Sustainable use of energy in the storage of halophytes used for food

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Abstract**—**Soil salinity has become an important issue in agriculture. Water and soil salinity adversely affects the growth and the yield of most crop plants, which are highly salt-sensitive. The idea of grow special crops using saline soil and brackish or saltwater for irrigation can bring high areas into human or animal food production. It has been recognized the potential of some halophytes for desalinization of soils or use in salty soils and also its use as food crops. Some of them are consumed today in Europe as fresh or cooked gourmet foods. For consumption as fresh food those plants, which are highly perishable, need refrigeration from harvest till they reach consumers. Refrigeration needs energy consumption with consequent economical cost and damage for the environment. The objective of this work was to use efficiently the energy for preserving the quality of the halophytes *Salicornia ramosissima* and *Sarcocornia perennis* used for fresh salads. Fresh branch tips were stored at 1, 4 and 9ºC for up to 21 days. In both species, fresh tips were of good consumer acceptability for up to 14 days at 9ºC. At 1 and 4ºC fresh tips could be stored in good conditions up to 21 days. It is concluded from this work that both *Salicornia ramosissima* and *Sarcocornia perennis* are suitable for consumption as fresh, in salads, replacing the salt. For energy saving, if they are to be in the market for up to 7 days, they can be stored in the higher temperature 9ºC with good quality. For longer storage periods temperatures of 4 and 1ºC shall be used.

Keywords**—** Energy efficiency, food salads, halophytes, postharvest, refrigeration, sustainability, salty environment.

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I. Introduction

Soil salinity is a serious environmental hazard in land used for agriculture. The long-term conservation and environmental risks of irrigated agriculture should never be neglected in view of the historical associations between irrigation, land degradation, human diseases and other adverse side effects. Salinity is increasingly affecting fresh water and soil, particularly in arid and semi-arid climatic regions. Irrigation has resulted in the accumulation of salt above normal concentrations in the rooting zone of arable land, as high rates of evaporation and transpiration draw soluble salts from deep layers of the soil profile. Also, continuous sea-level rise in a warming world threatens increased salinity in coastal lowlands [1]. Marginal land and saline wasteland are unproductive to be farmed by traditional crops. Some of those areas are naturally saline or have become salinized as a result of bad irrigation practices.

The idea of using halophytes, plants that occur throughout the world, thrive on water with high salt levels, for crop production, have been proposed over the last 30 years [2]. Therefore, different studies and investigations on the selection of halophytic species with economic value and their use on removing nutrients from water effluents of aquaculture and agricultural wastewater and reclaiming salt affected soil in arid-zone irrigation districts, have been conducted [3].

A halophyte is a plant which is capable of surviving in a highly salty environment. An estimated two percent of plant species are halophytic, with the vast majority of plants being glycophytes which will not survive on a salty substrate. Although halophytes make up a very small percentage of the overall plant population, they play a number of important roles in the environment, and they have some potentially useful industrial applications. These plants can survive in a number of environments. Many are designed to grow in salt marshes and estuaries, where there is a high concentration of salty water. Others can live on cliffs and dunes near the ocean, and some are adapted for near-desert environments where water supplies may be limited and highly saline (Figure 1). A halophyte which lives in the desert is typically a succulent, so that it can store water to ensure that it has an ample supply.

Growing special crops using saline soil and brackish or saltwater for irrigation, can bring high areas into human or animal food productions. Halophytes not only offer great potential as novel crops but are also important models for understanding salt resistance in plants. Recent research has highlighted physiological and molecular aspects of the adaptations of halophytes to salinity and the microbiology and productivity of halophyte-dominated ecosystems.

Fig. 1. Halophytes at their natural habitat in Ria Formosa, Algarve, Portugal

It has been recognized the potential of some halophytes for desalinization of soils and also its use as renewable enery crops and as food crops. World reserves of petroleum are being consumed rapidly and expected to exhaust till the end of this century. This scenario has led to the introduction of various renewable energy sources like ethanol supplemented fuel. However, ethanol demands met from sources used for food may cause food shortage.

