid and semi-arid regions of the Mediterranean helping not only toward increasing small-scale and family farmers' income and attracting young farmers who tend to abandon rural regions but also valorizing un/under-exploited species of the Mediterranean basin and preserving of domesticated and wild biodiversity. The biochemical content and the medicinal properties of selected WEPs will be presented, while the potential for using these species and/or identifying new candidates as alternative cash crops will be also discussed.

2 Chemical Composition and Health Effects of Halophytes

2.1 Biochemical Content of Halophytes

Halophytes have developed to adapt to extreme environmental conditions such as high salinity, seasonal cold, and xerothermic habitats. These plants naturally tolerate the presence of toxic ions, often in the form of sodium and chloride (Van Oosten and Maggio 2015). Among the crucial physiological–biochemical and anatomical–morphological characteristics of halophytes that allow their growing in such harsh conditions, there are ion compartmentation, ion transport and uptake regulation, osmotic fit and succulence, salt exclusion and excretion, and regulation of Na/K selectivity, besides preservation of redox and energetic status (Lopes et al. 2016; Marco et al. 2019). Not less important, there is a variety of biochemical and signalling pathways that occur under intricate genetic control (Shamsutdinov et al. 2017). For halophytic plants growing in arid and semi-arid zones, adaptive mechanisms of response to combined stresses (salinity and drought) operate in an even more sophisticated system (Lopes et al. 2016).

Oxidative stress comes out as a result of hyperosmolarity caused by the imposing of plants to drought or salt stress conditions, culminating in the generation of reactive oxygen molecules (ROS) like hydrogen peroxide, hydroxyl radicals, and superoxide anions (Lopes et al. 2016). The defense system to drought stress combines the action of enzymes implicated in antioxidant processes of the cell (especially superoxide dismutase, glutathione peroxidase, and catalase) with the existence of osmoprotectant substances (e.g., mannitol, betaine, and proline) (Stanković et al. 2015; Lopes et al. 2016). Also, ROS deleterious effects on cell macromolecules may be attenuated by the activity of non-enzymatic antioxidant molecules like vitamins (e.g., ascorbic acid), phenolics, carotenoids, glutathione, and thioredoxin. Biosynthesis and accumulation of polyphenols, glucosinolates, and other secondary metabolites in plants are considered as evolutionary response of biochemical pathways under adverse environmental conditions, including high salinity (Stanković et al. 2015; Di Gioia et al. 2018b; Petropoulos et al. 2018d).

Table 1 shows the major compounds identified in some common salt-tolerant medicinal herbs of the Mediterranean basin. The traditional halophytes *Asparagus officinalis* L. (asparagus) and *Salicornia* sp. (sea asparagus), for instance, constitute great sources of polysaccharides, polyphenols, and saponins (Lee et al. 2015; Karthivashan et al. 2018; Di Gioia and Petropoulos 2019; Guo et al. 2020). Common purslane (*Portulaca oleracea* L.), on its turn, shows a varied chemical composition. This WEP contains omega-3 fatty acids, α- and β-carotene, lutein and zeaxanthin, tocopherols, vitamin C, and oxalic acid, in addition to alkaloids, flavonoids (apigenin, kaempferol, luteolin, quercetin, myricetin, genistein, genistin, portulacanones A–D), phenolic acids (caffeic, chlorogenic, *p*-coumaric, ferulic, and rosmarinic acids), lignins, stilbenes, terpenoids, saponins, and tannins (Petropoulos et al. 2016b; Chen et al. 2019; Farkhondeh and Samarghandian 2019). Likewise, French tamarisk (*Tamarix gallica* L.) leaves are plentiful of phenolic compounds such as quercetin, kaempferol, and quercetin 3-*O*-glucuronide (Boulaaba et al. 2015).

Table 2 provides a compilation of biochemical composition data of emerging halophyte species cultivated worldwide, which are potential candidates for cropping in the Mediterranean basin. For example, the major phytoconstituents identified in *Juncus acutus* L. (sharp-pointed rush) extracts are phenanthrenes, dihydrophenanthrenes, and benzocoumarins (Oliveira et al. 2016). Correspondingly, *Spartina* spp. (cordgrasses) are rich in caffeic and ferulic acids, trihydroxymethoxyflavone, apigenin, and tricin derivatives (Faustino et al. 2019).

