30 The Potential of Edible Halophytes as New Crops in Saline Agriculture

The Ice Plant (*Mesembryanthemum crystallinum* L.) Case Study

Giulia Atzori

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30.1 INTRODUCTION

A growing population will result in an increased food global demand, with a greater consumption of processed food, meat, dairy and fish, all products known to add pressure to the food supply system (Godfray et al. 2010). The trend in world hunger

characterized by a steady decline in the last decades, reverted in 2015, with today more than 820 million people chronically hungry. Such a situation restricts the achievement of the Zero Hunger target by 2030 (FAO IFAD UNICEF WFP and WHO 2019). Also, about 2 billion people in the world experience moderate or severe food insecurity, with the lack of regular access to nutritious and sufficient food leading to a greater risk of malnutrition and poor health (FAO IFAD UNICEF WFP and WHO 2019). Global climate change represents a further threat, especially in marginal and already-stressed agricultural ecosystems, including areas affected by salinity (Cheeseman 2016). In these regions, the world's major crops are not adequate to supply the calories, proteins, fats and nutrients people need: new crops are needed, specifically appropriate to such particular ecological conditions (Cheeseman 2016).

Globally, the irrigation of conventional crops accounts for about 70% of total freshwater (FAO 2011). Such a percentage is already high for areas where freshwater is not limited but becomes impracticable where this resource is scarce. Sustainable agriculture in saline environments requires improved crops and efficient water use (Jez et al. 2016): with respect to this, the domestication of edible species that have naturally adapted to saline environments (Cheeseman 2015), namely halophytes, is an interesting approach to consider (Atzori et al. 2019; Ventura et al. 2015; Rozema and Schat 2013; Rozema and Flowers 2008; Rozema et al. 2013; Glenn et al. 1998). Halophytes can be defined as salt-tolerant plants capable of growth and reproduction at soil salinities greater than 200 mM NaCl, roughly corresponding to ~40% of salinity of seawater (Flowers and Colmer 2008). This group of plants is estimated to comprise 5,000–6,000 species (Glenn et al. 1999), an important number of which are edible species already consumed in many world regions, mainly as wild and not (yet) as cultivated crops. The interest in these species is timely, as their domestication could allow for the exploitation of more available brackish water and seawater sources for sustainable food production in salt-rich environments where conventional crops are proving inadequate; the growth of these plants could also benefit from the macro- and microelements which are important components of these water sources (Rozema and Flowers 2008).

The exploitation of endemic halophytes has the objective of developing local or regional food crops to feed people most at risk for food insecurity because of soil salinity or groundwater salinization (Cheeseman 2015). Since nutrition is an urgent issue in world areas affected by salinity, the development of new crops starting from wild, salt-tolerant relatives of conventional major crops (such as rice, wheat and barley), as opposed to using genetic resources to improve existing crop varieties, represents a valid option (Cheeseman 2015). As another even quicker opportunity, there is a large number of endemic salt-resistant species already used as food that have received very little attention in the scientific literature (Ventura et al. 2015): one “famous” example of species that started as a marginal indigenous crop and then experienced a rapid expansion and acceptance at a global level is quinoa (*Chenopodium quinoa* Wild.), which interestingly is highly salt tolerant (Smil 2001). Following the example of quinoa, the use of other species could face a similar expansion.

Regarding crops' nutritive qualities, the effect of salinity on the production of secondary metabolites has been richly studied with regard to plant salt tolerance, even if such compounds have rarely been considered as quality parameters for healthy food production and commercial purposes (Ventura et al. 2015). Halophytes production of secondary metabolites in response to salt stress is well known (Flowers and Muscolo 2015): such metabolites, or compatible solutes, seem to have different functions, among which a role in the prevention of oxygen radical production or in the scavenging of reactive oxygen species (Hasegawa et al. 2000). The secondary metabolites include simple and complex sugars, amino acids, polyols and antioxidants, which could potentially be utilized in functional food. Following the definition of Buhmann and Papenbrock (2013), defining functional food as having disease-preventing and/or health-promoting benefits, a saline environment could then potentially enhance the quality of products.

