Trends in Food Science & Technology 74 (2018) 69–84

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: www.elsevier.com/locate/tifs

Review

Edible halophytes of the Mediterranean basin: Potential candidates for novel food products

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ARTICLE INFO

Keywords:
Edible greens
Halophytic species
Mediterranean diet
Native plants
Underutilized species
Wild greens

ABSTRACT

Background: Recent trends in the food science industry and consumers' preferences for diversified diets suggest the consumption of wild greens not only as diet complements but also as healthy and functional foods for targeted conditions, rendering its commercial cultivation of major importance in order to avoid irrational gathering and genetic erosion threats. The Mediterranean basin abounds in wild edible species which have been used for food and medicinal purposes by human throughout the centuries. Many of these species can be found near coastal areas and usually grow under saline conditions, while others can adapt in various harsh conditions including high salinity.

Scope and approach: The aim of this review focuses on listing and describing the most important halophyte species that traditionally have been gathered by rural communities of the Mediterranean basin, while special interest will be given on their chemical composition and health promoting components. Cases of commercially cultivated halophytes will be also presented to highlight their potential as alternative cash crops, while results from *in vitro* and *in vivo* health effects will be presented.

Key findings and conclusions: The recent literature has provided useful information regarding the potential of wild halophytes as promising ingredients in functional food products and/or as sources of bioactive compounds. However, further research is needed regarding the chemical characterization of these species under commercial cultivation practices, while further clinical and model trials have to be conducted to assess their long term bioactivity and elucidate potential toxic effects and regulations of safe consumption.

1. Introduction

Mediterranean basin is thriving with native plants that have been used throughout the centuries by rural communities for food and therapeutic purposes, especially during periods of food scarcity, hence they are also called as "famine food". The diverse climatic conditions and terrain morphology of the wider Mediterranean region have contributed to the existing variation within the various species, with many ecotypes being present throughout the countries around the Mediterranean Sea (Sánchez-Mata et al., 2012). Many of these species are used as leafy greens and are the basic ingredients in many traditional dishes and local recipes of regional interest that constitute the so-called "Mediterranean diet" which is in the epicenter of scientific research during the last decades due to its health promoting effects and contribution to general well-being (Morales et al., 2014). Wild halophytes are usually richer in nutrients and bioactive compounds and have a taste similar to conventional salad crops (Ruiz-Rodríguez et al., 2011), which are considered as important mediators of its various health effects (Trichopoulou et al., 2000). Apart from hand-picked wild greens, the life style of modern people and the seasonality of these species have created a market niche for commercial cultivation of various species, e.g. *Cichorium intybus*, *C. spinosum, Crithmum maritimum*, *Capparis spinosa*, *Portulaca oleracea* to name but a few, in order to ensure availability throughout the year and fulfil consumers' demands (Petropoulos et al., 2015, 2016a).

The recent advances in food science and technology dictate the production of novel and healthy food products and incorporation of innovative processing techniques, with wild plants suggesting an important part of the food basket on a global scale, in both developed and developing countries since more than 120 species are being regularly used as dietary components (Bharucha & Pretty, 2010). Moreover, medicinal properties of various species native in the Mediterranean basin have been confirmed for the treatment and prophylaxis against various chronic diseases that afflict modern societies, including various

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https://doi.org/10.1016/j.tifs.2018.02.006
Received 29 December 2017; Received in revised form 1 February 2018; Accepted 2 February 2018
Available online 12 February 2018

types of cancer, heart diseases, diabetes and so forth (Ksouri et al., 2012). Therefore, consumers' renewed attention dictate a reversion to former diet habits where special concern is given to balanced nutrition and self-medication through "super" and "healthy foods", dietary supplements, botanical drugs and functional foods (Luczaj et al., 2012).

Considering increasing global climate change and severe conditions that prevail throughout the world, cultivation of conventional crops is facing various limitations related with scarcity of good quality water, temperature increase, salinization and degradation of soil properties and so forth, especially in arid and semi-arid regions of the Mediterranean basin where the abovementioned problems are intensified (Slama, Abdelly, Bouchereau, Flowers, & Savouré, 2015). Moreover, most of the wild species, are considered as weeds for conventional crops and farmers usually apply chemical fertilizers in order to eradicate them, a practice which in long term could result in extinction of vulnerable species and consequent genetic erosion (Tardío, Pardo-de-Santayana, & Morales, 2006), as well as in severe changes in terms of biodiversity of agro-ecological systems (Panta et al., 2014). Therefore, it is of utmost importance to propose alternative crop species that can adapt under harsh conditions within the framework of saline agriculture and make for good candidates as potential cash food and medicinal crops (Panta et al., 2014).

In the present review, a list of the most important edible halophytes and salt-tolerant species of the Mediterranean basin will be presented, in order to increase available knowledge regarding the value and uses of halophytes and wild greens. In addition, chemical composition and nutritional value of each species will be presented in order to highlight their pivotal role in human diet on a regular basis, while data from *in vitro* and *in vivo* models and ethnopharmacological studies regarding their health effects will be also noted. Finally, the review concludes with future prospects and research pathways that will contribute towards the valorization of native halophytes of the region as ingredients in novel functional food and products as well as sources of bioactive molecules for nutraceutical and medicinal purposes.

2. Edible halophytes native in the Mediterranean basin

In the following section the most important edible halophytes of the Mediterranean will be presented in alphabetical order, focusing on wild native species. The selected species have various uses with different plant parts being edible, as shown in Table 1, while they exhibit diverse health effects and chemical composition which are summarized in Tables 2 and 3, respectively, while the most important reported compounds are presented in Fig. 1. The various adaptation mechanisms to saline conditions that these species have developed through selection are presented in Fig. 2.

Table 2
Total phenolics content of various salt tolerant medicinal plants native in the Mediterranean region.

Scientific name	Plant parts	Total Phenolics[1] (mg GAE/g extract)	References
Beta vulgaris subsp. *maritima*	Leaves	61.91	Morales et al. (2014)
Capparis spinosa L.	Seeds	1.31–8.14	Tlili et al. (2015)
	Leaves	23.37–427.27	Tlili et al. (2017)
	Flower buds	4.19	Mansour et al. (2016)
			Anwar et al. (2016)
Cichorium spinosum L.	Leaves	7.85–39.9*	Petropoulos et al. (2017a)
Crithmum maritimum L.	Leaves	7.16–35.1	Meot-Duros et al. (2008)
	Flowers	32.6	Mekinić et al. (2016)
	Stems	7.6	Jallali et al. (2012)
Cynara cardunculus	Leaves	9.9–10.5	Colla et al. (2013)
	Heads	98–132	Petropoulos et al. (2017d)
Eryngium maritimum L.	Leaves	16.44–43.83	Meot-Duros et al. (2008)
	Seeds	20	Amessis-Ouchemoukh et al. (2014)
			Mejri et al. (2017)
Inula crithmoides L.	Aerial parts	6.7–14.1	Jallali et al. (2014)
Lepidium latifolium L.	Aerial parts	0.0.-172.4	Xiang et al. (2017)
		26.89–50.51	Kaur, Bhat, et al. (2013) and Kaur, Hussain, et al. (2013)
Plantago coronopus L.	Roots	0.56–30.6	Pereira et al. (2017b)
	Leaves	2.07–28.1	Jdey et al. (2017)
	Flowers	1.26–15.7	
Portulaca oleracea L.	Leaves and stems	7.65–20.1	Petropoulos et al. (2015)
			Ramadan et al. (2017)
Salicornia herbaceae L.	Whole plants	53.8	Essaidi et al. (2013)
Suaeda fruticosa L.	Shoots	31.7	Oueslati, Trabelsi, et al. (2012); Oueslati, Ksouri, et al. (2012)

[1]Total phenolic content is expressed as gallic acid (GAE) equivalents (mg gallic acid g^{-1} dry weight (DW)).
*Total phenolic compounds as determined by LC-DAD-ESI/MS.

Table 1
The most important edible halophytes of the Mediterranean basin.

Scientific name	Common name	Family	Plant part used	References
Suaeda fruticosa Forssk.	Shrubby seablight	Amaranthaceae	Seeds	Weber et al. (2007)
Salicornia herbacea L.	Grasswort		Seeds	Kang et al. (2014)
Beta vulgaris subsp. *maritima* (L.) Arcang.	Wild beet		Aerial parts	Zardi-Bergaoui et al. (2017)
Crithmum maritimum L.	Sea fennel	Apiaceae	Leaves, stems and flowers	Pereira et al. (2017a)
Eryngium maritimum L.	Sea holly		Leaves	Mejri et al. (2017)
Inula crithmoides L	Golden samphire	Asteraceae	Aerial parts	Fontana et al. (2014)
Cichorium spinosum L.	Spiny chicory		Leaves	Petropoulos et al. (2017a)
Cynara cardunculus var. *altilis*	Gardoon		Leaves	Lattanzio et al. (2009)
Lepidium latifolium L.	Pepperwort	Brassicaceae	Leaves	Conde-Rioll et al. (2017)
Capparis spinosa L.	Caper	Capparaceae	Leaves and seeds	Chedraoui and Rajjou (2017)
Salsola soda L.	Opposite-leaved saltwort	Chenopodiaceae	Aerial parts	Polat and Satıl (2012)
Chenopodium album L.	Lambsquarters		Leaves	Salam Jekendra et al. (2011)
Plantago coronopus L.	Buck's-horn plantain	Plantaginaceae	Leaves and flowered part	Jdey et al. (2017)
Portulaca oleracea L.	Common purslane	Portulacaceae	Leaves and stems	Petropoulos et al. (2015; 2016b)
Tribulus terrestris	Puncturevine	Zygophyllaceeae	Stems, leaves and fruits	Šalamon et al. (2016)

Table 3
Biological activity of the selected medicinal halophytes and their constituents.