2.2 Halophytes as Medicinal Herbs: Health Effects

Medicinal attributes of manifold halophyte WEPs from the Mediterranean basin have been verified for the treatment and/or prophylaxis of various chronic ailments

Table 1 Chemical composition and biological activities of some of the most representative edible halophytes of the Mediterranean basin, listed in alphabetic order of the species name

Halophyte species	Common name	Major bioactive compounds	Biological activities	References
Asparagus officinalis L.	Asparagus	Polysaccharides, polyphenols, anthocyanins, and saponins	Multiple in vitro and in vivo experiments have evidenced the anticancer, anti-tumor, antioxidant, immunomodulatory, hypoglycemic, anti-hypertensive, and anti-epileptic effects of *A. officinalis*	(Di Gioia and Petropoulos 2019; Guo et al. 2020)
Beta vulgaris subsp. *maritima* (L.) Arcang.	Sea beet	Leaves are rich in 2,4-dihydroxybenzoic acid, 5-*O*-caffeoylquinic acid, quercetin 3-*O*-galactoside, quercetin 3-*O*-rutinoside, and kaempferol-3-*O*-rutinoside. The essential oil contains oxygenated sesquiterpenes, sesquiterpene hydrocarbons, and apocarotenoids	The methanolic leaf extract of sea beet showed in vitro antioxidant activities in ABTS, DPPH, ORAC, and FRAP assays, whereas the essential oil exhibited promising cytotoxic effects against human lung carcinoma cells	(Zardi-Bergaoui et al. 2017; Gonçalves et al. 2019)
Cichorium spinosum L.	Spiny chicory	α-Tocopherol, γ-tocopherol, 5-*O*-caffeoylquinic acid, chicoric acid, caftaric acid, kaempferol-3-*O*-glucuronide, quercetin 3-*O*-glucuronide, and apigenin-*O*-glucuronide	Spiny chicory extracts displayed great in vitro antioxidant potential in both chemical and cell-based methods. Moreover, a hot water leaf extract of *C. spinosum* presented relevant liver-detoxifying effects	(Petropoulos et al. 2016a, 2017b)
Crithmum maritimum L.	Sea fennel	Tisanes are especially rich in chlorogenic acid, also presenting *p*-hydroxybenzoic and ferulic acids, epicatechin, pyrocatechol, and 4-hydroxybenzaldehyde. The essential oil is mainly composed of γ-terpinene, β-phellandrene, and carvacrol methy lether	*C. maritimum* leaf extracts displayed in vitro antioxidant effects and modulatory action against stress (heat-induced stress in pre-treated cells). Furthermore, the essential oil of sea fennel is a potent larvicidal agent	(Pavela et al. 2017; Pereira et al. 2017; Ben Othman et al. 2018; Generalić Mekinić et al. 2018)

Cynara cardunculus subsp. *altilis* DC	Cultivated cardoon	The leaves contain chlorogenic acid, 1,5-*O*-dicaffeoylquinic acid and monosuccinildicaffeoylquinic acid, luteolin, and apigenin derivatives, besides the sesquiterpene lactone cynaropicrin. Also 5-*O*-caffeoylquinic and 3,5-*O*-caffeoylquinic acids were detected in the seeds	Extracts obtained from the leaves and seeds of cultivated cardoon presented significant antioxidant activities and cytotoxicity against tumor cell lines and also inhibited the growth of several Gram-positive and Gram-negative bacteria	(Petropoulos et al. 2019b; Scavo et al. 2019)
Foeniculum vulgare Mill.	Fennel	*p*-Hydroxybenzoic acid, 5-*O*-caffeolylquinic acid, caffeic acid, epicatechin, *p*-coumaric acid, quercetin 3-*O*-rutinoside, and quecetin-3-*O*-glucoside. Moreover, the volatile aroma compounds *trans*-anethole, estragole, and fenchone	Not only fennel leaf extracts but also *F. vulgare* essential oil possesses excellent antioxidant and antimicrobial potentials	(Caleja et al. 2015; Rather et al. 2016; Gomes et al. 2018)
Portulaca oleracea L.	Common purslane	Omega-3 fatty acids, α- and β-carotene, lutein and zeaxanthin, tocopherols, vitamin C, and oxalic acid. Also, several alkaloids, flavonoids (apigenin, kaempferol, luteolin, quercetin, myricetin, genistein, genistin, portulacanones A–D), phenolic acids (caffeic, chlorogenic, p-coumaric, ferulic and rosmarinic acids), lignins, stilbenes, terpenoids, saponins, tannins	Purslane has anti-tumor, hypoglycemic, antioxidant, antibacterial, anti-inflammatory, and anticholinesterase actions. Recent studies have indicated the gastroprotective and hepatoprotective effects of *P. oleracea*	(Petropoulos et al. 2016b; Chen et al. 2019; Farkhondeh and Samarghandian 2019)

