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Salicornia: An emerging super food with health benefits

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Abstract
Salicornia, also known as pickle weed or sea asparagus, is a remarkable halophyte with growing significance in various fields. Its name, originating from the Latin word from "salt," reflects its extraordinary ability to thrive in high-salinity environments, with some species exhibiting tolerance levels as high as 3% NaCl. This review paper explores its taxonomy, nutritional composition of *Salicornia* and health benefits. It delves into *Salicornia* potential as a salt substitute and discusses various techniques for its production. Additionally, the review examines the role of *Salicornia* in land reclamation and phytoremediation, highlighting its versatility and promising applications.

Keywords: *Salicornia,* halophyte, salt substitute, land reclamation, phytoremediation, nutritional composition, health benefits

Introduction

Salicornia, often referred to as pickle weed, glasswort, sea beans, sea asparagus, crow's foot greens and samphire, is categorized as a halophyte and belongs to the *Amaranthaceae* family (Singh *et al.,* 2014) [35]. Indeed, the term "*Salicornia*" finds its roots in Latin, where it signifies "salt." Research findings indicate that certain species, such as *Salicornia europaea*, exhibit a remarkable resilience to salinity levels, with some studies showcasing tolerance levels as high as 3% NaCl (Yamamoto *et al.,* 2009) [37]. *Salicornia* species typically initiate their life cycles during the spring when they appear as green plants. As the seasons progress into autumn, these plants undergo a transformation, taking on a reddish-yellow hue, and eventually, they perish during the winter months. From a taxonomic perspective, the *Salicornia* genus presents a complex classification, encompassing numerous species, aggregates, and subspecies (Kadereit *et al.*, 2007) [18]. Worldwide, *Salicornia* species are naturally found in various regions, both inland and along coastlines, which encompass environments such as saltpans and salt marshes. They are regarded as some of the most promising halophytes for potential commercial cultivation due to their remarkable adaptability to diverse climate and salinity conditions (Dong-He *et al.*, 2010) [8].

Salicornia finds its way into culinary practices through various methods, including fresh consumption, fermentation, cooking, dehydration, and pickling for seasoning purposes. Dating back to ancient times, this plant has held a significant culinary presence in Asian coastal areas, notably in the form of fermented food and as a seasoning agent. Additionally, *Salicornia* has a historical association with traditional medicine, where it has been utilized to address a range of health issues, encompassing obesity, diabetes, constipation, and even cancer (Lopes *et al.,* 2017) [24]. A daily intake of sodium ranging from 0.18 to 0.23 grams is required to maintain crucial biological functions (WHO, 2006) [36]. Nonetheless, in contemporary society, many individuals frequently consume an excessive amount of sodium, commonly in the form of salt. This has emerged as a concern in countries and presents as an issue in developing nations where there is a growing preference for high-sodium diets (Li *et al.*, 2014) [22]. Table 1. Offers an overview of different species of *Salicornia*, presenting their botanical names, commonly known names, and the regions where they are geographically distributed.

Consequently, there is a compelling need for a comprehensive review that synthesizes the key studies and underscores the emerging industrial trends associated with *Salicornia*. Such an endeavour is essential to not only offer valuable insights for future investigations but also to unlock its potential as a sustainable and commercially viable plant across different domains of Worlds.

Table 1: *Salicornia* species and their geographical distribution

S. No.	Botanical Name	Common Names	Geographical Range	References
1.	*Salicornia europaea*	Common glasswort	Britain, France, Ireland	Zhang *et al.* (2014) [41]
2.	*Salicornia bigelovii*	Dwarf glasswort	USA, Mexico	Zhang *et al.* (2015) [40]
3.	*Salicornia brachiata*	Umari keerai	India	Jha *et al.* (2012) [16]
4.	*Salicornia virginica*	American glasswort, pickle weed	Canada, USA, Mexico	Rosso *et al.* (2005) [30]
5.	*Salicornia maritima*	Slender glasswort	Canada, USA, Mexico	-
6.	*Salicornia ramosissima*	Purple glasswort	France, Iberia	Isca *et al.* (2014) [15]
7.	*Salicornia herbacea*	-	Korea	Cho *et al.* (2015) [42]
8.	*Salicornia persica*	-	Iran	Singh *et al.* (2014) [35]

At present, *Salicornia* remains relatively obscure within the food sector, despite its remarkable potential as a nutraceutical food source rich in bioactive compounds. Its unique ability to thrive in extreme salinity conditions with minimal resource requirements further underscores its significance and warrants in-depth exploration (Cárdenas-Pérez *et al.*, 2021) [2]. This review examines the current standing of this plant genus within the realm of food and assesses its potential future prospects.

