Halophyte Common Ice Plants

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The problems associated with the salinization of soils and water bodies and the increasing competition for scarce freshwater resources are increasing. Current attempts to adapt to these conditions through sustainable agriculture involves searching for new highly salt-tolerant crops, and wild species that have potential as saline crops are particularly suitable. The common ice plant (Mesembryanthemum crystallinum L.) is an edible halophyte member of the Aizoaceae family, which switches from C3 photosynthesis to crassulacean acid metabolism (CAM) when exposed to salinity or water stress. The aim of this review was to examine the potential of using the ice plant in both the wild and as a crop, and to describe its ecology and morphology, environmental and agronomic requirements, and physiology. The antioxidant properties and mineral composition of the ice plant are also beneficial to human health and have been extensively examined.

Keywords: Mesembryanthemum crystallinum ; Functional foods ; Sustainability

1. Introduction

Climate change, the lack of global water resources, and the increase of saline and dry conditions have negatively affected arable lands. By 2050, it is estimated that crop production must increase by 70% to 100% to meet global food demand [1]. As the actual trend is a 1% to 1.5% annual yield increase for major crops, guaranteeing sustainable agriculture in the future is a challenge [[2]]. Technological progress and the improvement of cultivation techniques are among the key factors determining wellness in contemporary populations, and have led to extensive population growth in recent decades. Increased soil use due to the growth in production has led to a loss of fertility and the phenomena of salinization and desertification, which render soils unsuitable for cultivation. In particular, salinity induces constraints in plants that are associated with a reduction in their primary production, leaf expansion, and biomass losses. Sustainability in terms of water resource preservation, food availability for poor populations, and a reduction in production inputs is thus a major challenge for researchers. The adoption of tolerant species and good agronomic practices, and the reduction of resource waste are, thus, significant research topics. Seawater and coastal lands represent potentially cultivable areas, but they are useless for conventional agriculture. Halophytes are an exception, as they are highly productive under saline conditions [[3]]. Saline agriculture with halophyte crops could be one solution to the problems of fresh water resource depletion and the increase of salinized soil areas, as they allow for the cultivation of marginal areas and can enable coastal and salt lands to be productive [[4]]. Halophytic cash crops can be domesticated through conventional breeding programs and thus improve their productivity and salt tolerance [[5]].

Halophytes are species that are able to complete their life cycles in environments where the concentration of sodium chloride is greater than 200 mM [[6]]. They are characterized by anatomical changes such as in the bladder cells and the salt glands, through which the excretion of excessive sodium occurs [[7]]. The leaves of halophytes can be used as human food (i.e., Chenopodium quinoa [[8]]), for fodder (i.e., Atriplex spp. [[9]]), or as oil seeds (i.e., Salicornia bigelovii [[10]]). They can also be sources of secondary metabolites [11]with potential economic value [12]Wild halophyte domestication is an approach that should therefore be considered. Menzel and Lieth[13] produced a list of over 2600 halophyte species that differ in their degree of tolerance to salinity. Some belong to the group "obligatory halophytes", which require saline environments for optimal growth, such as the common ice plant (Mesembryanthemum crystallinum L.). The aim of this review was to assess the potential of adapting the wild ice plant as a crop, describing its ecology and morphology, its environmental and agronomic requirements, and its physiology.

In addition, the ice plant’s antioxidant properties and mineral composition were examined, as it is a food crop that can be highly beneficial to human health.

2. Crop and Salt Stress Regulation

Epidermal bladder cells are external vesicles that have a water and NaCl storage function for osmotic adjustments [[14], [15], [16], [17], [18], [19], [20]], and betacyanins, flavonoids, myoinositol, pinitol, and transcripts for antifungal proteins, which are related to UV protection and/or pathogen defence [[21], [22], [23], [24]]. They are present in the leaves, stem, sepals, and buds, but not on the roots, during all stages of ice plant development. When plants are unstressed and in the juvenile phase, epidermal cell bladders remain appressed, but they swell in volume in stressed plants [[25]]. Three forms of bladder cell develop in mature tissues: the first along the side shoots; the second are the largest and develop in the seed capsules; and the third develop at the tips of leaves and sepals. This indicates that the bladders could be modified trichomes [[14]].

Environmental stress, such as salt and drought stress, is known to play an important role in M. crystallinum gene expression and development, but some molecules are significant in these gene modifications. Abscisic acid (ABA) for example is considered to be involved in signaling water stress and stimulating stomata closure [[24], [25], [26], [27]], and it has been observed that salt treatment increases the level of ABA and proline [[28]]. Cytokinins also play an important role in flower initiation and their increase may signal the transition from juvenile form to adult growth and reproduction [[29], [30], [31]].

M. crystallinum demonstrate the typical halophyte behavior of performing best in the presence of NaCl ranging between 50–250 mM NaCl [[32]]. This is in agreement with Atzori's findings, who observed better production under high salinity levels, suggesting that a saline environment stimulates growth (the FW and DW of juvenile control leaves were lower than in those treated with salt) [[4]].

Similar experiments have shown that maximum growth was obtained with a 100 mmol L−1 NaCl-solution [[33]] with a tolerance of up to 300 mmol l−1.

The high photosynthetic activity at high saline concentration could be explained by a general biochemical stimulation of plants, rather than CAM activity induction [[33]].

As mentioned, the ice plant is not only a saline-tolerant plant, but also has drought resistance: the results of growth response and biomass accumulation recorded in previous studies demonstrate that the ice plant is well adapted to drought and may grow even better with low amounts of water [[34], [35], [36], [37], [38]]. Tembo-Phiri found no difference among several water treatments regarding growth and biomass accumulation, and the stress conditions were mitigated by the CAM metabolism [[39], [40]].

Atzori et al. found differences in the life cycle length between stressed and unstressed plants: senescence in the control plants started in August, while the stressed plants were still in the vegetative phase. Thus, stressed plants may have more time to increase their biomass production [[4]]. Similar results are reported by Adams et al. [[14]].

In addition, the Na^+ storage ability of the epidermal bladder cells enables the ice plant to avoid the saline stress condition, leading to a decrease in antioxidant compounds [[41]].

M. crystallinum is also able to store Ca^{2+} and Mg^{2+}. This is an ability common to the Caryophyllaceae family [[36], [37], [38]], in addition to high Zn^{2+} concentrations in shoots. As many people throughout the world are Ca2+ deficient in their diets, this could represent a significant finding [[42]].

Thus, the ice plant can produce a significant amount of biomass through utilizing marginal soils and irrigation water (a height of 0.26 m was reached with a water pot capacity of 80% and 0.23 m with 25%). Accumulation can also increase under saline conditions [[43]].

3. Conclusions

Salinization of both soil and water and the high competition for scarce freshwater resources are increasing problems. Sustainable agriculture is required to adapt to these conditions, and new highly salt-tolerant crops are sought. Particularly suitable are wild species that have potential as saline crops. They have a remarkable capacity for acclimation and flexibility in their development, which is lacking in glycophytic plants. The high salt tolerance and content in the bioactive compounds, in addition to the excellent capacity for phytoremediation, makes the ice plant an important candidate for use in several areas, such as human food and medical care, and in the decontamination of polluted sites. By improving the cultivation system of ice plants, future large-scale production can be developed.

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