(continued)

Table 1 (continued)

Halophyte species	Common name	Major bioactive compounds	Biological activities	References
Salicornia sp.	Sea asparagus	Polysaccharides, vitamins, fatty acids, phenolic compounds, flavonols, sterols, and saponins	*Salicornia* sp. extracts exhibit antioxidant, cytotoxic, and antiproliferative activities, besides anti-inflammatory and immunomodulatory properties Sea asparagus also exerts lipid lowering, antibacterial, antidiabetic, and anti-neuroinflammatory effects	(Lee et al. 2015; Karthivashan et al. 2018)
Tamarix gallica L.	French tamarisk	Phenolic compounds; mainly quercetin, kaempferol, and quercetin 3-*O*-glucuronide	French tamarisk methanol extracts from leaves and flower displayed substantial in vitro antibacterial activity (especially against *Micrococcus luteus*), besides anti-fungal effects (toward *Candida* spp.)	(Boulaaba et al. 2015)

Table 2 Chemical composition and bioactive properties of emerging halophytes studied worldwide in the past 5 years, listed in alphabetic order of the species

Halophyte species	Common name	Sample origin	Bioactive compounds identified	Biological activities	References
Artemisia campestris subsp. *maritima* (DC.) Arcang.	Field wormwood	Tunisia	Flavonols and flavonones, primarily luteolin-7-*O*-rutinoside, rhamnetin, isorhamnetin, hydroxycoumarin, kaempferol, rutinoside, and di-*O*-caffeoylquinic acid isomers	The ethyl acetate extract of *A. campestris* was active against *Bacillus thuringiensis* and *Vibrio vulnificus*, whereas the methanolic extract was effective against *Listeria monocytogenes*	(Megdiche-Ksouri et al. 2015)
Carpobrotus edulis L.	Hottentot-fig	Portugal and Tunisia	Gallic and salicylic acids, quercetin, and low methoxyl pectic polysaccharides composed of arabinose, xylose, rhamnose, and mannose	*C. edulis* leaf extracts protected neuronal cells from oxidative stress imposed by H_2O_2 treatment and reduced NO production in lipopolysaccharide (LPS)-stimulated microglia cells. Also, *C. edulis* polysaccharides displayed strong antioxidant activity and significant inhibition of protein glycation in glucose-BSA system model	(Rocha et al. 2017; Hafsa et al. 2018)
Cistanche phelypaea (L.) Cout	"Ginseng of the deserts"	Portugal	Iridoid glycosides, especially gluroside and bartsioside, phenylethanoid glycosides echinacoside and tubuloside A, and iridoids	*C. phelypaea* aqueous extracts of roots and flowers showed significant antioxidant and enzymatic inhibitory activities	(Trampetti et al. 2019)
Daucus carota ssp. *gummifer* L.	Wild carrot	France	Phenolic compounds, mainly chlorogenic acid and catechin	Wild carrot extracts displayed good antioxidant potential and inhibited *Staphylococcus aureus* and *Salmonella enterica* growth	(Jdey et al. 2017)
Frankenia laevis L.	Sea heath	France	Phenolic compounds, mainly chlorogenic acid and catechin	Sea heath extracts exhibited relevant in vitro antioxidant activities and were effective against *Micrococcus luteus* and *S. enterica*	(Jdey et al. 2017)

(continued)

Table 2 (continued)