1. Cultivation

Salicornia is considered an ideal candidate for land reclamation, particularly in barren lands, salt flats and coastal areas, making it a viable option for seawater agriculture. With the looming threat of global warming leading to land submersion and freshwater scarcity, a transition to salt-tolerant crops appears to be a sensible choice (Katschnig *et al.*, 2013) [19]. In this context, *Salicornia* stands out as a suitable candidate for cultivation (Singh *et al.*, 2014) [35]. Regarding its cultivation, various levels of success have been observed worldwide. Some *Salicornia* species are commercially cultivated for purposes such as biodiesel production, animal feed, salt and oil extraction, with *S. bigelovii* being a notable example (Cybulska *et al.*, 2014) [6]. This particular species yields oleaginous seeds that have shown promise as a feedstock for biodiesel production (Falasca *et al.*, 2014) [10].

Another potential use of *Salicornia* lies in heavy metal remediation. The controlled cultivation of various species of *Salicornia* sourced from different habitats has yielded varying results. For instance, the greenhouse cultivation of *S. bigelovii* demonstrated that crop yield can differ depending on the plants' origins. Although successful, the greenhouse environment led to a reduction in biomass and fruit yield (Bresdin *et al.*, 2016) [1]. Furthermore, species-specific variations in yield were observed, with *S. ramosissima* producing more harvestable biomass compared to *S. dolichostachya* (Singh *et al.*, 2014) [35]. Even if future research determines that *Salicornia* is not suitable for direct human consumption, it remains valuable for other purposes, such as biofuel production or use as livestock feed.

2. Methods for Transforming *Salicornia* into a Salt Alternative

To produce *Salicornia* as a salt substitute, the initial step involves the collection of the plant, which is followed by a cleaning process that may vary slightly according to different reports (Gosh *et al.*, 2005; Lee, 2011; Seong *et al.*, 2017; Oliveira-Alves *et al.*, 2021) [13, 21, 31, 28]. The cleaning process involve washing the plants with either sea water or saline water (Seong *et al.*, 2017) [31]. Subsequently, the plants are typically cut and subjected to heating (Lee, 2011; Lyra *et al.*, 2021) [21, 25], or they may undergo a drying process, as reported by (Ghosh *et al.*, 2005) [13]. Drying is a crucial step that allows for the extended storage of plants, and methods such as freeze-drying and oven-drying have been employed for this purpose (Oliveira-Alves *et al.*, 2021) [28]. It is essential to conduct the drying process carefully to avoid damaging of the plants. Following these initial steps, various methods may be employed, some of which involve filtration, or mixing the extract with distilled water (Gosh *et al.*, 2005; Shin and Lee, 2013) [13, 33].

According to (Liang *et al.*, 2002) [23], A common procedure includes cleaning fresh *S. bigelovii* stalks under tap water, followed by washing at 95–98 °C for 4–6 minutes, quick cooling, and further processing using a high-speed tamping machine homogenizer. Afterward, the filtrate is concentrated through rotary evaporation at 85 °C (vacuum degree at 0.06 MPa) to produce liquid plant salt, which is then stored at -20 °C for the preparation of plant salt feed.

In another procedure involving fresh *S. bigelovii*, fractionation is achieved using a twin-screw press equipped with a coarse screen with 1mm whole sizes. After the first fractionation, the fiber is rewetted in a 1:1 weight ratio of fiber and saline irrigation water and pressed for a second time. The resulting juice and fiber samples are frozen, and the remaining biomass is dried at 70 °C and then ball-milled into a powder (Christiansen *et al.*, 2021) [5].

Various other drying methods for *S. bigelovii*, *S. brachiata*, and *S. herbacea* have been reported that include hydrothermal liquefaction, an efficient technology that converts high-moisture *S. bigelovii* stems into biofuel intermediates. This process eliminates the need for a drying step and uses of water in the biomass as a reaction medium at elevated temperatures (180–375 °C) and pressures (4–30 MPa) (Dandamudi *et al.*, 2020) [7]. Oven-drying has also been utilized for *S. brachiata* at 80°C for seven days and for *S. herbacea* at 70 °C for 48 hours (Jung *et al.*, 2019) [17].