Scientific name	Biological activity	Reference
Beta vulgaris subsp. *maritima* (L.) Arcang.	Antioxidant, Antiholinesterase, Anti-tyrosinase, Cytotoxic	Zardi-Bergaoui et al. (2017)
Capparis spinosa L.	Antioxidant, Antidiabetic, Anti-hyperlipemic, Anti-helminthic, Anti-inflammatory, Cytotoxic, Neuroprotective	Akkari et al. (2016); Azhary et al. (2017); Bakr & Bishbishy (2016); Mollica et al. (2017); Tlili et al. (2017); Turgut et al. (2015); Anwar et al. (2016)
Cichorium spinosum L.	Antioxidant, Detoxifying	Brieudes et al. (2016)
Chenopodium album L.	Antioxidant, Antimicrobial, Antirrheumatic, Anticonceptive, Ant-inflammatory, Laxative	Beyrouthy et al. (2008); Ksouri et al. (2011); Salam Jekendra et al. (2011)
Crithmum maritimum L.	Antioxidant, Anti-cholinesterase, Vasoactive, Antibacterial, Cytotoxic, Diuretic, Antiscorbutic, Depurative, Digestive, Anti-inflammatory, Antiplatelet-aggregator	Jallali et al. (2012); Kulisic-Bilusic et al. (2010); Mekinić et al. (2016); Meot-Duros and Magné (2009); Meot-Duros et al. (2010); Pereira et al. (2017a)
Cynara cardunculus L.	Anticarcinogenic, Antioxidative, Antibacterial, Hepatoprotective	Kollia et al. (2016); Lattanzio et el. (2009)
Eryngium maritimum L.	Antioxidant, Cytotoxic, Anti-inflammatory, Antinociceptive	Amessis-Ouchemoukh et al. (2014); Küpeli et al. (2006); Mejri et al. (2017); Meot-Duros et al. (2008); Yurdakök and Baydan (2013)
Inula crithmoides L	Antioxidant, Anti-tyrosinase, Antifungal, Antibacterial, Anticlastogenic, Antimutagenic, Herbicidal	Abdel-Wahhab et al. (2008); Andreani et al. (2013); Bucchini et al. (2015); Jallali et a. (2014); Jdey et al. (2017); Lopes et al. (2016); Malash et al. (2015); Omezzine et al. (2011)
Lepidium latifolium L.	Antioxidant, Anitumor, Anticancer	Conde-Rioll et al. (2017); Hanschen et al. (2015); Tabassum and Ahmad (2011); Xiang et al. (2017)
Plantago coronopus L.	Antioxidant, Anti-cholinesterase, Anticancer, Antimicrobial, Anti-inflammatory, Analgesic, Astringent, Expectorant, Diuretic, Antipyretic, Emollient	González-Tejero et al. (2008); Jdey et al. (2017); Neves et al. (2009); Pereira et al. (2017b)
Portulaca oleracea L.	Antioxidant, Anti-mutagenic, Cardioprotective, Anti-inflammatory, Anti-nociceptive, Anti-hyperlipemic, Anti-atherogenic, Hepatoprotective, Immunomodulatory	Alam et al. (2014); Choi et al. (2016); Chowdhary et al., 2013); Ramadan et al. (2017); YouGuo et al. (2009)
Salicornia herbacea L.	Antiproliferative, Anticancer, Cytotoxic, Anti-oxidation, Anti-thrombosis, Anti-HMGB1	Choi et al. (2016); Kang et al. (2014); Ksouri et al. (2011); Lee et al. (2016); Tuan et al. (2015); Zhao et al. (2014)
Salsola soda L.	Antioxidant, Anti-cholinesterase, α-amylase inhibitor	Loizzo et al. (2007); Polat and Satıl (2012); Tundis et al. (2007; 2009)
Suaeda fruticosa Forssk.	Antioxidant, Hypoglycemic, Anti-hyperlipemic	Benwahhoud et al. (2001); Ksouri et al. (2011); Oueslati, Trabelsi, et al. (2012); Oueslati, Ksouri, et al. (2012); Qasim et al. (2017)
Tribulus terrestris L.	Antioxidant, Aphrodisiac, Anticancer	Hammoda et al. (2013); Šalamon et al. (2016); Vale et al. (2017); Wei et al. (2014)

3. *Beta vulgaris* subsp. *maritima* (L.) Arcang

Sea or wild beet (*Beta vulgaris* subsp. *maritima* (L.) Arcang.) belongs to the Chenopodiaceae family and is a wild relative of cultivated beets (*B. vulgaris*) which thrives in salt marshes and seashore cliffs and exhibits high salt-stress tolerance (Ribeiro et al., 2016) (Fig. 3a). In a recent study, Ribeiro et al. (2016) observed that sea beet populations from contrasting environments showed physiological plasticity and recovered from severe stress conditions (drought and salinity stress), while Skorupa et al. (2016) reported that several genes related with carbon fixation, biosynthesis of ribosomes and expansion and formation of cell walls are involved in salt tolerance. The edible parts of the plant are its leaves and leaf stems which are eaten as cooked or raw greens throughout the Mediterranean basin (Turner et al., 2011).

3.1. Chemical composition

According to Morales et al. (2014), the basal leaves of the plant are good sources of vitamin E vitamers (α- and γ-tocopherol), vitamin C and citric and oxalic acid. In the same study, the authors detected a significant amount of total phenolics and flavonoids (61.91 and 21.55 mg GAE/g extract, respectively), which contribute to antioxidant properties of the species (Morales et al., 2014). Moreover, the basal leaves of the plant are good sources of α-linolenic (57.8%), linoleic (21.28%) and palmitic acid (11.03%) (Zardi-Bergaoui et al., 2017). The essential oils of the aerial parts of the plant consist of oxygenated sesquiterpenes, sesquiterpene hydrocarbons and apocarotenoids, while the main detected compounds were γ-irone, α-cadinol, T-cadinol, bicyclogermacrene and δ-cadinene (Zardi-Bergaoui et al., 2017).

3.2. Health effects

Regarding the medicinal properties, Zardi-Bergaoui et al. (2017) found that essential oil from aerial parts of wild beet displays strong antioxidant activity, as well as cytotoxic effect against A549 cell lines. Moreover, ethnopharmacological studies have recorded the use of cooked leaves and leaf stems against digestive disorders (González-Tejero et al., 2008), burns, throat pains and anemia (Guarrera & Savo, 2013), while the juice of squeezed leaves and cooked leaves exhibit emollient, digestive, diuretic and laxative properties (Morales et al., 2014). However, the high content of oxalic acid in edible parts (581 mg/100 f.w.) indicates that people susceptible to kidney stone formation should avoid regular consumption of *B. maritima* leaves (Morales et al., 2014).

4. *Capparis spinosa* L

Caper (*Capparis spinosa* L.) is a perennial xerophytic plant and a member of the Capparaceae family, which is native in the Mediterranean basin (Chedraoui & Rajjou, 2017) (Fig. 3b). The edible part of the plants include its leaves, flower buds and fruit, while apart from culinary purposes plant tissues are a basic ingredient in traditional medicine (Chedraoui & Rajjou, 2017). According to Mahmood, Aslam, Rehman, and Naqvi (2013), within *C. spinosa* species there are two subspecies common in the Mediterranean basin *C. spinosa* subsp. *spinosa* and *C. spinosa* subsp. *rupestris*. The species is both drought and salt tolerant due to its extended root system and thrives under the Mediterranean arid and semi-arid conditions (Mahmood et al., 2013).

4.1. Chemical composition

Caper contains several classes of bioactive molecules, among them alkaloids (capparisine, tetrahydroquinolin, stachydrin, cappariloside A, flazin, capparine, spermidine alkaloids), saponins, terpenes (citral, eukalyptol, β-pinene, myrcene, eugenol, and terpineol), phenolic compounds (caffeic acid, catechin, epicatechin, chlorogenic acid, coumarin,