In addition to high value nutritional components, halophytes can also accumulate undesired factors including oxalates, nitrates and salts (Ventura et al. 2015). Yet, agrotechnical practices can be applied in order to decrease their content: examples are represented by the reduced use of NO_3^- fertilization in favor of NH_4^+ to decrease the oxalate content in *Portulaca oleracea* (Palaniswamy et al. 2002) or by adjusting iron fertilization to decrease nitrate accumulation in *Aster tripolium* (Ventura et al. 2013). Also cooking methods can provide a way to decrease the content of such undesired factors (Caparrotta et al. 2019). Nonetheless, species-specific investigations are required because of the different species' responses, e.g. significantly decreasing nitrates in the halophyte *Tetragonia tetragonioides* with increasing salinity (Atzori et al. 2020) as opposed to their increased accumulation in *Aster tripolium* with increasing salinity (Ventura et al. 2013). Also sodium accumulation is species-specific; for example in *Mesembryanthemum crystallinum* adult leaves accumulate more Na^+ than young leaves (representing the edible part of the species): such a strategy prevents the edible leaf product from having a too high sodium content (Atzori et al. 2017).

One last issue that the development of halophyte-based crops could address is represented by soil remediation. Phytodesalination is defined as a species aptitude to remove salts from soils by accumulating this in the tissues (Rabhi et al. 2015). A number of halophyte species are characterized by an enhanced ability to take up sodium. Examples of phytodesalinating halophytes are *Mesembryanthemum crystallinum* (Loconsole et al. 2019; Tembo-Phiri 2019; Cassaniti and Romano 2011; Hasanuzzaman et al. 2014), *Tetragonia tetragonioides* (Hasanuzzaman et al. 2014; Bekmirzaev et al. 2011; Neves et al. 2007, 2008; Atzori et al. 2020), *Salsola soda* and *Portulaca oleracea* (Graifenberg et al. 2003; Karakas et al. 2017; Bekmirzaev et al. 2011). Interestingly, phytodesalination is the only existing process in terms of sodium removal that occurs under non-leaching conditions (Rabhi et al. 2015), thus having an important potential value in water-scarce areas.

Even if in the last decades many results indicating the potential of halophytes as possible new crops have been published, scientific documentation of large-scale experiments is still limited and no cultivation protocols have been optimized for such crops (Ventura et al. 2015). Research is, in fact, still needed to ensure the lasting

sustainability of saline agriculture, since adequate cultivation systems are of importance. Coastal sandy soils seem an ecologically safe choice for large-scale halophyte production without the risk of salt contamination that could occur on fertile soils. Similarly, also underground freshwater contamination must be avoided. As a different option to consider, cropping systems as soil-less methods would prevent soil contamination and alleviate environmental concerns as the irrigation water would be reused until its depletion (Atzori et al. 2016; 2019). The belief in the importance of halophytes as potential sources of food in saline environments is widespread, particularly because they do not compete with the requirements of conventional food crops in terms of water and soil. In fact, research is currently directed both to the determination of the salt tolerance of halophytes and also to the improvement of their agricultural traits such as yield, palatability, chemical composition, use of mechanical harvesting, testing of market potential and, finally, securing farmers' income (Ventura et al. 2015).

30.2 ICE PLANT (*MESEMBRYANTHEMUM CRYSTALLINUM* L.)

Common ice plant (*Mesembryanthemum crystallinum* L.) is an annual prostrate succulent member of the Aizoaceae family, Caryophyllales (Figure 30.1). It is native to southern and eastern Africa and has now been introduced into western Australia, around the Mediterranean, the coasts of the western United States, Mexico, Chile, and the Caribbean (Adams et al. 1998). This species is already consumed as a vegetable crop in India, Australia, New Zealand and in some countries in Europe (Agarie et al. 2009), e.g. in Germany (Herppich et al. 2008) and the Netherlands.