Halophyte species	Common name	Sample origin	Bioactive compounds identified	Biological activities	References
Glaucium flavum Crantz.	Horned poppy	Tunisia	Flavonoids and condensed tannins, among which kaempferol, caffeic acid, catechin hydrate, syringic acid, chlorogenic acid, isoquercitrin, and trans-hydroxycinnamic acid	The ethanolic and ethyl acetate fractions obtained from the shoots of *G. flavum* exhibited in vitro antioxidant activities, in addition to strong antiproliferative cytotoxicity against MCF-7 cells and anti-inflammatory effects	(Boulaaba et al. 2019)
Juncus acutus L.	Sharp-pointed rush	Portugal	Juncunol, phenanthrenes, dihydrophenanthrenes, and benzocoumarins	The root dichloromethane extract of *Juncus acutus* showed promising in vitro anti-*Trypanosoma cruzi* activity	(Oliveira et al. 2016)
Limonium algarvense Erben	"Ladina"	Portugal	Gallic acid, catechin, salicylic acid, and epigallocatechin gallate	The methanolic flower extract of *L. algarvense* presented significant antioxidant activity assessed by manifold in vitro chemical methods	(Rodrigues et al. 2015, 2020)
Limonium densiflorum (Guss.) Kuntze	–	Tunisia	*Trans* 3-hydroxycinnamic acid, myricetin, and isorhamnetin	*L. densiflorum* extracts were active against colon carcinoma cell lines and displayed relevant anti-inflammatory effects in RAW 264.7 macrophages	(Medini et al. 2015)
Limonium tetragonum (Thunb.) Bullock.	"Jin-Chi-Ye-Cao" or "Bu-Xue-Cao"	Korea	Flavonoid glycosides myricetin 3-galactoside and quercetin 3-*O*-beta-galactopyranoside	*L. tetragonum* extracts and isolated compounds exhibited matrix metalloproteinase inhibitory effects in a human fibrosarcoma cell model	(Bae et al. 2017)
Limoniastrum guyonianum Boiss	"Zita"	Tunisia	Flavonoids, mainly catechin, quercetin, and isorhamnetin-3-*O*-rutinoside, besides kaempferol and isorhamnetin in lower contents	The root crude extract of *L. guyonianum* displayed in vitro antioxidant activities and cytoprotective action on H_2O_2-challenged rat small intestine epithelial cells	(Bettaib et al. 2017)

Lythrum salicaria L.	Purple loosestrife	Portugal	Flavonoids, condensed tannins, and hydroxycinnamic acids	Aqueous acetone extract of purple loosestrife displayed promising radical scavenging activity for both DPPH and ABTS assays, besides metal chelating activity on copper and iron	(Lopes et al. 2016)
Lobularia maritima (L.) Desv.	Sweet alyssum	Tunisia	α-Pinene, benzyl alcohol, linalool, pulegone, 1-phenyl butanone, globulol, γ-terpinene, terpinen-4-ol, α-terpineol, ledol, epi-α-cadinol, and α-cadinol	The essential oil of sweet alyssum exerted hepatoprotective effects against CCl_4-induced oxidative stress in a rat model and anti-inflammatory action in LPS-stimulated murine RAW 264.7 cells	(Hsouna et al. 2019)
Pistacia lentiscus L.	Mastic tree	Portugal	Flavonoids, condensed tannins, and hydroxycinnamic acids	Aqueous acetone extract of mastic tree leaves had the capacity to inhibit tyrosinase	(Lopes et al. 2016)
Polygonum maritimum L.	Sea knotgrass	Portugal	Myricitrin, catechin, and monogalloyl-hexose	Acetone extracts showed relevant in vitro antioxidant and anti-inflammatory effects besides skin care properties (anti-aging potential)	(Rodrigues et al. 2018, 2019)
Puccinellia maritima (Hudson) Parl.	Seaside alkaligrass	Portugal	Caffeic and ferulic acids, trihydroxymethoxyflavone, apigenin, and tricin derivatives	Antioxidant, anti-acetylcholinesterase, antibacterial, and antifungal activities	(Faustino et al. 2019)
Reaumuria vermiculata L.	Reaumuria	Tunisia	Myricetin, kaempferol 3-*O*-rutinoside, isorhamnetin 3-*O*-rutinoside, isorhamnetin	Reaumuria extracts presented great in vitro and ex vivo antioxidant activities, besides anti-inflammatory effects in LPS-stimulated RAW 264.7 cells. The shoot extracts had antiproliferative activities against lung carcinoma cell lines	(Karker et al. 2016)

(continued)

Table 2 (continued)

Halophyte species	Common name	Sample origin	Bioactive compounds identified	Biological activities	References
Salvadora persica L.	Saltbush	India	Organic acids, fatty acids, sugars with considerable amount of sugar alcohols, amino acids, and alkaloid (dopamine)	The saltbush methanolic leaf extract showed prominent antioxidant capacities in the DPPH, ABTS, superoxide, and hydrogen peroxide radical scavenging assays	(Kumari and Parida 2016)
Spartina maritima (Curtis) Fernald	Small cordgrass	Portugal	Caffeic and ferulic acids, trihydroxymethoxyflavone, apigenin, and tricin derivatives	Antioxidant, anti-acetylcholinesterase, antibacterial, and antifungal activities	(Faustino et al. 2019)
Spartina patens (Aiton.) Muhl.	Saltmeadow cordgrass	Portugal	Caffeic and ferulic acids, trihydroxymethoxyflavone, apigenin, and tricin derivatives	Antioxidant, anti-acetylcholinesterase, antibacterial, and antifungal activities	(Faustino et al. 2019)
Suaeda salsa L.	Seepweed	Korea	Polyphenols, especially flavonoids and tannins	High reducing potential was verified in an ethyl acetate fraction obtained from the subterranean parts of *S. salsa*	(Kang et al. 2017)