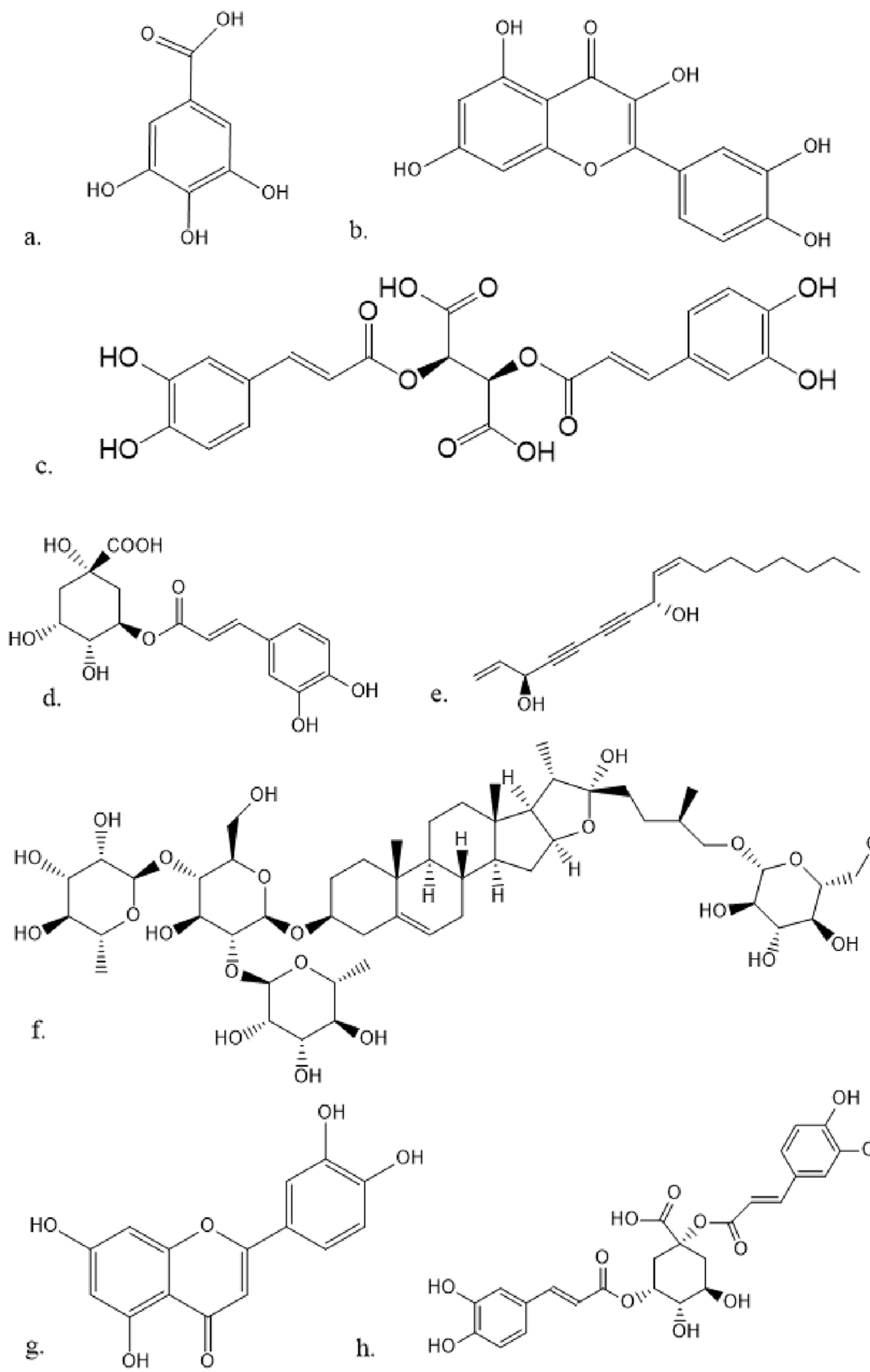

Fig. 1. Chemical structure of some active constituents of salt-tolerant species native in the Mediterranean basin: a) gallic acid ($C_7H_6O_5$), b) quercetin ($C_{15}H_{10}O_7$), c) chicoric acid ($C_{22}H_{18}O_{12}$), d) chlorogenic acid ($C_{16}H_{18}O_9$), e) falcarindiol ($C_{17}H_{24}O_2$), f) protodioscin ($C_{51}H_{84}O_{22}$), g) luteolin ($C_{15}H_{10}O_6$), and h) cynarin ($C_{25}H_{24}O_{12}$).

ferulic acid, gallic acid, kaempferol, luteolin, naringenin-7-*O*-glucoside, naringin, *p*-coumaric acid, protocatechuic acid, quercetin, resveratrol, rutin, syringic acid, taxifolin and vanillic acid), glucosinolates (glucocapperin, butyl-isothiocyanate, isopropyl-isothiocyanate, glucobrassicin and glucoiberin), lipids and liposoluble compounds (tocopherols: α- and γ-tocopherol, carotenoids: β-carotene and lutein, and fatty acids) and ascorbic acid (Aichi-Yousfi et al., 2016). Other important secondary metabolites include resins, tannins, anthocyanins, organic acids, aldehydes and ketones, monoterpenes and sesquiterpenes, polysaccharides and sugars, as also hemicelluloses and pectin which have also been reported for caper plant tissues (Akkari et al., 2016; Mansour et al., 2016). Seed oil is rich in unsaturated fatty acids, while apart from commonly found oleic, linoleic and palmitic acid it also contains significant amounts of vaccenic acid (Argentieri, Macchia, Papadia, Paolo, & Avato, 2012). Also important to point out is that chemical composition of caper is affected by various factors such as environmental conditions, genotype, harvesting stage and time, plant part, as also by extraction solvent used (Aichi-Yousfi et al., 2016; Chedraoui & Rajjou, 2017; Tlili, Feriani, Saadoui, Nasri, & Khaldi, 2017).

4.2. Health effects

Capparis spinosa exert a pronounced antioxidant activity, being

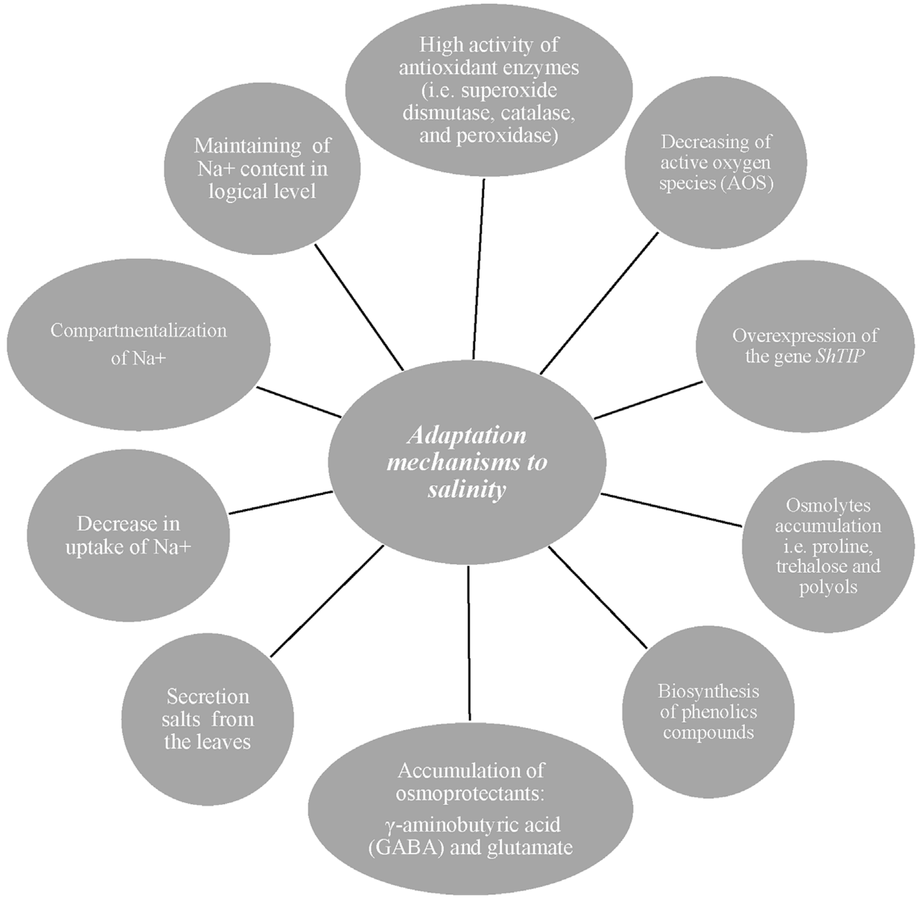

Fig. 2. Selected adaptation mechanisms of native Mediterranean plant species to salinity.

clearly evident its effect as lipid peroxidation inhibitor, free radical's scavenger and modulator of antioxidant enzymes (i.e. superoxide dismutase and catalase) (Mansour et al., 2016). The *in vivo* antidiabetic and anti-hyperlipidemic properties of this halophytic plant has also been reported (Mollica et al., 2017), while animal studies have confirmed nephroprotective and hepatoprotective effects of leaf extracts (Tlili et al., 2017). Mollica et al. (2017) reported a significant decrease in fasting blood glucose levels and glycosylated hemoglobin in treated patients when compared to control group; triglyceride levels also decreased in a significant manner, without causing kidney toxicity or other side effects. Cytotoxic activity of the plant was also assessed, being observed a high selectivity against human cancer cell lines, namely: breast adenocarcinoma (MCF-7), hepatocellular carcinoma (Hep-G2), and colon carcinoma (HCT-116 and HT-29) cells, suggesting their upcoming use as a promissory candidate for nutraceutical researches (Bakr & Bishbishy, 2016). Anthelmintic effects of the species were also reported as being related to its phenolic content and antioxidant activity (Akkari et al., 2016). The authors found a promissory anthelmintic activity against eggs and adult worms of *Haemonchus contortus* from sheep, while they correlated these effects to the high content of phenolic compounds (i.e. flavonoids and tannins (Akkari et al., 2016). The anti-inflammatory activity of caper was also detected in animal studies, where leaf extracts were able to reduce edema in treated mice in a dose-dependent manner, as also a significant decrease in immune cells infiltration, vasodilatation and in dermis thickness (Azhary et al., 2017). Furthermore, leaf extracts of the same study inhibited the cytokine gene expression, namely IFNγ, IL-17 and IL-4 (Turgut et al., 2015). More interestingly, this plant also conferred a significant protection against DNA bands damage and on cognitive impairment induced by D-galactose in mice via inhibition of oxidative stress (Anwar, Muhammad, Hussain, Zengin, & Alkharfy, 2016), leading to an increase of memory retention and attenuating D-galactose-induced learning dysfunctions in mice. Finally, and not least important to point out is that this plant is traditionally used to prevent and/or treat a number of health disorders such as diabetes, hepatitis, obesity and kidney problems, and cardiovascular, digestive, respiratory system and nutritional disorders (Anwar et al., 2016).

5. *Chenopodium album* L

Lambsquarters or white goosefoot (*Chenopodium album* L., Chenopodiaceae) is an important annual broad-leaved and moderately tolerant to Cl^- and SO_4^{2-} induced salinity weed, while it is also considered a wild edible green with young shoots and leaves being used as salad or cooked vegetables (Bianco, Santamaria, & Elia, 1998; Panta et al., 2014) (Fig. 3c). In the study of Ivanova et al. (2016), it was reported that *C. album* has the ability to maintain the concentration of Na^+ and Cl^- in cell organs at a level similar to untreated plants by using them for osmoregulatory purposes, while concomitant ultrastructural changes in cell organelles were observed. According to these researchers, the contribution of Na^+ and Cl^- to osmolarity in leaves increased with increasing NaCl concentrations in nutrient solution up to the highest concentration (more than 100 mmol/kg f.w.) at 250 mM NaCl, without a further increase being observed at higher salt concentrations, which indicates an efficient mechanism of using these ions for osmoregulation along with K^+ which is the usual plant osmoregulator.