M. crystallinum is typically distributed on coastal sand dunes and saline areas. It is tolerant to low temperatures and salt accumulation in the top soil and grows in well-drained sandy and loamy soils, even if nutritionally poor and saline, with an ambient temperature range from 12 to 30°C (Loconsole et al. 2019). It has also been

FIGURE 30.1 Ice plant during the flowering phase.

FIGURE 30.2 Examples of epidermal bladder cells.

known as a traditional medicine, characterized by demulcent and diuretic effects (Bouftira et al. 2012) and by naturally occurring superoxide dismutase (SOD) and related anti-oxidant molecules, which have a role in the protection of the skin against radiation exposure (Bouftira et al. 2008). The species is also characterized by anti-septic properties (Ksouri et al. 2008).

30.2.1 PHYSIOLOGY AND MORPHOLOGY

Ice plant has a developmentally programmed switch which enables it to move from C3 to Crassulacean acid metabolism (CAM) photosynthesis: this switch can be accelerated by salinity and drought stresses (Adams et al. 1998) and is connected to the transition from the juvenile to adult phase. The ability to switch to CAM allows plants to accumulate CO₂ during the night and then use it during the day, increasing both water use efficiency and carbon fixing ability (Loconsole et al. 2019).

Morphologically, the above-ground part of the ice plant is covered by epidermal bladder cells (shown in [Figures 30.1](#) and [30.2](#)), giving to the plant a shiny and gleaming appearance from which derives the common name of ice plant (Bohnert and Cushman 2000; Loconsole et al. 2019). The bladder cells are modified unicellular trichomes, ranging from 1 to 3 mm in diameter (Vivrette and Muller 1977), filled with a water solution and functioning as peripheral salinity and water reservoirs providing protection from short-term high salinity or water deficit stress (Agarie et al. 2007; Luttge et al. 1978).

Five stages of development have been described in terms of plant morphology and physiology (Adams et al. 1998):

Phase 1: *Germination*: Only the cotyledons are present; C3 photosynthesis; CAM has not yet been induced.

Phase 2: *Juvenile*: Seven leaf pairs develop on the primary axis; there are no side shoots and no flowers; C3 photosynthesis; CAM has not yet been induced; visible epidermal bladder cells.

Phase 3: *Adult*: Secondary leaves are on side shoots; senescence of primary leaves; no flowers; CAM becomes gradually inducible; visible epidermal bladder cells.

Phase 4: *Flowering*: Flowers occur at the terminus of the primary and side axes; CAM photosynthesis; epidermal bladder cells increase in number and size.

Phase 5: *Seed-formation*: Seed capsules are visible; water uptake ceases; epidermal bladder cells are prominent.

30.2.2 SALT TOLERANCE

Thanks to its considerable resistance to salt and drought stress (Bloom 1979; Vivrette and Muller 1977), the ice plant was studied from the 1980s onwards as a model species (Bohnert et al. 1988). A number of laboratory experiments aiming at elucidating the physiological and molecular mechanisms behind its stress resistance have been published since then including Agarie et al. (2007), Barker et al. (2004), Cosentino et al. (2010), Kore-eda et al. (2004), Oh et al. (2015), Sanada et al. (1995), Thomas et al. (1992), Thomas and Bohnert (1993) and Winter and Holtum (2007).

Mesembryanthemum is a sodium includer: after salt stress, sodium accumulates in a gradient from roots (about 70 mM) to the growing shoot apices, reaching a concentration of 1 M in the epidermal bladder cells. At the cellular level sodium is effectively partitioned to the vacuoles especially in the epidermal bladder cells (Bohnert and Cushman 2000). Also, salinity induces the accumulation of osmolytes, methylated inositols (ononitol and pinitol) and proline, with the objective of balancing the sodium accumulation in the vacuoles, where sodium may exceed 1 M concentration (Adams et al. 1998). Although the epidermal bladder cells are formed in the plant's juvenile phase, they remain pressed to the surface in unstressed plants, whereas under salinity conditions their volume increases dramatically (Adams et al. 1998).