that distress modern societies, such as several types of cancer, diabetes, and heart diseases (Petropoulos et al. 2018d). Accordingly, consumers' renewed awareness dictates a return to former diet practices where particular attention is given to balanced nutrition and self-therapy through "super" and "healthy foods," natural products, drugs, and supplements, besides functional foods (Petropoulos et al. 2018a; Corrêa et al. 2019). In this context, there is a clear demand for using WEPs not only for nutrition but also for medicinal formulations and therapeutic applications (Petropoulos et al. 2018d, 2020).

Phenolic compounds are the prevalent class of secondary metabolites in higher plants and exert pivotal biological effects, including antioxidant and anti-inflammatory activities (Lopes et al. 2016). Thereby, they play a significant role in human health improvement owing to their capacity to refrain oxidative stress and inflammation in sundry medical disorders, such as skin aging (Corrêa et al. 2018). In the past years, WEP halophytes have been assessed as effective sources of polyphenols and other secondary metabolites of therapeutic properties in adaptive responses to stress conditions (Lopes et al. 2016; Petropoulos et al. 2018a). Several authors have demonstrated the antioxidant (Zardi-Bergaoui et al. 2017; Karthivashan et al. 2018; Di Gioia and Petropoulos 2019; Petropoulos et al. 2019c), antimicrobial (Megdiche-Ksouri et al. 2015; Jdey et al. 2017; Petropoulos et al. 2019b), anti-inflammatory, and anticancer potentials of extracts from different parts of halophytic species (Boulaaba et al. 2019; Hsouna et al. 2019), in addition to other health-promoting effects (Bae et al. 2017; Faustino et al. 2019). The bioactive properties of some of the most representative and emerging halophyte species reported in the past 5 years are summarized in Table 1 and Table 2, respectively.

A number of in vitro and in vivo experiments have evidenced the promising antioxidant potential of *A. officinalis* (asparagus), *Cichorium spinosum* L. (spiny chicory), *Cynara cardunculus* var. *altilis* DC (cultivated cardoon), and *P. oleracea* (purslane) extracts (Petropoulos et al. 2017a; Scavo et al. 2019), which also present immunomodulatory, hypoglycemic, anti-hypertensive, and anti-epileptic actions (Di Gioia and Petropoulos 2019; Guo et al. 2020), likewise gastroprotective and hepatoprotective properties (Petropoulos et al. 2018d; Farkhondeh and Samarghandian 2019). Essential oils obtained from the traditional WEP halophytes *Beta vulgaris* subsp. *maritima* (L.) Arcang. (sea beet), *Crithmum maritimum* L. (sea fennel), and *Foeniculum vulgare* Mill (fennel) displayed cytotoxic effects against human lung tumor cells (Gonçalves et al. 2019), promising larvicidal potential (Pavela et al. 2017) and excellent antimicrobial effects (Rather et al. 2016), respectively (Table 1). Herbal extracts of *Limonium* spp. from Portugal, Tunisia, and Korea showed significant in vitro antioxidant capabilities (Rodrigues et al. 2015) and antiproliferative, anti-inflammatory (Medini et al. 2015), and matrix metalloproteinase inhibitory actions (Bae et al. 2017) (Table 2). Furthermore, recent studies indicate that *Polygonum maritimum* L. acetone extracts possess skin care properties including anti-aging effects (Rodrigues et al. 2018, 2019).

3 Halophytes as Cash Crops: The Special Case of Small-Scale Farms

The ever-increasing demand for food along with the expected global population growth and the decrease of agricultural land has shifted research focus on alternative/complementary species that could be incorporated in existing farming systems and meet the current challenges. Moreover, the interest for commercial and recreational harvesting of wild edible species shows increasing trends and has to be attended to avoid genetic erosion of valuable genetic resources (Molina et al. 2014). For this purpose, halophytes are considered a promising option since they can grow where conventional crops are either low yielding and uneconomical to grow or they cannot grow at all (Ladeiro 2012). The concept of saline agriculture is not something new, and scientists have tried several decades ago to make this real by following two main strategies: (a) to create salt-tolerant genotypes of otherwise sensitive species through extensive breeding programs, including wild, resistant relatives, or (b) to domesticate wild naturally salt-tolerant species (Ventura et al. 2015). According to the second strategy, several species were suggested with various uses, including production of food or feed and industrial raw materials and chemicals, landscaping, phytoremediation, and medicinal purposes (Koyro et al. 2011; Petropoulos et al. 2018d, 2019c).