5.1. Chemical composition

C. album is a good source of β-carotene, diterpenes and retinol precursors, since it exhibited a significant *in vivo* efficacy in rising

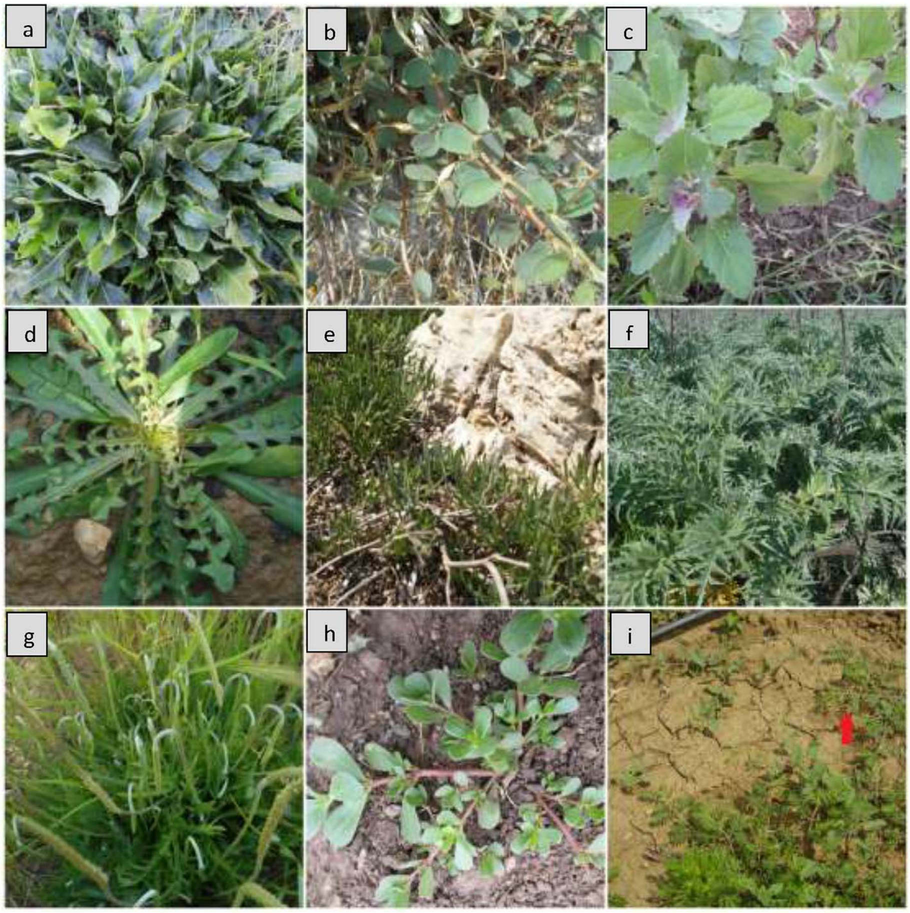

Fig. 3. Important edible halophytes of the Mediterranean basin: a) *Beta vulgaris* subsp. *maritima*, b) *Capparis spinosa*, c) *Chenopodium album*, d) *Cichorium spinosum,* e), *Crithmum maritimum*. f) *Cynara cardunculus*, g) *Plantago coronopus*, h) *Portulaca oleracea*, and i) *Tribulus terrestris*.

plasma retinol levels in retinol deficient rats (Sangeetha & Baskaran, 2010). Moreover, Guil, Rodríguez-García, and Torija (1997) detected significant ascorbic and dehydroascorbic acids (155 mg 100 g^{-1}) and carotenoids (12.5 mg 100 g^{-1}) content, while it contains significant amounts of minerals such as K, Mg and Ca, especially when comparing to common cultivated vegetables Bianco et al. (1998). However, the high oxalic acid content (1100 mg 100 g^{-1}) observed in the study of Guil et al. (1997) indicates potential toxic effects when high amounts ($>$ 400 g on a daily basis) are consumed, especially from people that are sensitive to kidney stone formation.

5.2. Health effects

With respect to medicinal properties, Salam Jekendra, Joylani, Rebika, & Priyadarshini (2011) observed that *C. album* extracts exhibited higher antioxidant activity (IC_{50} = 206 µg/ml) than vitamin C (IC_{50} = 15.1 µg/ml) and quercetin (IC_{50} = 6.45 µg/ml). Besides, Lone et al. (2017) observed that the extracts of *C. album* exhibited considerable antimicrobial activity against *Staphylococcus aureus*, *Pseudomonas multocida* and *Escherichia coli.* Moreover, Beyrouthy, Nelly, Annick, and Frederic (2008) have described the use of alcoholic decoctions of aerial parts against rheumatism and arthritis in traditional medicine of Lebanon, while Ksouri et al. (2012) have reported unspecified medicinal uses of the species, mostly in the region of Albania. Other therapeutic properties include diuretic, laxative, sedative, hepatoprotective and antiparasitic activities, and notable anti-pyretic, antinoceptive, anti-inflammatory and cancer preventing effects (Ksouri et al., 2012).

6. *Cichorium spinosum* L

Spiny chicory (*Cichorium spinosum* L., Asteraceae) is a perennial species commonly found in coastal and mountainous areas throughout the Mediterranean region, while it has been recently cultivated commercially as a leafy vegetable (Petropoulos et al., 2016a, 2017b) (Fig. 3d). It is a common ingredient of the so-called Mediterranean diet whose beneficial health effects have been confirmed in numerous studies (Ntatsi, Aliferis, Rouphael, & Napolitano, 2017). It is also considered as a highly salt-tolerant species, with the main osmoprotectants compounds being γ-aminobutyric acid (GABA), glutamate, pyroglutamate, L-proline, and sucrose, as well as total phenolics content which serve as antioxidant compounds (Klados & Tzortzakis, 2014).

6.1. Chemical composition and health effects

This species exhibits considerable antioxidant activity since its leaves contains tocopherols and phenolic compounds (Petropoulos, Fernandes, Barros, & Ferreira, 2017). Alpha-Tocopherol, gamma-Tocopherol, 5-O-Caffeoylquinic acid, chicoric acid, caftaric acid kaempferol-3-O-glucuronide, quercetin-3-O-glucuronide, and apigenin-O-glucuronide are the main bioactive compounds isolated from the leaves of the species (Brieudes et al., 2016). Moreover, Michalska and Kisiel (2007) and Melliou, Magiatis, and Skaltsounis (2003) detected four alkylresorcinol derivative (cichoriol A, B, C and D), various sesquiterpene lactones ((4R)-3,4-dihydrolactucopicrin, lactucin and its derivatives, leucodin, tanacetin) and four coumarins (umbelliferone, scopoletin, aesculetin and cichoriin 4). Regarding the health effects of the species, there is limited number of reports which focus mainly on the antioxidant compounds content. According to a recent study, water decoctions of *C. spinosum* leaves exhibit significant antioxidant activities and liver detoxifying properties which could be attributed to its high contents in chicoric and caftaric acid (Brieudes et al., 2016).

7. *Crithmum maritimum* L

Sea fennel (*Crithmum maritimum* L.) is a facultative and perennial halophyte, very common in several Mediterranean countries such as Greece, Tunisia and Spain (Jallali et al., 2012; Pereira et al., 2017a; Renna & Gonnella, 2012). It is an edible and medicinal species which is commonly used in traditional dishes throughout the Mediterranean basin, while it usually grows within coastal areas, piers, rocks and sandy beaches (Renna & Gonnella, 2012) (Fig. 3e). The edible parts of the species are its leaves, which can be consumed fresh as salad vegetables, or pickled, while Renna, Gonnella, Caretto, Mita, and Serio (2017) have suggested the use of dried leaves for human consumption, as well as a coloring agent. Moreover, Siracusa et al. (2011) suggested the use of flower tops and stalks infusions as herbal teas, while Pereira et al. (2017b) reported that all aerial parts can be an alternative source for health promoting beverages. According to Ben Amor, Ben Hamed, Debez, Grignon, & Abdelly (2005), the salt tolerance of the species may be is due to its ability to exhibit high activities of antioxidant enzymes, like superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), preventing the accumulation of active oxygen species (AOS).

7.1. Chemical composition

Sea fennel contains a wide variety of chemical constituents. Phenolic compounds represent a small but interesting proportion in both stems, leaves and flowers of *C. maritimum*, being the phenolic acids, chlorogenic acid, followed by neochlorogenic, cryptochlorogenic, ferulic and caffeoylquinic acids and its derivatives the most commonly detected phenolic compounds (Jallali et al., 2012). Interesting amounts of gallic, caffeic, vanillic, rosmarinic and *p*-coumaric acids were also identified and quantified in this edible halophyte (Jallali et al., 2012), while small amounts of *trans*-2-hydroxycinnamic and *trans*-cinnamic acids were also reported. Moreover, the flavonoids rutin, apigenin, quercetin-3-galactoside, epicatechin, epigallocatechin, catechin, and even other polyphenols, such as pyrocatechol and 4-hydroxybenzaidehyde are also present, but in low amounts (Jallali et al., 2012; Meot-Duros et al., 2010). Volatile compounds, such as limonene, α-pinene, *p*-cimene, γ-terpinene, β-myrcene, thymol, carvacrol, eugenol, β-ionone, dillapiole, anisaldehyde, β-caryophyllene, carvone, myristicine, have been also identified in essential oils of various plant parts (Atia, Debez, Barhoumi, & Abdelly, 2010; Burczyk, Wierzchowska-Renke, Glowniak, Glowniak, & Marek, 2002). Small amounts of coumarins, namely two furanocumarins, scopoletin and scoparone were also identified (Atia et al., 2010; Burczyk et al., 2002). More recently, a polyacetylene compound, namely falcarindiol was also identified in *C. maritimum* leaf extracts (Meot-Duros et al., 2010), from which very interesting bioactive effects have been proposed. Seeds contain significant amounts of oils (44.4% on d.w. basis) which are similar in composition to olive and canola oil being consisted mainly of oleic (78.6%), linoleic (15.4%) and palmitic acid (4.8%) (Atia et al., 2010).