30.3 FIELD EXPERIMENT

A field experiment was conducted in 2015 to test the growth of common ice plant under conditions of increasing soil salinity (complete results published in Atzori et al., 2017). The twofold aim of the experiment was:

1. To evaluate the crop potential of *M. crystallinum*, by determining the effects of a range of irrigation salinities on the growth and productive performance of the plant in an agricultural setting. A full screening of morphological and physiological characteristics was conducted to investigate adaptations to salinity.
2. To assess the effects of different salinity levels on the accumulation of mineral elements (especially sodium and calcium) related to physiological adaptation and nutritive value of the crop.

30.3.1 MATERIALS AND METHODS

30.3.1.1 Research Location, Irrigation and Soil Salinity

M. crystallinum was grown in an experimental field on Texel island (53.012837°N, 4.755306°E), the Netherlands, from May to August 2015. The experimental field was divided into 21 plots (8 × 20 m each) with seven salt concentrations randomly distributed and replicated three times: a view of the experimental field is shown in [Figure 30.3](#).

Drip lines, shown in [Figure 30.4](#), were located at 40 cm intervals and provided plots with irrigation characterized by different salinity levels. The irrigation water

FIGURE 30.3 Particular of the field experiment.

FIGURE 30.4 Particular of the drip irrigated field.

was a mixture of fresh water collected from a rainwater basin and natural seawater (electrical conductivity EC_w 35 dSm^{-1}) from a nearby ditch fed from the Waddensea. Using a custom built proportional-integral-derivative controller, fresh and saline waters were mixed with an automatic accuracy check of salinity levels in the irrigation water. Drainage pipes, located 60 cm below the surface with 5 m spacing between any two pipes, assured the rapid drainage of irrigation water and aeration of the soil.

The seven salinity treatments used in the experiment (each repeated in three plots) had electrical conductivities (EC_w) values of 2 dSm^{-1} (control), 4, 8, 12, 16, 20 and 35 dSm^{-1} . The soil salinity was monitored by means of samplers capable of collecting soil pore water; these were collected in all plots on three occasions during the experiment.

30.3.1.2 Plant Material, Samplings and Growth Measurements

Seeds of *M. crystallinum* were sown on the 14 April 2015 and young seedlings were transferred into the experimental fields at the rate of 30 plants per plot after one month. Three sampling events were performed during the experiment:

1. *T0 (time zero sampling)*: Six untreated juvenile plants were harvested 5 weeks after germination. Shoot fresh weight and dry weight data were collected ($n = 6$). Dry material was used to assess the Na^+ and Ca^{2+} concentration in juvenile plants;
2. *T1 (at potential commercial maturity, as young fully expanded leaves were ready to be harvested)*: 16 July 2015. Harvests were made of 3 plants per plot, 9 per treatment). Shoot fresh weight and the fresh weight of 3 young

fully expanded leaves per plant were recorded. Leaf area (LA), specific leaf area (SLA) and leaf succulence were determined on young fully expanded leaves ($n = 9$). Young fully expanded leaves ($n = 9$) were also analyzed for concentrations of carotenoids. Dried biomass was then determined and samples from young fully expanded leaves were used for measuring the Na^+ and Ca^{2+} concentration;

3. *T2 (at the end of the crop cycle)*: 11 August 2015. Harvests were made of 3 plants per plot, 9 per treatment) with the same measurements performed in the T1 sampling.

30.3.2 RESULTS AND DISCUSSION

30.3.2.1 Seawater Irrigation Extended the Growing Season

Figure 30.5 shows the growth of the ice plant shoots. There were no significant effects of salinity at T1, whereas at T2 saline conditions (especially EC_w 20 dSm^{-1}) led to higher biomass accumulation, both in terms of fresh and dry weight, compared to freshwater irrigation (control).