The entire saltwort plant can be micronized to create a table salt substitute. The sodium chloride (NaCl) content of liquid plant salt can be determined by using the indirect precipitation titration method. Utilizing the entire plant reduces waste and provides advantages compared to plant extracts. Micronization enables the use of entire plants as food additives for various health foods, offering new applications in the food industry (Siddiqui *et al.*, 2021; Ogawa *et al.*, 2003) [34, 27]. To enhance the characteristics of micronized powders from entire plant sources, fluid-bed dryers can be used for drying. Products obtained from fluid-bed driers exhibit improved preservation characteristics, better flow ability, controlled release, and are easier to handle (Shin and Lee, 2013) [33].

In an alternative approach, instead of heating or drying the plants, extraction from the plants can be carried out with water after cutting. This extraction, when performed at higher temperatures, results in increased sodium content and decreased amino acids. Conversely, lower temperatures or shorter extraction times (4–10 hours) yield an inverse outcome i.e, increasing amino acids content by up to 200–400% and reducing sodium content to approximately 1–3%. The resulting product is then subjected to centrifugation and ultrafiltration, making *Salicornia* suitable for use as a salt substitute (Gosh *et al.*, 2007) [12] and (Castañeda-Loaiza *et al.*, 2020) [3]. Additionally, herbal salt infused with plant oil can be created through a process involving drying, incineration and filtration. The plants are then dried and pulverized to obtain a granulose extract (Kim *et al.*, 2017) [20].

3. Nutritional Composition and Health Benefits of *Salicornia*

One of the key reasons for the growing interest in *Salicornia* is its impressive nutritional profile. This section delves into the plant's composition, highlighting its rich content of essential nutrients such as vitamins, minerals, and antioxidants including health benefits.

A study investigating the impact of *S. bigelovii* plant salt on the blood pressure of Sprague Dawley rats has shed light on its mechanism and effects. The research findings indicate that white common edible salt can induce hypertension and it does not have the same effect. *Salicornia* when used as a substitute for salt, exhibits a protective influence on the liver and kidneys. Furthermore, it enhances the body's antioxidant capacity, thus safeguarding the liver and kidneys from potential damage caused by a high salt intake which also serve as a preventive measure against hypertension (Zhang *et al.*, 2015) [40].

The consumption of *Salicornia* is generally regarded as having a low risk due to its iodine content, which could potentially lead to hypokalemia (Patel, 2016) [29]. It is essential to note that, as of now, there have been no reported hypokalemia issues associated with its consumption. However, there have been isolated cases of a rare hypokalemic condition known as "thyrotoxic periodic paralysis", which has been linked to hyperthyroidism. In the case of *S. brachiata*, a notable presence of sulfur-rich amino acids, including cysteine and methionine, has been observed. This observation is attributed to the disruption of sulfur bonds and the subsequent release of these amino acids when the plant is under stress. Furthermore, Eganathan and colleagues in 2006 conducted an analysis that identified the fatty acids found in the fat of *S. brachiata*. The analysis revealed the presence of palmitic acid (16.48%), myristic acid (12.88%), oleic acid (32.79%), and notably, 10-undecenoic acid (37.85%). This discovery suggests the potential for commercial utilization, particularly in the production of lubricants or as pheromones targeting crop pests (Eganathan *et al.*, 2006) [9].

A metabolomic examination of *S. brachiata* has identified the presence of abundant polyunsaturated fatty acids and sulfur containing amino acids, accounting for approximately 55–64% of its composition (Mishra *et al.*, 2015) [26]. Selenium, a micronutrient crucial for growth and known for its potent antioxidant properties, plays a vital role in maintaining a robust immune system (Godfrey, 1981) [14]. This discovery underscores the rationale for exploring the extraction of selenium from *Salicornia* for human dietary purposes.

Additionally, another study has shown that *S. brachiata* possesses the capability to absorb salts of nickel, arsenic, and cadmium (Sharma *et al.*, 2010) [32]. This finding suggests that *Salicornia* plants have significant potential as an effective tool in the phyto remediation of heavy metal contaminated saline coastal regions.

4. Conclusion and Future Perspectives

Salicornia, commonly known as pickleweed or sea asparagus, is emerging as a versatile and promising plant with a wide range of applications. Furthermore, *Salicornia's* role in land reclamation and phytoremediation underscores its significance in environmental sustainability. Its ability to thrive in saline coastal regions and absorb heavy metals makes it a valuable asset for addressing environmental challenges.

As we look to the future, research into genetic modification, sustainable cultivation practices, and collaborations with industries will be pivotal in realizing full potential of *Salicornia*. Additionally, educational initiatives can foster greater awareness of *Salicornia's* benefits, driving its widespread adoption and contributing to a more sustainable and resilient future.

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