7.2. Health effects

Chrithmum maritimum is a medicinal halophyte with a widely recognized antioxidant capacity, being particularly evident their antiradical, reducing power and lipid peroxidation inhibition abilities (Kulisic-Bilusic, Blažević, Dejanović, Miloš, & Pifat, 2010; Meot-Duros & Magné, 2009). However, its biological potential is highly affected by the content in bioactive molecules, which are directly influenced by physiological stage and extraction method selected (Jallali et al., 2012). Furthermore, no significant toxicity was detected against four different mammalian cell lines, which indicates that *C. maritimum* may be a safe and rich source of biomolecules to be used for multiple pharmaceutical purposes (Pereira et al., 2017a). Another aspect regarding the health effects of the species is that the antioxidant activity of plant extracts is markedly higher than essential oils (Mekinić et al., 2016). On the other hand, a pronounced ability to inhibit acetylcholinesterase and butyrylcholinesterase activity was also observed when both the plant extracts and essential oils were used, although the potency of essential oils was higher than the extracts (Mekinić et al., 2016). In the same study, the authors found strong vasoactive effects in the noradrenaline-precontracted rat aortic rings, namely all the examined samples evidenced a high vasodilatory potency (Mekinić et al., 2016). An appreciable antimicrobial activity was also observed for this halophyte, being able to strongly inhibit the growth of Gram-positive (*S. aureus, S. faecalis, Bacillus cereus, B. subtilis* and *Micrococcus luteus*) and Gram-negative (*E. coli, Salmonella typhi* and *P. aeruginosa*) bacteria in a similar extent to the widely used antibiotic gentamicine (Meot-Duros et al., 2010). Besides, and also interesting to highlight is that *C. maritimum* also evidenced a pronounced cytotoxic activity against L1210 (mouse lymphocytic leukemia), CEM-C7H2 (lymphocytic leukemia) and even RPMI-8226 (human myeloma) cell lines, without displaying cytotoxic potential against FHs 74 Int. (normal human intestinal cells) cell line (Meot-Duros et al., 2010). Moreover, sea fennel has been widely used in traditional medicine as a diuretic, antiscorbutic, depurative, digestive and purgative, as also anti-inflammatory, antiplatelet-aggregator and antimutagenic, which shows the high potential for possible uses of the species as a source of bioactive molecules for medicinal purposes (Meot-Duros et al., 2010). Pereira et al. (2017a) have also observed that sea fennel exhibits strong antioxidant activity, which is closely associated to its high content of phenolic compounds such as chlorogenic acid. In addition, Meot-Duros et al. (2010) isolated falcarindiol from leaves extracts, which exhibited cytotoxicity against IEC-6 cells.

8. *Cynara cardunculus* L

Cardoon (*Cynara cardunculus* L., Asteraceae) is a species native in the Mediterranean basin, which gradually has adapted in various microclimates and abiotic stress factors, including saline soils and water deficit (Ceccarelli et al., 2010). Three botanical varieties are included in the species, namely wild cardoon (*C. cardunculus* var. *sylvestris* (Lamk) Fiori), and globe artichoke (C. *cardunculus* var. *scolymus* (L.) Fiori) and cultivated cardoon (*C. cardunculus* var. *altilis* DC; Pagnotta, Fernandez, Sonnante, and Egea-Gilabert (2017)), which derived from wild cardoon (Ceccarelli et al., 2010). The edible parts of wild and cultivated plants are the immature inflorescences or heads which are used in many traditional dishes throughout the Mediterranean countries, while the whole plant may be used for medicinal and industrial purposes, as well as in the food industry as natural rennet for cheese production (Fernández, Curt, & Aguado, 2006) (Fig. 3f). According to Colla et al. (2013) wild cardoon and globe artichoke are more salt sensitive comparing to cultivated cardoon, probably due to less efficient osmoregulatory mechanisms, as being evidenced by lower Na accumulation and higher proline content in cultivated cardoon leaves (Lattanzio, Kroon, Linsalata, & Cardinali, 2009).

8.1. Chemical composition

Cardoon plant parts contain several bioactive compounds, with chlorogenic acid and lutein derivatives being the most pronounced ones (Lattanzio et al., 2009). The majority of phenolic compounds consists of caffeic acid derivatives, with caffeoylquinic acid derivatives such as chlorogenic acid and cynarin being those credited with significant therapeutic activities (Lattanzio et al., 2009). Other phenolic compounds have also been detected in plant parts, including cumaric acid, luteolin derivatives and apigenin (Petropoulos, Pereira, Ntatsi, Danalatos, Barros, & Ferreira, 2017; Petropoulos, Pereira, Barros, & Ferreira, 2017). Moreover, according to Petropoulos et al. (2017d) fatty acids of artichoke heads consist mainly of palmitic and linolenic acid (42.9 and 29.6, respectively). Flower heads are one of the richest vegetable sources of inulin with the highest polymerization degree among the various plant species, while they are also considered rich sources of minerals and dietary fibers (Ceccarelli et al., 2010). In a recent study, Colla et al. (2013) observed that increased salinity in the nutrient solution improved the quality features of leaves by increasing their antioxidant activity, total polyphenols, chlorogenic acid, cynarin and luteolin levels, while apigenin was affected in a genotype dependent manner.

8.2. Health effects

Cardoon varieties are considered rich sources of bioactive compounds and apart from food uses, most of the plant parts may be used for medicinal purposes. The broad therapeutic spectrum of cardoon could be associated with the various phenolic compounds that have been detected in flower heads and leaf parts of the plant, which probably act synergistically with additive pharmacological effects (Petropoulos et al., 2017c). The plant extracts of *C. cardunculus* var. *scolymus* possess hepatoprotective, anticarcinogenic, antioxidative, diuretic, choleretic, cholagogue, antidiabetic and antibacterial activities (Lattanzio et al., 2009). Plant tissue extracts and infusions exhibited significant *in vitro* antioxidant activities, whose potency depends on plant part and the extraction method (Kollia, Markaki, Zoumpoulakis, & Proestos, 2016). Moreover, leaf extracts have been attributed with protective effects against HIV and bile discard, as well as with inhibitory activities against cholesterol biosynthesis and LDL oxidation (Lattanzio et al., 2009). The high content of cardoon in inulin has been associated with beneficial effects on gut microflora and minerals absorption, as well as with protective effects against colon cancer (Lattanzio et al., 2009).

9. *Eryngium maritimum* L

Sea holly (*Eryngium maritimum* L.) is a halophyte species of the Apiaceae family and one of the most important species belonging to *Eryngium* genus. It is a perennial herbaceous shrub which prefers saline conditions and low nitrogen availability (Clausing, Vickers, & Kadereit, 2000). The species grows usually in sand hills, while it can be found along the coasts in Southern Europe (Lajnef, Pasini, Politowicz, Tlili, & Khaldi, 2017), as well as in the Atlantic coasts of Europe and North Africa (Clausing et al., 2000). The edible parts of the species are its leaves and roots, while the aerial parts and roots have been traditionally used in folk medicine as remedies against various diseases (Lajnef et al., 2017; Lisciani et al., 1984). Moreover, Amessis-Ouchemoukh, Madani, Falé, Serralheiro, and Araújo (2014) highlighted the potential use of the species in the development of plant-derived drugs considering the increasing demands of the pharmaceutical industry and consumers preferences to such products. However, the commercial exploitation of the species has to be carried out with special care in order to avoid genetic erosion, since according to Bracchetti and Conti (2014) the species did not show great adaptability to the rapid changes that occurred during the last decade in the coastlines.

9.1. Chemical composition

Sea holly has a significant content of phenolic acids, being caffeic acid and gallic acid the major compounds (Mejri et al., 2017). Besides to these compounds several other constituents are also present, namely flavonoids (flavone, rutin trihydrat, quercetin dihydrat, kaempferol, apigenin, luteolin) and phenolic acids (rosmarinic acid, *trans*-hydroxycinnamic acid, *trans*-cinnamic acid, 4-Hydroxybenzoic acid, 3,5-Dimethoxy-4-hydroxybenzoic acid, syringic acid and salicylic acid) (Mejri et al., 2017). Moreover, Amessis-Ouchemoukh et al. (2014) reported differences in bioactive contents between leaves and stems, with leaves contain higher amounts of total phenolics, flavonoids, flavonols, proanthocyanidins and total tannins. *E. maritimum* seeds have also a rich oil content, which according to (Lajnef et al., 2018) ranged between 22.9 and 34.2%, with the oleic acid being the main fatty acid (58.3%–62.8%). Recently, sixty-six volatile compounds, such as germacrene D (13.62–31.71%), 15-hydroxy-α-muurolene (12.04–18.58%), and germacrene B (6.77–15.04%) were also identified in the essential oils from air-dried seeds, representing from 32.4% to 65.3% of total volatiles content (Darriet, Andreani, Cian, Costa, & Muselli, 2014). Apart from seeds, roots also contain essential oils, which according to Darriet et al. (2014) are rich in 2,4,5-trimethylbenzaldehyde and 2,3,6-trimethylbenzaldehyde and α-muurolene (39.8, 29.0 and 23.5%, respectively). In the same study, the essential oils composition of the separated aerial parts (flowers, stems and leaves) consisted mostly of germacrene D, 4βH-muurol-9-en-15-al, 4βH-cadin-9-en-15-al and 4βH-cadin-9-en-15-ol (Darriet et al., 2014).

9.2. Health effects

Eryngium maritimum is also an important halophyte, since leaves extracts exhibited strong antioxidant activity and antibacterial activity against *Pseudomonas aeruginosa* and *Pseudomonas fluorescens* (Meot-Duros, Le Floch, & Magné, 2008), while Yurdakök and Baydan (2013) reported that extracts from the aerial and root parts showed cytotoxic effects against human hepatocellular carcinoma (HepG2) and human laryngeal epidermoid carcinoma (Hep2) cells. In a recent study, Amessis-Ouchemoukh et al. (2014) observed that leaves extracts exhibited significant acetylcholinesterase inhibitory activity, while stems had a stronger metal chelating activity than leaves. Also, interesting to highlight is that the extracts from the *E. maritimum* displayed anti-inflammatory and antinociceptive activities (Küpeli, Kartal, Aslan, & Yesilada, 2006). Other therapeutic effects include nephroprotective, hepatoprotective and antifibrotic properties from seed methanolic extracts (Mejri et al., 2017), while Meot-Duros et al. (2008) reported several medicinal uses such as kidney stone formation inhibition and aphrodisiac, expectorant, diaphoretic, diuretic, stimulative, cystotonic, and anthelmintic properties.