Similarly, for the FW and DW of young fully expanded leaves (yfel, 3 per plant), saline conditions also led to significant differences. At T2, salinity caused an increased weight of yfel (corresponding to the edible part of the tested species) compared to the control (Figure 30.6). Moreover, while total shoot DW significantly increased compared to control only at the 20 dSm^{-1} treatment, the youngest fully expanded leaves increased in DW with the majority of salinity treatments (i.e. 8, 12, 20 and 35 dSm^{-1}).

The better performance of plant biomass at higher salinity levels suggest growth stimulation by increased salinity, acting similarly to other halophytes. For many dicotyledonous halophytes, optimal growth occurs in fact at concentrations of

FIGURE 30.5 Fresh weight (FW) and dry weight (DW) of the ice plant shoot, collected at T1 and T2. Values are means $\pm$ s.e. ($n = 9$) expressed in grams per plant. Different letters indicate significant differences among treatments at $P < 0.01$ in FW and at $P < 0.05$ in DW plot (Tukey's Test). (Reprinted with permission from Elsevier from Atzori et al. "Effects of Increased Seawater Salinity Irrigation on Growth and Quality of the Edible Halophyte *Mesembryanthemum crystallinum* L. under Field Conditions" *Agricultural Water Management* 187 (2017): 37–46.)

FIGURE 30.6 FW and DW of 3 young fully expanded leaves per plant, collected at T1 and T2. Values are means $\pm$ s.e. ($n = 9$) expressed in grams. Different letters indicate significant differences among treatments at the same harvest event at $P < 0.01$ (Tukey's Test). (Reprinted with permission from Elsevier from Atzori et al. "Effects of Increased Seawater Salinity Irrigation on Growth and Quality of the Edible Halophyte *Mesembryanthemum crystallinum* L. under Field Conditions" *Agricultural Water Management* 187(2017): 37–46.)

50–250 mM NaCl (corresponding to EC_w values of ~ 5 and ~ 25 dS m⁻¹) in the root medium (Flowers and Colmer 2008). In our experiment, seawater irrigation was related to good growth performance of the ice plant, indicating its potential for saline agriculture. Salinity conditions also led to an extension of the growing season: control plants started to senesce and proceed to the seed production phase in August, whilst in plants treated at high salinity senescence was delayed by about one month. Likewise, Adams et al. (1998) reported that salinity slows down the plant's developmental physiology. Such a slow-down in development is particularly important for our testing of ice plant as a potential salt-tolerant crop in saline agriculture: young leaves, the species edible part, are picked leaving the plant undamaged and can extend the vegetative stage enabling an extra month of harvest compared to plants grown under non-saline conditions. Moreover, the number of young leaves produced and the grams of potential harvest were increased by the extended cycle length.

30.3.2.2 Morphological, Physiological and Osmotic Response to Increased Salinity

As shown in Table 30.1, increased salinity did affect LA and leaf succulence, whereas the SLA did not show any significant difference among treatments at any sampling event. Over time, the main morphological change observed was the increased leaf succulence at higher salinity levels, possibly representing an essential part of the ice plant salt tolerance. In fact, halophytes balance their growth rate with their requirement for the salt needed for osmotic adjustments (Flowers and Yeo 1986): the increase in leaf succulence plays, in fact, a major role in the osmotic adjustment to a low external water potential induced by salinity (Flowers and Colmer 2008). Moreover, an increased leaf succulence, thus an enhanced water content per unit area, translates to an augmented carbon assimilation capacity per unit area, assuring plants growth despite a possibly relatively

TABLE 30.1
Morphological Adaptations of 3 Young Fully Expanded Leaves per Plant at T1 and T2