3.1 Identifying Halophytes as Crop, Ornamental, Medicinal, and Energy Production Plants

Wild edible plants may have several uses with most of the species being multipurpose, e.g., food plants, food additives, animal fodder, production of industrial materials, uses in the pharmaceutical and medicinal industry, landscaping, energy production, etc. (Schippmann et al. 2002; Idolo et al. 2010; Panta et al. 2014; Pinela et al. 2017). Several paradigms of cultivation of wild edible plants under commercial conditions confirm their potential integration in sustainable farming systems, especially those of small scale that usually exist in the broader Mediterranean basin. An example of the potential of halophyte wild edible plants as future crops is given by the case of *Diplotaxis tenuifolia* (L.) DC. also known as "wild rocket" a salt-tolerant wild edible plant commonly found in the Mediterranean basin especially along the coastal areas and traditionally consumed either raw or cooked in a number of dishes. After the domestication process started in the 1990s, today *D. tenuifolia* is produced year-round at commercial scale as a high-value fresh-cut baby leaf grown on thousands of hectares around the world (De Vos et al. 2013; Di Gioia et al. 2018a). Recent examples of studies where the potential commercial cultivation of wild species was evaluated include *Silene vulgaris* (Moench) Garke (bladder campion) which has been cultivated in Spain and Italy (Laghetti and Perrino 1994; Alarcón et al. 2006; Egea-Gilabert et al. 2013), purslane (Cros et al. 2007; Gonnella et al. 2010; Egea-Gilabert et al. 2014; Petropoulos et al. 2015; Sdouga et al. 2019), wild asparagus (Rosati et al. 2005; Benincasa et al. 2007) and spiny chicory (Petropoulos et al. 2017b, 2018a), sea fennel (Atia et al. 2011; Pereira et al. 2017; Renna et al. 2017b; Montesano et al. 2018; Renna 2018), sea beet (Molina et al. 2014), wild asparagus (Molina et al. 2012), and *Salicornia* and *Sarcocornia* (Ventura and Sagi 2013; Urbano et al. 2017; Loconsole et al. 2019a). Halophyte herbaceous species have unique morphological, anatomical, and physiological traits that provide those plants high resilience allowing their growth under extreme salt stress conditions (Grigore et al. 2014; van Zelm et al. 2020). For such traits wild halophytes species are considered pioneer plants from an ecological point of view and have great potential as multipurpose future crops and are being used already to recover and rehabilitate land that otherwise cannot be cultivated and will not provide revenues (Ventura and Sagi 2013). This is the case, for example, of *Salicornia patula* Duval-Jouve a hyperaccumulator of minerals normally growing in salt marshes along the coastline of the Mediterranean basin as well as in other coastal areas, which demonstrated great potential for the rehabilitation of saline land (Santos et al. 2017). Extended research has been carried out regarding the cultural requirements of *Salicornia* and *Sarcocornia* which can be used as multipurpose crops (Ventura et al. 2011; Ventura and Sagi 2013). Grown primarily as vegetables to harvest the most tender shoots commonly used as raw or cooked in combination with fish-based dishes, *Salicornia* is also a rich source of antioxidants and other bioactive compounds. Used in the folk medicine as a source of vitamin C especially by sailors to prevent the scurvy disease during long navigation periods, today several studies have demonstrated the pharmacological properties of these plants suggesting their use as medicinal plants (Rhee et al. 2009; Patel 2016; Karthivashan et al. 2018). *Salicornia bigelovii* belonging to the North American tetraploid branch of *Salicornia* has potential to be used also as a forage crop, oilseed crop, and energy crop with the production of bioethanol (Bañuelos et al. 2018; Reiahisamani et al. 2018). *Aster tripolium* is another potential candidate for biosaline agriculture which shown improved salt tolerance through filtering excessive Na and Cl ions in lateral shoots and shoots, as well as a positive response to elevated CO_2 through increasing photosynthetic rate and water use efficiency (WUE) (Geissler et al. 2009). Eisa et al. (2017) have also suggested *Chenopodium quinoa* Willd. as an alternative cash crop to be grown in the salt-affected soils of Egypt with promising results in terms of the quality of the produced seeds.