10. *Inula crithmoides* L

Golden samphire (*Inula crithmoides* L., syn. *Limbarda crithmoides* (L.) Dumort.) is a succulent dicotyledonous species commonly found in the Mediterranean basin (Zurayk & Baalbaki, 1996). The salt tolerance of this species may be based on its ability to accumulate glycine betaine and proline for osmoregulatory purposes (Hassan, Estrelles, Soriano, Boscaiu, & Vicente, 2017). Moreover, young leaves of the species are edible and exhibit various medicinal activities (Zurayk & Baalbaki, 1996).

10.1. Chemical composition

Golden samphire present on their chemical composition a wide variety of molecules, among them the essential oil obtained from aerial parts have on their content hydrocarbons, such as 1-methylethyl-trimethylbenzene (18.7%); monoterpene hydrocarbons (32.1%), being α-pinene the most abundant component, followed by *p*-cymene, β-phellandrene and α-phellandrene (Fontana, Bruno, Senatore, & Formisano, 2014). Phenols are also present (19.6%), with thymol being the main component. Sesquiterpenes hydrocarbons (19.4%) and oxygenated sesquiterpenes (12.0%) are also part of the chemical composition of oil, with germacrene D (5.9%) and t-cadinol (6.2%) being the most abundant compounds (Fontana et al., 2014). Besides, scopoletin (15.3%), phenolic compounds, such as rutin, syringic, ferulic, gallic and chlorogenic acids have also been reported as ingredients of the aerial parts of the species, as well as carotene derivatives, fatty acids, sesquiterpenes and other terpenoids compounds (Omezzine, Ladhari, Rinez, & Haouala, 2011). The compounds 3,5-Dicaffeoylquinic acid and chlorogenic acid have been also isolated from aerial parts of *I. crithmoides* plants, as well as quercetin, α-amyrin, β-sitosterol and β-sitosterol-3-O-β-D-glucopyranoside (Malash, Ibrahim, Ibrahim, Kabbash, & El-Aasr, 2015). Also, interesting to highlight is that the chemical composition of this plant is highly affected by culture and harvesting conditions as also pronounced differences are observed between species obtained from distinct regions due to different growing conditions.

10.2. Health effects

Inula crithmoides is also an interesting antioxidant halophyte, acting as free radical's scavenger, reducing agent and even superoxide anion quencher (Jdey et al., 2017). In a recent study, Andreani et al. (2013) also reported that the essential oils of the aerial plat parts exhibited antioxidant activity. Significant anti-tyrosinase effects have also been evidenced, namely acting as inhibitor of diphenolase, while moderate effects were observed as monophenolase inhibitor (Jdey et al., 2017). According to Bucchini et al. (2015), the antifungal potential against *Alternaria solani* and *Phytophthora cryptogea* and fungistatic effects against *Fusarium* species were comparable with the activity of the positive control nystatin. Furthermore, this plant also exerts a pronounced antibacterial effect, both against Gram-positive (*S. aureus* and *Bacillus cereus*) and Gram-negative species (*Escherichia coli* and *Pseudomonas aeruginosa*), being even the observed effect similar to those obtained by the positive control gentamycin (Jallali et al., 2014). Anticlastogenic and antimutagenic effects were also observed, being even proposed that the use of the aqueous plant extracts are safe and succeeded in counteracting the oxidative stress and protect against the cytotoxicity (Abdel-Wahhab, Abdel-Azim, & El-Nekeety, 2008). The use of this halophytic plant as an herbicidal has been also proposed without affecting germination index of crop plants (Omezzine et al., 2011). Many medicinal uses have been confirmed through ethnopharmacological studies, since according to Lopes et al. (2016) and (Jallali et al., 2014) *I. crithmoides* is widely appreciated in traditional medicine for treatment of bronchitis, tuberculosis, anemia, as astringent, for malaria and diseases of urinary system, while the methanolic extracts from this species possess hepatoprotective activity (Malash et al., 2015).

11. *Lepidium latifolium* L

Pepperwort or broaded pepperplant (*Lepidium latifolium* L., Brassicaceae) is a weed native in several Mediterranean countries, as well as in Northern America and Asia (Kaur, Hussain, Koul, Vishwakarma, & Vyas, 2013). Pepperwort is a perennial plant which prefers moist areas, it has a height of 0.3–2 m, woody stems, waxy leaves and small white flowers, while it produces a great number of seeds (Kaur, Bhat, & Raina, 2013). It is also reported to have salt-tolerance properties through the glutathione induction of antioxidant enzymes (Dagar, Minhas, & Kumar, 2011; Kaur, Bhat, et al., 2013). All the aerial parts of the plant are edible, while they also have medicinal uses. The species has gained great research interest during the last decades due to its invasive and competitive behavior in the habitats where it is present, mostly due to its ability to reflect solar radiation and consequently to reduce the available energy for photosynthetic purposes from the ecosystem and especially from other herbaceous plants (Sonnentag et al., 2011). This feature along with its perpetual reproduction through sexual (seeds) and asexual methods (root propagules) render the species a potential threat for the ecosystems and special care is required prior to its commercial exploitation.

11.1. Chemical composition

Pepperwort contains a wide variety of chemical constituents with bioactivities, among them Apetalumoside B6, Quercetin-3-O-β-d-sophoroside-7-O-α-l-rhamnoside, Quercetin-3-O-(2,6-di-O-β-D-glucopyranosyl)-β-D-glucopyranoside-7-O-α-L-rhamnopyranoside, Kaempferol-7-O-α-L-rhamnopyranoside and various Kaempferol derivatives (Xiang, Haixia, Lijuan, & Yanduo, 2017). The leaves of *L. latifolium* also contain the epithionitrile1-cyano-2,3-epithiopropane (CETP; Conde-Rioll et al. (2017)). Moreover, leaves of pepperwort contains several glucosinolates such as glucoiberin, glucobrassicin, glucocherolin, glucoraphanin, sinigrin, gluconapin, glucotropeolin, and phenylethyl glucosinolate in amounts that differed between the tested ecotypes and plant parts (leaves and roots), while sinigrin was the most abundant one (Kaur, Bhat et al., 2013; Kaur, Hussain et al., 2013). Leaves contained higher amounts of phenols and flavonoids than roots, while fatty acids of leaves consisted mostly of linolenic, palmitic and stearic acid (Kaur, Hussain, et al., 2013).

11.2. Health effects

Regarding the medicinal properties of pepperwort, Conde-Rioll et al. (2017) observed that the extract from leaves of *L. latifolium* exhibited considerable *in vitro* antitumor activity against HT-29 human colon cancer cells which was directly attributed to the compound 1-cyano-2,3-epithiopropane (CETP) that isolated in leaves extracts. According to Hanschen, Herz, Schlotz, and Kupke (2015), although firm results regarding apoptotic and selective toxic effects of CEPT against human cancer cells were not obtained, the authors suggested that antitumor activity should be attributed to inhibition of mitochondrial dehydrogenase activity of human hepatocellular carcinoma (HCC) cells. Ethanolic extracts of *L. latifolium* leaves also contain several natural antioxidants which exhibit significant free radical scavenging activity, especially compounds Quercetin-3-O-β- D-sophoroside-7-O-α-L-rhamnoside, Apetalumoside B6, Kaempferol-7-O- α-L-rhamnopyranoside and Kaempferol-3-O- robinoside-7-O-(2‴′-(E)-feruloyl)-sophoroside (Xiang et al., 2017). Other health effects of the species include diuretic and hypotensive properties, and activities against prostate hyperplasia (Lisciani et al., 1984; Martínez Caballero, Carricajo Fernández, & Pérez-Fernández, 2004), as well as traditional uses against renal lithiasis and kidney disorders (Tabassum & Ahmad, 2011).

12. *Plantago coronopus*

Plantains (*Plantago* sp.) belongs to Plantaginaceae family. Several species of this genus such as *P.* coronopus L., *P. crassifolia* Forssk. and *P. maritima* are commonly found in saline environments, while other species such as *P. major* are not salt-tolerant and damaged under high salinity conditions (Al Hassan, Pacurar, Gaspar, Vicente, & Boscaiu, 2014). Gil, Lull, Boscaiu, Lidón, and Vicente (2011) reported that sorbitol may play a role in stress tolerance of *P. crassifolia* plants, while salt tolerance of *P. maritima* is associated with proline and antioxidant enzymes accumulation in leaves and roots, respectively (Sleimi, Guerfali, & Bankaji, 2015). According to Neves, Matos, Moutinho, Queiroz, and Gomes (2009) the leaves and flowered part of *P. coronopus* are used in traditional medicine in Portugal, while leaves from other *Plantago* species can be also used for culinary purposes (Fig. 3g).

12.1. Chemical composition

Plantago species comprise the largest group of the Plantaginaceae family, containing a wide variety of chemical constituents, among them high contents of primary and secondary metabolites, namely phenolic acids (gallic acid, *p*-hydroxybenzoic acid, vanillic acid, syringic acid, salicylic acid, caffeic acid, coumaric acid, ferulic acid, rosmarinic acid and verbascoside), flavonoids (catechin, epicatechin, quercetin, flavone, luteolin-7-*O*-glucoside, luteolin, apigenin), coumarins, lignans, glycosides, triterpenes and polysaccharides that seems to be determinant to the widely recognized bioactive effects (Jdey et al., 2017).

Beara et al. (2009) reported that *P. coronopus* has a high polyphenols, flavonoids, minerals, and amino acids content, while displays high antioxidant capacity. Also interesting to highlight is that the phenolic profile of *Plantago* spp. is highly dependent on the organ and extraction solvent used, as well as on the species (Beara et al., 2009). For example, in a study performed by Pereira et al. (2017b), roots presented the highest phenolic content and diversity in phenolic compounds, followed by flowers and leaves. Moreover, this species is also a valuable source of amino acids (arginine, leucine, lysine, phenylalanine, threonine, serine, proline, tyrosine and glycine) and minerals (sodium, calcium, potassium, magnesium and iron) (Pereira et al., 2017b), which may be a promissory factor to incite their upcoming use as an ingredient in human nutrition on a wider scale.