Treatment	Young Fully Expanded Leaves, T1			Young Fully Expanded Leaves, T2		
	LA (cm ²)	SLA (cm ² g ⁻¹)	Leaf	LA (cm ²)	SLA (cm ² g ⁻¹)	Leaf
			Succulence (g cm ⁻²)			Succulence (g cm ⁻²)
Control	120.67 ± 10.47	110.31 ± 12.91	0.20 ± 0.01 ^b	25.38 ± 2.46 ^b	70.12 ± 4.14	0.24 ± 0.02 ^c
4dS m ⁻¹	86.76 ± 6.96	101.42 ± 7.90	0.20 ± 0.01 ^{ab}	30.75 ± 3.42 ^{ab}	66.51 ± 4.98	0.27 ± 0.01 ^{bc}
8dS m ⁻¹	91.58 ± 5.91	88.68 ± 3.69	0.22 ± 0.01 ^{ab}	38.83 ± 3.66 ^a	63.86 ± 3.53	0.24 ± 0.02 ^{bc}
12dS m ⁻¹	102.87 ± 7.93	87.83 ± 7.70	0.23 ± 0.01 ^{ab}	37.92 ± 2.27 ^a	60.86 ± 3.56	0.31 ± 0.01 ^{ab}
16dS m ⁻¹	116.55 ± 9.20	93.59 ± 9.35	0.24 ± 0.01 ^a	36.48 ± 2.30 ^{ab}	72.24 ± 4.07	0.30 ± 0.01 ^{ab}
20dS m ⁻¹	110.66 ± 8.31	105.68 ± 11.88	0.22 ± 0.01 ^{ab}	37.44 ± 3.34 ^{ab}	66.52 ± 5.31	0.30 ± 0.01 ^{abc}
35dS m ⁻¹	113.64 ± 8.08	87.09 ± 5.23	0.24 ± 0.01 ^{ab}	34.81 ± 2.24 ^{ab}	56.82 ± 3.07	0.33 ± 0.01 ^a

Note: Values are means ± s.e. (n=9). Different letters in the same column indicate significant differences at *P*<0.05 (Tukey’s Test).
Data obtained with permission from Elsevier from Atzori et al. “Effects of Increased Seawater Salinity Irrigation on Growth and Quality of the Edible Halophyte *Mesembryanthemum crystallinum* L. under Field Conditions” *Agricultural Water Management* 187(2017): 37–46.

low SLA (de Vos et al. 2013). Indeed, in dicotyledonous halophytes, the increase in leaf succulence is often connected to a SLA decrease (Rozema et al. 2015; de Vos et al. 2013; de Vos et al. 2010; Geissler et al. 2009; Ayala and O’Leary 1995), a morphological adaptation associated with the plants need to limit transpiration (Flowers and Flowers 2005). Nevertheless, no significant decrease of SLA occurred in treated plants compared to the control, confirming that none of the treatments did effectively stress the plant, but increased its physiological activity and yield. In fact, in this experiment, LA of salt-treated leaves did rise compared to the control (even if significantly only at the intermediate salinity treatments). It can be suggested that the ice plant leaf area was not reduced by salinity because another feature helped in regulating the leaf ion concentration: the epidermal bladder cells, which are filled with a water solution and function as peripheral salinity and water reservoirs (Agarie et al. 2007; Luttge et al. 1978).
Beyond morphology adjustments, at a physiological level, the concentration of carotenoids, reported in [Figure 30.7](#), augmented in time at increased salinity, whereas the control remained stable. Plants with the higher concentration of carotenoids at both harvests were those of the 20 dS m⁻¹ treatment.

30.3.2.3 Nutritive Quality of the Edible Leaves

[Figure 30.8](#) shows the concentration of sodium and calcium in the edible leaves. The concentrations of both sodium and calcium was significantly higher in every treatment compared to the control, at both sampling events.

FIGURE 30.7 Concentration of carotenoids in young fully expanded leaves at T1 and T2. Values are means $\pm$ s.e. ($n = 9$) expressed in microgram per gram of fresh weight. No significant differences were assessed among treatments at $P < 0.05$ (Tukey's Test). (Reprinted with permission from Elsevier from Atzori et al. "Effects of Increased Seawater Salinity Irrigation on Growth and Quality of the Edible Halophyte *Mesembryanthemum crystallinum* L. under Field Conditions" *Agricultural Water Management* 187(2017): 37–46.)