At this moment, cultivation practices for such species are based on practices for related conventional crops; therefore more research is needed to fine-tune all the requirements for sustainable production and rational use of natural resources and agrochemicals. Propagation is also an important issue to be addressed, since most of the species present seed dormancy and various techniques have to be considered either to break dormancy (e.g., osmoregulation, scarification, etc.) or to vegetatively produce plant material for commercial cultivation (Grigoriadou and Maloupa 2008).

3.2 Halophytes and Small-Scale Farming

Mediterranean agriculture is characterized by small-scale farming which is the backbone of farming sector and crop production (Guiomar et al. 2018). To be competitive in a global market, small farms are adopting a mixture of marketing strategies and in many cases are focusing on the production of crops that are particularly valued from the local market (Björklund et al. 2009; Pieniak et al. 2009; Leroux et al. 2010). Such strategy often is meant to intercept the increasing demand of traditional food products that besides being considered local are also considered more natural and healthier (Pieniak et al. 2009). In recent years, the traditional consumption of WEP and its association with the Mediterranean diet and the health properties attributed to many WEP (Sánchez-Mata et al. 2012; Corrêa et al. 2020) stimulated also by the re-evaluation of traditional recipes carried out by renowned chefs have contributed to develop a renewed interest of consumers for WEP including many halophyte species, thereby opening new market opportunities for small farms that traditionally have served this market channel. This is the case, for example, for many small farms of the Gargano area in Puglia (Southern Italy) that in response to the increasing demand of restaurants and local consumers, they are producing the so-called zauzaridd or sea asparagus (*Salicornia patula* Duval-Jouve) in the salt marsh along the shore of the Lesina lagoon (Urbano et al. 2017; Biscotti et al. 2018). The practice of gathering and consuming WEP in Puglia is quite ancient (Cantore et al. 2005), and according to Nunzia and Lamusta (1997), salicornia was consumed in Puglia already in 1709. Passed on generation after generation, today the traditional culinary use of *Salicornia* is still alive, and recently "boiled salicornia preserved in oil" was recognized by the Ministry of Agriculture and Forestry as one of the traditional food products in Puglia. Urbano et al. (2017) report that the domestication of salicornia likely started in the 1950s in the gardens of small farms along the Lesina lagoon that were cultivating *Salicornia* mainly for the consumption of the household. More recently, the limited possibility to harvest spontaneous *Salicornia* from its natural environment due to the protection of most coastal areas considered endangered habitats, coupled with the increased demand of product, has stimulated many small farms around the Lesina lagoon to invest their marginal salt marsh land to the cultivation of salicornia. This is a virtuous example of how, intercepting the local demand of a traditional product, small farms can use halophyte WEP to put in production marginal land that is not suitable for the cultivation of standard crops and generate profit in a sustainable way, providing a service for the local community and preserving the environment and the on-farm biodiversity. The same model has been applied also in Israel and other European countries, as well as in other countries around the world where salicornia is produced for multiple purposes (Stanley 2008; Ventura and Sagi 2013). The cultivation of high-added-value species instead of conventional crops could increase the income of farmers, while the use of newly introduced farming systems such as floating culture and hydroponics has shown promising results for cultivating wild species under controlled conditions increasing yields and regulating secondary metabolite biosynthesis and ultimately the quality of the final product (Bonasia et al. 2017; Ceccanti et al. 2018; Di Gioia et al. 2018a; Petropoulos et al. 2018b). An example of the application of advanced soilless cultivation systems for the production of high-value and high-quality vegetable products employing underutilized genetic resources, including some halophyte WEPs, is given by the production at commercial scale of *Salicornia*, sea fennel, and many other species in the form of microgreens (Fig. 1; Di Gioia et al. 2017d). Used by chefs of upscale restaurants primarily for their aesthetic quality and their aromatic profile, microgreens are increasingly popular high-value products that being consumed fresh have the potential to exalt also the flavor and nutritional profile of many halophyte

Fig. 1 Example of (**a**) wild plant of *Salicornia patula* Duval-Jouve growing along the salt marsh of the Gargano region in Puglia (Southern Italy) and (**b**) high-value salicornia microgreens produced at commercial scale using soilless systems and intended for the use of chefs of upscale restaurants. (Photo credits: Francesco Di Gioia)

WEPs (Kyriacou et al. 2016; Renna et al. 2017a). Moreover, the use of alternative growing media and nutrient solutions tailored for the needs of specific genotypes may allow to improve the product quality, further enhancing the nutritional properties and adding value to the final product (Di Gioia et al. 2017b, 2019; Petropoulos et al. 2019a).