12.2. Health effects

Plantago coronopus is a medicinal halophyte with a wide variety of ethnomedicinal uses, although the scientific assessment of their biological activity is relatively scarce. More recently it has been reported a very interesting antioxidant capacity, mainly acting as a free radical's scavenger, chelating agent and even reducing power (Jdey et al., 2017). Furthermore, *P. coronopus* shown a capacity to inhibit the cholinesterase enzymes, monophenolase and diphenolase, which suggests their upcoming use as effective biomolecules towards new natural skin-whitening agents (Jdey et al., 2017). In fact, the recent data obtained has allowed to understand the main traditional uses given to this plant, which in turns emphasizes their potential as a source of biomolecules particularly useful to prevent multiple disorders, including those of oxidative stress-related diseases. The aerial parts and roots of the plant are widely used in folk medicine as anticancer, antimicrobial, antiviral, anti-inflammatory, analgesic, astringent, expectorant, diuretic, antipyretic, emollient agents and even in the treatment of upper respiratory disorders (Pereira et al., 2017b), while González-Tejero et al. (2008) reported its use against kidney and reproduction system disorders. Finally, Neves et al. (2009) described the skin protective and oral antiseptic uses of the aerial parts. Considering the great number of *Plantago* species, further studies should be performed in order to deepen knowledge on this field.

13. *Portulaca oleracea* L

Common purslane (*Portulaca oleracea* L., Portulacaceae) is an important annual weed, native to the Mediterranean basin and widespread throughout the world (Karkanis & Petropoulos, 2017). The edible parts of the species are its stems and leaves, which are used as salad vegetables and contain significant amounts of omega-3 fatty acids (Petropoulos et al., 2015; Petropoulos, Karkanis, Martins, & Ferreira, 2016) (Fig. 3h). Its chemical composition and cultivation practices were reviewed recently in detail by Petropoulos, Karkanis, et al. (2016), where the nutritional value of the species was highlighted. However, in the study of Petropoulos et al. (2015) as well as in the review paper of Gonnella, Charfeddine, Conversa, and Santamaria (2010), the high content of edible parts in antinutrients such as oxalates was noted, a feature that has to be considered before further commercial exploitation of the species as a ready-to-use vegetable. Regarding its salt tolerance, common purslane is considered a moderately salt tolerant species, since it has the capacity to withstand up to 240 mM of soil salinity (Kafi & Rahimi, 2011), while Anastácio and Carvalho (2013) did not observe toxicity symptoms under the same salinity levels in hydroponically grown purslane plants. In a recent study, Karakaş, Çullu, and Dikilitaş (2017) also reported that common purslane can be used for phytoremediation purposes to reduce the Na^+ and Cl^- concentrations in saline soils. This species is also used in traditional medicine for the treatment of several diseases (Ramadan, Schaalan, & Tolba, 2017).

13.1. Chemical composition

Common purslane is widely known as one of the richest plant source of omega-3 fatty acids, although several fatty acids have been also detected, namely, α-linolenic acid, followed by palmitoleic, palmitic, linoleic, oleic and stearic acids (Uddin et al., 2014). Moreover, according to Anastácio and Carvalho (2013), salinity levels resulted in changes of relative percentage of the main fatty acids (palmitic, α-linolenic and linoleic acid) without however affecting ω6/ω3 ratio. The carotenoids α- and β-carotene, lutein and zeaxanthin are also abundant in purslane, with important bioactive properties being attributed to these compounds (Dias, Camões, & Oliveira, 2009). Tocopherols, vitamin C and some vitamers of complex-B (B1 - thiamine, B2 - riboflavin, B3 – niacin, B5 - pantothenic acid, B6 – pyridoxine, and B9 – folates) have also been identified in purslane, as also relatively high contents of oxalic acid and minerals, such as iron (Fe), zinc (Zn), potassium (K), boron (B), nitrogen (N), manganese (Mn), calcium (Ca), copper (Cu), magnesium (Mg), and slightly lower amounts of phosphorus (P), sulfur (S), sodium (Na) (Alam et al., 2014). Besides to the above referred bioactive constituents, different types of alkaloids (oleraceins A-E, betalain alkaloid pigments – reddish betacyanins and yellow betaxanthins), mucilages and pectins, 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, chlorophyll, bergapten and robustin have been also detected (Erkan, 2012). Finally, it has to be mentioned that the chemical composition of purslane shows a seasonal variation, while it also varied depending on growing and harvesting conditions and plant part (Alam et al., 2015).

13.2. Health effects

Portulaca oleracea is an omnipresent halophyte that displays promising antioxidant properties, mainly acting as free radical scavenger, metal quencher, lipid peroxidation inhibitor and even significant DNA protectant against hydroxyl radicals (Alam et al., 2014). The antimutagenic potency of this plant was also investigated, and directly correlated with the antioxidant potential conferred by various phytochemicals present in plant tissues (YouGuo, ZongJi, & XiaoPing, 2009). Some of these biomolecules, namely phenolic constituents are also able to promote cardiovascular function, mainly acting as anti-inflammatory and anti-nociceptive agents, at same that reduce the human cancer risk (Ramadan et al., 2017). Linked with these effects, anti-atherogenic, anti-hyperlipidemic, and hepatoprotective benefits may be also reached, at same time that pronounced improvements in kidney and nervous system have been stated (Chowdhary, Meruva, Naresh, & Elumalai, 2013). Furthermore, promising antispasmodic, anti-arthritic, antidiabetic, antiseptic, diuretic, antimicrobial, vermifuge, tonic and febrifuge potentialities have been also reported, besides their unquestionable action as an immunomodulatory agent (Chen, Li, Zhang, Xia, & Zhang, 2016). *P. oleracea* extracts may also stimulate the signaling in β-cells and thus can be used for diabetes prevention (Ramadan et al., 2017). In addition, extract of this species inhibited the acetylcholinesterase (AChE) enzyme, which is a key target in Alzheimer's disease treatment (Chen et al., 2016). According to these researchers, this activity may be due to compounds dopamine and norepinephrine that are present in *P. oleraceae* ethanolic extracts. Apart from its beneficial effects common purslane is considered to contain great amounts of oxalic acid which may has severe implications on human health, especially to people that have a tendency to kidney stone formation. However, according to (Petropoulos et al., 2015) oxalic acid content is a genotype dependent feature and could be minimized through genotype selection and breeding techniques and incite commercial cultivation and consumption on a regular basis.

14. *Salicornia herbacea* L

Grasshort (*Salicornia herbacea* L., Amaranthaceae) is an edible halophytic species commonly found in salt marches (Kim et al., 2017). According to Lee, Kim, Kim, and Sohn (2016) this species can withstand l00 mM of NaCl, through the accumulation of shikimic acid, vitamin K1, and indole-3-carboxylic acid in root system as a primary response to salinity stress. Ermawati et al. (2009) also reported that the gene *ShTIP* (*Salicornia herbacea* tonoplast intrinsic protein) was highly expressed in the shoots and roots under salt stress conditions which indicate its involvement in salt tolerance mechanisms through ionic transport regulation. The aerial parts of the plant are edible and eaten as seasoned vegetable in many Mediterranean countries (Ksouri et al., 2012), while Zhao, Wang, Wang, Liu, and Xin (2014) have suggested the use of glasswort powder for the production of a novel vinegar with anti-fatigue effects.

14.1. Chemical composition

Several caffeoylated quinic acid derivatives (CQAs) such as 3-O-Caffeoyl-5-O-dihydrocaffeoyl quinic acid, 4,5-di-O-dihydrocaffeoyl quinic acid and 3,5-di-*O*-caffeoyl quinic acid were isolated from methanolic extracts of the aerial parts of *S. herbacea*, as well as flavonol glucosides such as quercetin 3-O-β-d-glucopyranoside, isorhamnetin 3-O-β-D-glucopyranoside and isoquercitrin 6″-O-methyloxalate (Cho et al., 2016). More recently, two new triterpene saponins salbige A and salbige B and other already reported compounds such as echinocystic acid, gypsogenin and pheophorbide A were identified in methanolic extracts of the aerial parts of *Salicornia herbacea* (Zhao et al., 2014). Kim et al. (2012) isolated three already known saponins and one newly found triterpenoid saponin 3b-hydroxy-23-oxo-30-noroleana- 12,20(29)-diene-28-oic acid 3-O-b-D-glucuronopyranosyl-28-O-b- D-glucopyranoside. According to Kim, Cho, et al. (2014) and Kim, Jun, et al. (2014), phenylpropanoic acids and flavonols content depends on growth stage with higher contents being detected at maturity stage. Other reported compounds include pentadecyl ferulate, phytol, stearolic acid, (3Z,6Z,9Z)-tricosa-3,6,9-triene, stigmasterol, ergosterol, dioctyl phthalate, dibutyl phthalate, vanillic aldehyde, and scopoletin (Wang et al., 2013). Fatty acids of stems consist mainly of linoleic and linolenic acids, while palmitic and stearic acids were detected in lower amounts (Essaidi et al., 2013).

14.2. Health effects

Salicornia herbacea contains several bioactive compounds which have been associated with various medicinal properties. In a recent study, Kang et al. (2014) reported that the seed extracts of *S. herbacea* exhibit cytotoxic effects on HCT 116 and HT-29 colon cancer cells, while Lee et al. (2016) suggested the use of seed extracts as potential anti-coagulation agents. Tuan et al. (2015) found that the extract of *S. herbacea* possess anti-HMGB1 (high mobility group box 1 protein) activity, while some compounds isolated from the aerial parts of this species exhibited vascular protective activity against HMGB1 induced inflammatory reaction. Compounds such as salbige A and salbige B which have been isolated from the aerial plant parts of the species exhibited antiproliferative activities, while pheophorbide possessed inhibitory activity against A549 and HepG2 cancer cells (Zhao et al., 2014). Dicaffeoylquinic acid derivatives and flavonoid glucosides have been attributed with several health promoting bioactivities due to their high antioxidant potency, including neuroprotective, anti-inflammatory, antiadipogenic, hepatoprotective, skin whitening, anti-hypelipidemic and antibacterial effects (Choi, Kang, & Hong, 2016; Essaidi et al., 2013; Kim, Jun, & Kim, 2014; Tuan et al., 2015). Moreover, Ksouri et al. (2012) has reported biological effects such as hepatoprotective properties and inhibitory effects against oxidation-induced cellular damage, as well traditional medicinal uses against constipation, diabetes, obesity and cancer.