The sodium concentration results were expected because of the sodium inclusion strategy of *Mesembryanthemum*, with an increasing sodium gradient from roots to shoot apices (Bohnert and Cushman 2000). Interestingly, adult leaves accumulated more Na^+ than young leaves: this strategy prevents the edible leaf product from having too high sodium content, which could otherwise have negative effects for human health. The increased presence of sodium might also suggest that the ice plant leaves could be used as potential salt substitute.

FIGURE 30.8 Concentration of Na^+ and Ca^{2+} in young fully expanded leaves at T1 and T2. Values are means $\pm$ s.e. ($n = 9$) expressed in milligram per gram of dry weight. Different letters indicate a significant difference among treatments at the same harvest event at $P < 0.0001$ (Tukey's Test). (Reprinted with permission from Elsevier from Atzori et al. "Effects of Increased Seawater Salinity Irrigation on Growth and Quality of the Edible Halophyte *Mesembryanthemum crystallinum* L. under Field Conditions" *Agricultural Water Management* 187(2017): 37–46.)

The increased calcium concentration with increasing salinity is in accord with the results reported by a number of authors (Agarie et al. 2007; Adams et al. 1998; Yang et al. 2007) and may be connected with the salt tolerance of the ice plant; experimental evidence has correlated increased Ca^{2+} with salt adaptation (Parida and Das 2005). Calcium is believed to protect the structure and function of membranes under salt stress (Yan et al. 1995), and its concentration increase under salinity stress may ameliorate the inhibitory effect on growth (Epstein 1972). From the point of view of the quality of food, the significant increase of Ca^{2+} may point to an interesting nutritional improvement achievable under salinity conditions, as calcium is among the main mineral elements lacking in the diet of over two-thirds of the world's population (White and Broadley 2009). Encouragingly, a strong correlation also exists between the ability of many plants to accumulate Ca^{2+} and Mg^{2+} (White and Broadley 2009). Furthermore, species from families within the Caryophyllales tend to accumulate high concentrations of Mg^{2+} and Zn^{2+} in leaves (White and Broadley 2009; Broadley et al. 2004; White 2001). Investigations on possible patterns between salinity and other mineral elements with an important role in human diet (i.e. Cu^{2+} , Fe^{2+} , Mg^{2+} , Zn^{2+}) could add important information to the ice plant nutritional enrichment opportunity in saline environments.

Finally, the carotenoids – another nutritive goal – rose between T1 and T2 in all salt-treated plants, while no increase was found in the control. Also in this feature, the ice plant seems to distinguish itself positively compared to some other halophyte plants in which the carotenoid concentration may decrease with increasing salinity (Redondo-Gomez et al. 2010; Aghaleh et al. 2009; Qiu et al. 2003).

30.3.2.4 Prospective for Saline Agriculture

As none of the tested salt concentrations resulted in biomass loss, it seems possible to cultivate *M. crystallinum* for saline agriculture, at salinities up to EC_w values of 20–35 dSm^{-1} . Perhaps even higher salinity levels are possible since we did not identify a threshold for substantial biomass reduction, although the highest biomass production was suggested to occur at an EC_w of about 20 dSm^{-1} . The already appreciated taste of saline agriculture vegetables in different countries (Rozema and Schat 2013) and of the ice plant, in particular, helped by its gleaming appearance (Agarie et al. 2009; Herppich et al. 2008), also encourage this possibility.

Many results indicating the potential of halophytes as possible new crops have been published in the last decades. Yet, scientific documentation of large-scale experiments is still limited, especially addressing cultivation protocols (Ventura et al. 2015). Since adequate cultivation systems are of major importance, research is still needed to ensure the lasting sustainability of saline agriculture.

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