

Editorial

Special Issue on Advances in Marine Biotechnology: Exploitation of Halophyte Plants

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Halophyte (salt tolerant) plants encompass roughly 1% of the world's plant species that can thrive in a multitude of saline biotopes, where glycophytes (non-salt tolerant) cannot [1,2]. They are highly resistant to the abiotic constraints characteristic of saline ecosystems, such as salinity, drought, extreme temperatures, and UV radiation, having evolved specialized morphological and physiological adaptations in response to the challenges of living in such harsh conditions [1,3]. The response mechanisms to handle abiotic stress include the synthesis and accumulation of bioactive metabolites, like phenolic compounds, terpenoids, vitamins, etc. These molecules are usually powerful antioxidants but can display other biological activities such as enzyme inhibition, antimicrobial, anti-inflammatory, and antitumoral activities, among others, thus granting halophytes with potential biotechnological applications for the food, pharmaceutical and cosmetic industries [4–17].

Halophyte plants have long been used for food, forage and ethno-medicinal/veterinary purposes and are nowadays raising scientific and commercial interest particularly in the agri-food sector due to their nutritional, functional and organoleptic properties [2,4,6,18–20]. Being naturally adapted to salinity, halophytes appear pivotal within the context of soil and water salinization and freshwater scarcity for agriculture. They are promising sustainable alternatives to the traditional glycophytic crops, since they can be cultivated under saline conditions using brackish and salt water for irrigation [1,15,19,21–23]. In fact, several halophyte species are emerging as candidates for alternative crops with applications in various commercial segments, from human and/or animal nutrition to pharmaceutical and/or cosmetic industries, being an approach to the sustained management of saline areas, revegetation, soil-remediation, or even ecosystem-engineering purposes [1–6,18,21,24–27]. In the scientific literature, halophytes are increasingly proven to be an important source of relevant compounds, ingredients, and/or raw material with multiple potential biotechnological applications [7–17,19,20,22,23,28–36]. Moreover, several halophyte species are still traditionally used in many parts of the world as food and folk remedies [4], which stands to prove their great potential.

Altogether, halophyte plants represent an outstanding (and underexplored) reservoir of natural biologically active compounds and a promising source for a new generation of sustainable bioproducts (such as foods, drugs and/or health-promoting products) awaiting imaginative exploration. Hence, this Special Issue “Advances in Marine Biotechnology: Exploitation of Halophyte Plants” aimed at providing a platform for current studies on the exploitation of halophytes in view of their vast potential biotechnological applications in all fields of science.

A total of five articles, three research papers and two review papers, are presented in this Special Issue. The three research articles concerned halophyte cultivation, but two of them focused on halophyte culture coupled with Integrated Multi-Trophic Aquaculture (IMTA) systems. Custódio et al. [37] assessed the conditions that benefit the performance of the sea purslane *Halimione portulacoides* in extracting dissolved inorganic nutrients from saline aquaculture effluents under IMTA systems by investigating the influence of lighting



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conditions and planting density on its vegetative development and nutrient (nitrogen and phosphorous) extraction capacity. The authors discovered that plant growth was unaffected by artificial lighting type, although LED systems proved more energy-efficient, and that high-density planting produced more biomass per unit of area and extracted more dissolved inorganic nitrogen and phosphorus. They state that *H. portulacoides* can be hydroponically cultivated using nutrient-rich saline effluents, employing LEDs as an alternative to fluorescent lighting, and using high-density planting to promote higher yields and extraction efficiencies. Marques et al. [38] investigated the fatty acids (FA) profiles of three halophyte species (*H. portulacoides*, *Salicornia ramosissima* and *Sarcocornia perennis*) whose nutritional properties for human consumption have been documented, comparing wild specimens retrieved from donor sites with conspecifics cultivated in aquaponics coupled with an IMTA system. The authors found that the FA profiles of halophytes from aquaponics differed significantly from those of the wild specimens, displaying higher content of omega-3 FAs in edible parts, and mostly in the form of α -linolenic acid. Their results suggest that halophytes were not nutrient-limited under aquaponic conditions and they highlight the nutritional value of these species, reinforcing the potential of aquaponics coupled with IMTA to produce high-quality halophytes for human consumption. The third research article considered the role of different salt types on specific salinity stress conditions for plants [39]. Nissim et al. [39] compared the effects of seawater at moderate and high concentrations and analogous NaCl solutions on salt-tolerant (*Tetragonia tetragonioides*) and salt-sensitive (*Lactuca sativa*) crops grown in hydroponics, theorising that, due to its mineral composition, diluted seawater would result in a less stressful growing medium than NaCl. The authors confirmed this hypothesis and found significant differences between the halophyte and the glycophyte species: the growth rates in *T. tetragonioides* did not vary between the two types of stress, but in *L. sativa* the diluted seawater led to higher biomass yield in both fresh weight and dry weight. Their results in terms of physiological parameters and concentration of minerals, phenolics, and proline also showed that seawater is a less detrimental growing medium than a similar NaCl solution, potentially due to different mineral composition.

From the two review articles, Hulkko et al. [40] addressed the contents of various types of compounds in halophyte biomass, while Karkanis et al. [41] focused on *Crithmum maritimum* (sea fennel) as an alternative crop for saline agriculture. Hulkko et al. [40] encompassed proanthocyanidins (condensed tannins), total phenolic compounds, photosynthetic pigments (chlorophyll and carotenoids), and vitamins in various halophytes, also considering extraction and analytical methods, and showed that several species have potential for nutrient-rich food production in salt-affected areas as well as to produce nutraceuticals and ingredients for cosmetics and pharmaceutical industries. They also postulate that waste repurposing could help identify new bio-derived sources for valuable compounds, while improving the sustainability and economic feasibility of existing production systems. Karkanis et al. [41] compiles recent literature on farming practices that may allow the establishment of sea fennel cultivation protocols for farmers, while also presenting the main constraints that hinder its further exploitation. Additionally, the authors gathered up-to-date information on the chemical composition (e.g., volatile and polyphenolic compounds, fatty acids, amino acids, minerals) and health-related properties (e.g., antimicrobial, insecticidal, anticholinesterase activities) of different plant organs to help uncover potential alternative uses that can increase the sea fennel's added value, contributing to its commercial exploration. The authors conclude that cultivation of halophytes as cash crops allows the use of salinized soils and/or salinized water in coastal areas to produce high-added-value products, and that sea fennel possesses features that fit this context.

Overall, the published studies provided advances on the biotechnological exploitation of halophytes, but more research in the field will continue to address the potential applications of these salt-tolerant plant species to uncover all that they have to offer.

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