15. *Salsola soda* L

Opposite-leaved saltwort (*Salsola soda* L., Chenopodiaceae) is an annual species native to several Mediterranean countries (Polat & Satıl, 2012). It is a halophytic succulent shrub that can be used for bio-desalination of saline soils and as a companion plant with conventional crops, while its leaves are edible and commonly used as raw or cooked salad vegetables (Colla, Rouphael, Fallovo, Cardarelli, & Graifenberg, 2006). Apart from grown in the wild, *S. soda* has been introduced as a commercial cash crop with important high added value products, while in Italy is commonly known as 'agretti' vegetable (Centofanti & Bañuelos, 2015).

15.1. Chemical composition

Opposite-leaved saltwort or barilla plant contains several bioactive compounds including flavonoids (isorhamnetin-3-O-glucoside and isorhamnetin-3-O-rutinoside), acetophenones, coumarins, sterols as also simple tetrahydroisoquinoline alkaloids, such as salsoline, salsolidine, *N*-Methylisosalsoline and carnegine, with very interesting phytopharmacological effects being attributed to these molecules (Tundis et al., 2009). Minerals, such as aluminium (Al), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), zinc (Zn), selenium (Se) and boron (B) are also present in *S. soda* aerial parts, being even observed marked differences in mineral composition of leaves, stems and roots (Centofanti & Bañuelos, 2015).

15.2. Health effects

Salsola soda is a halophyte with a very interesting antidiabetic potential, since it has been attributed with inhibitory effects against α-amylase enzyme, probably due to its high content in phenolic compounds, namely flavonol glycosides (Tundis, Loizzo, Statti, & Menichini, 2007). Also, in the study performed by Tundis et al. (2009), promissory antioxidant effects were also reached using an alkaloid extract from the aerial parts of the plant, mainly acting as free radical's scavenger. Furthermore, the same authors also evaluated the role of plant extracts for Alzheimer's disease treatment through the assessment of the anti-cholinesterase activity of this matrix, finding both acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) inhibitory effects, mainly conferred by its chemical constituents tetrahydroisoquinoline alkaloids (Tundis et al., 2009). The observed anti-cholinesterase effects present a dose-response relationship, i.e. different quantitative composition of bioactive constituents modified the final biological activities. According to Polat and Satıl (2012) the aerial parts of *S. soda* are used for medicinal purposes in Turkey, while Tundis et al. (2009) reported that the extracts from the aerial parts of some *Salsola* species (*S. oppositofolia, S. soda* and *S. tragus*) exhibited significant antioxidant activity. Moreover, Loizzo, Calabria, Tundis, Calabria, and Pisa (2007) observed that the extracts of this species exhibited anti-hypertensive properties through the inhibition of angiotensin converting enzymes.

16. *Suaeda fruticosa* Forssk

Shrubby seablight (*Suaeda fruticosa* Forssk.) is a halophytic species of the Amaranthaceae family. This species is commonly found in moist areas with high salinity, pH, Na and Cl (Chenchouni, 2017), while *S. fruticosa* plants can withstand salinity levels up to 300 mM NaCl through the increase of sugars, proline and proteins content (Hameed et al., 2012). According to Devi et al. (2016) this species is a salt hyperaccumulator and can be used for phytoremediation of saline soils. Regarding the nutritional value of *S. frtuticosa*, its seeds contains about 25% oil that can be used for human consumption, while its leaves are edible and used for human consumption or as forage (Weber, Ansari, Gul, & Ajmal Khan, 2007).

16.1. Chemical composition

Shrubby seablight is a halophytic plant with a varied chemical composition of fatty acids, such as linoleic and oleic acids, followed by palmitic and stearic acids (Ozcan, 2014); minerals (aluminium, calcium, phosphorus, potassium, magnesium, iron, manganese, copper and zinc, and relatively lower contents of cobalt, chromium and nickel) (Towhidi, Saberifar, & Dirandeh, 2011). Pronounced amounts of phenols, flavonoids (gallic acid, catechin, chlorogenic acid, caffeic acid, quercetin and kaempferol), tannins, proanthocyanidins, carotenoids, alkaloids and saponins have been also detected (Oueslati et al., 2012a; Qasim et al., 2017), which have been direct associated with the phytopharmacological potential of the species.

16.2. Health effects

Suaeda fruticosa exhibits several bioactive effects which are attributed to its high phenolic compounds content. Promissory *in vitro* and *ex vivo* antioxidant properties were also reported by Oueslati et al. (2012b), who found that *S. fruticosa* displayed both free radicals scavenging, lipid peroxidation inhibition and oxidation prevention effects. Furthermore, the authors also revealed that 2,5-dihydroxybenzoic acid and rutin hydrate were the major molecules, and concluded that the effectiveness of the extract is highly depended on the content of these bioactive molecules. Similar findings were also stated by Qasim et al. (2017), in a detailed study aiming to assess the antioxidant capacity, phenolic composition and bioactive compounds of *S. fruticosa* and other medicinal halophytes commonly used as herbal teas. In addition, the authors highlighted that the species showed strong radical scavenging and reducing power capacities, which were higher than synthetic positive controls (Qasim et al., 2017). Further, and not least important to point out is that this plant is also used in traditional medicine as an effective hypoglycemic and anti-hyperlipidemic agent (Benwahhoud, Jouad, Eddouks, & Lyoussi, 2001), while Ksouri et al. (2012) reported that dichloromethane extracts of *S. fruticosa* exhibited significant anticancer activity against human lung carcinoma and colon adenocarcinoma cell lines.

17. *Tribulus terrestris* L

Puncturevine (*Tribulus terrestris* L., Zygophyllaceae) is an important weed commonly found in sandy soils throughout the Southern Europe, while it is considered moderately salt tolerant (Šalamon, Gruľová, & Feo, 2016) (Fig. 3i). It is a widely distributed species and a basic ingredient in folk medicine with several uses against various human conditions (Hammoda et al., 2013). Recently, there are available several dietary supplements with *T. terrestris* as the basic ingredient, based on health claims regarding its aphrodisiac and testosterone production enhancing properties (Antonio, Uelmen, Rodriguez, & Earnest, 2000; Gonçalves, Aguiar, & Wolff, 2017). Moreover, Šalamon et al. (2016) evaluated the potential of commercial growing of puncturevine and suggested that transplantation of seedlings was more effective than direct sowing in terms of both biomass production and bioactive compounds content.

17.1. Chemical composition

Puctuverine contains protodioscin and several other furostanol saponins which have been isolated from the aerial parts of the plant (De Combarieu, Fuzzati, Lovati, & Mercalli, 2003). Moreover, Wang, Zu, and Jiang (2009) isolated in extracts of *T. terrestris* several constituents including terrestriamide, quercetin-3-O-β-D-glucoside, hecogenin -3-O-β-D-glucopyranosyl (1–4)-β-D-galactopyranoside, and uridine. Sixteen steroidal saponins have been isolated from hydroethanolic extracts fo the aerial parts of the plant, including seven newly reported compounds including terrestrinin C, D and E (Kang et al., 2014). Other reported compounds include two oligosaccharides and the stereoisomer of di-p-coumaroylquinic acid; 4,5-di-p-cis-coumaroylquinic acid (Hammoda et al., 2013).

17.2. Health effects

Puncturevine is one of the most researched aphrodisiac plants known as “plant Viagra”, with its therapeutic properties being attributed to the presence of furostanol saponins (Šalamon et al., 2016). Protodioscin is the main phytochemical compound in *T. terrestris* plants and is suggested to stimulate the production of testosterone in men, while women with hypoactive sexual desire disorder (HSSD) who received *T. terrestris* exhibited increased levels of testosterone (Vale, Zanolla Dias de Souza, Rezende, & Geber, 2017). In contrast, Antonio et al. (2000) reported that oral administration of tribulus (a herbal preparation of *T. terrestris*) at a dose of 3.21 $mg\ kg^{-1}$ body weight, had no significant effect on body composition or exercise performance in resistance-trained subjects. However, Ma, Guo, and Wang (2017) suggested that *T. terrestris extracts* did not increase body mass and testosterone levels, but they increased anaerobic performance of trained boxers and gave relief to muscle damage through the decrease of IGF binding protein-3 in plasma. Several other constituents of *T. terrestris* exert medicinal properties. In a recent study, Wei et al. (2014) reported that the terrestrosin D inhibited the growth and angiogenesis of prostate cancer cells and endothelial cells. Further, and not least important to point out is that this plant has also exhibited antioxidant activity, with 5-di-p-trans-coumaroylquinic acid being responsible for this activity (Hammoda et al., 2013).

18. Conclusion and future perspectives

Wild halophyte species of the Mediterranean basin are considered a valuable genetic source with great adaptation to severe conditions such as soil and irrigation water salinity that could be used as alternative cash crops in a saline agriculture regime. Moreover, the diversified and increased content in bioactive compounds render these species as very promising candidates for the food industry in order to design and produce novel food products with functional and health beneficial properties, such as beverages, leafy salads, microencapsulated oils, food additives, antimicrobial agents etc. However, a multi-step approach has to be implemented before these products become commercially available including: a) the evaluation of various ecotypes of the candidate species in order to select those with the most promising properties, b) the integration of selected genotypes in breeding programs for further improvement of selected features, e.g. enhanced bioactivity and bioactive compounds content, improved agronomic features, decreased content of possible antinutrients, c) the evaluation of cultivation practices to find the most suitable and purpose made practice guides d) the assessment of bioactive compounds content under commercial cultivation conditions, e) extended clinical and model trials to determine the health effects mechanisms, the recommended consumption on a daily basis, to exclude possible toxicity effects, e) the design and marketing of novel food products from halophytes, f) the shaping up of alternative approaches for healthy diets and well-being and the increase of consumer awareness, and g) the legislation regarding consumers safety issues and genetic conservation of the halophyte species.

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