One of the main challenges for the domestication and cultivation of wild halophytes is represented by the propagation of these plants. Usually, the seeds of these crops are not easily available on the market, and farmers have to produce their own seeds and develop their own propagation method with additional burden for their business. Another challenge is represented by phenomenon of seed dormancy and the low levels of germinability often observed for many wild halophyte species (Khan and Gul 2006; Gul et al. 2013). Recent studies revealed that certain strains of plant growth-promoting bacteria associated with the rhizosphere and endosphere of salicornia may contribute to enhance seed germination and plant growth under high salinity levels (Zhao et al. 2016; Yamamoto et al. 2018). Nevertheless, depending on the species, some seed treatments may be necessary to overcome phenomenon of seed dormancy and enhance the level of germinability of these plants especially when grown outside their natural environment (Khan et al. 2002; Conversa et al. 2010).

On the other hand, an advantage of the cultivation of wild halophytes is represented by the low inputs required, which may allow the adoption of organic production methods, thus offering an additional opportunity to obtain premium prices by serving consumers that value organic produce (Shafie and Rennie 2012).

3.3 Phytoremediation and Soil Reclamation

Phytoremediation is an environmentally friendly tool to deal with agricultural soil salination, while cropping species adapted to saline conditions could result in reclamation of such soils in the long term (Lutts et al. 2004; Kiliç et al. 2008;

Eid and Eisa 2010; Ali et al. 2013). Several halophytes have been proposed for saline agriculture, including purslane, cardoon, New Zealand spinach, sea fennel, sea asparagus, sea beet, etc. (Kiliç et al. 2008; Ksouri et al. 2012; Petropoulos et al. 2018d), while other wild species have been proved suitable for soil reclamation of heavy metal-contaminated soils (Ait et al. 2004; Chandra and Yadav 2010; da Silva et al. 2014; Mancilla-Leytón et al. 2016). Recent research has also shown the potential of Na and heavy metal hyperaccumulation from polluted soils with several mechanisms such phytoextraction, phytostabilization, or phytoexcretion which allow plants to tolerate arduous conditions (Manousaki and Kalogerakis 2011; Van Oosten and Maggio 2015). *Suaeda fruticosa* is a good example of phytoremediation with high potential of Na, Pb, and Zn accumulation (Bankaji et al. 2016), while other species could be used such as *Tamarix gallica* for As and Al uptake and accumulation (Sghaier et al. 2016), purslane for Cr phytoremediation (Tiwari et al. 2008; Kale et al. 2015), and *Atriplex halimus* for Cd, Cu, and Zn (Pérez-Esteban et al. 2013), etc. Other phytoremediation strategies proposed integrated farming systems with halophytes and organic soil amendments which provide apart from contaminant and heavy metal removal the phytostabilization of contaminated soils (Clemente et al. 2012).

4 Conclusionary Remarks and Future Challenges

Chefs revisiting and re-proposing recipes of the rural traditional based on the use of wild herbs and the increased consumer awareness for healthy and nutritious foods have given rise to marketing of niche food products obtained from wild edible species. However, considering that harvesting of most of these species is time- and labor consuming and availability of wild products is seasonal and highly dependent on environmental conditions, commercial cultivation is necessary to make the step forward and reduce the threat of genetic erosion from irrational gathering while at the same time making these products less expensive and affordable to everyone. Preliminary studies and paradigms with edible halophytes cultivated under commercial conditions show promising results in regard to total yield; however special attention must be given on the quality of the final product. The best practice guides and the optimum growing conditions should be defined to ensure high-quality products with enhanced bioactive compound content and minimum content of anti-nutritional factors such as oxalic acid and nitrates. Moreover, considering the great diversity and the existence of numerous ecotypes for each species, more research is needed to identify genotypes with better and more stable performance under various climate and growing conditions within the ongoing climate change framework. Therefore, more efforts are needed, and these species have to be incorporated in targeted breeding programs that will result in elite genotypes and a continuous flow of genetic material that will cater the increasing needs of the farming sector. Finally, small-scale farmers in the Mediterranean need to be encouraged and offered incentives to shift from non-sustainable cultivation systems and conventional crops to sustainable cropping systems integrating and exploiting alternative species such as wild edible halophytes.

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