This necessitates exploiting saline lands to produce non-food ligno-cellulosic biomass which, may be converted into ethanol without compromising human food production. Halophytes which produce plenty of biomass using saline resources (water and soil) may be an important energy supply alternative.

Almost all our modern crops are derived from glycophytes, plants apparently lacking the genetic basis for salt tolerance, and they have received the most research attention. All sides now call for a better understanding of how naturally adapted plants (halophytes) handle salts. Study of halophytes can be instructive from three perspectives. Halophytic plants, including *Salicornia* ssp., *Aster tripolium, Atriplex* ssp. and *Inula crithmoides* are consumed today in Europe as fresh or cooked gourmet foods. However, the supply of these plants is limited because there are few cultivated and most of them are harvested from the wild. Their market is presently based mostly on amateur gathering of branches and leaves from wild plants, which limits the market supply because most natural wetlands are protected areas where harvesting is limited or forbidden [4].

Several studies with these species reported their high nutritional content, which includes proteins, carbohydrates, fiber, calcium, potassium, magnesium, iron, manganese, copper, vitamin C and beta-carotene [5], which made it an ideal nutritional and diet supplement. Also, it has been reported therapeutic applications of *Salicornia* based on scientific research [6] indicating that several types of immunomodulatory polysaccharides originated from were isolated from Salicornia, which has been used to treat a variety of diseases including cancers in traditional oriental remedy. Food system in our days is built upon refrigeration. For many foods, refrigeration is a feature of almost every stage in the supply chain [7]. Fresh horticultural products are important components of human food. However, those products are highly perishable and losses can be of great importance if postharvest correct measures are not provided [8].

To ensure the highest and appropriate quality of horticultural products availability for consumers, it is very important that all parts involved in the chain from farm to plate (production, packaging, storage, transport, distribution and marketing) do everything correctly [9].

This means correct production, harvest and postharvest practices, so that we can have a high quality product which needs less energy consumption for keeping quality through the marketing chain.

Temperature is the most important factor in maintaining quality after harvest. Refrigeration is the first approach to increase storage life of fresh fruits and vegetables since it reduces respiration and other metabolic processes. Refrigerated storage retards deterioration in perishable crops such as, aging due to ripening, softening, and textural and colour changes; undesirable metabolic changes and respiratory heat production; moisture loss and the wilting that results; spoilage due to invasion by bacteria, fungi, and yeasts; undesirable growth, such as sprouting of potatoes [10].

However, lower temperature limits depend on product commodities since, for some, chilling injuries that damages product can occur above the freezing point [11].

Sustainable development has been defined as the development which meets the needs of the present without compromising the ability of future generations to gather their own needs [12], and integrates economic, social and environmental factors [8]. Sustainable agriculture is the one that produces enough food without depleting the earth's resources or polluting its environment. It is agriculture that follows the principles of nature to develop systems for raising crops and livestock that are, like nature, self-sustaining [13].

In postharvest, good management of energy saving in refrigeration is also through a good management of pre-cooling and cooling systems and storage chamber insulation. Also, while refrigeration entails the use of energy it can of course also help save energy by reducing food waste [14].

Usually, fresh horticultural products are stored at temperatures as lower as possible without causing chilling or freezing injury, to preserve them for as longer as possible with good acceptable quality. However, some produce is consumed earlier and some later through time after harvest, so refrigeration needs can be reduced, accordingly. The reduction of energy consumption for refrigeration through the supply chain of fresh horticultural products, gives advantages as reducing costs and protecting the environment.

Halophytes are plants which tolerate or even demand sodium chloride concentrations in the soil water they absorb. Commercial use of halophytes as fresh food is not very common in our days, but due to recent global changes desertification enhances the need of irrigation with sub-saline water, which provokes the increase of soil salinization. At the same time, the need for renewable energy production from agricultural crops will extend this use to low quality soils and furthermore, limited fresh water resources may increase the use of low quality irrigation water. Hence, intensified use of salt tolerant crop plants will be necessary even in Europe. Several halophyte species are nowadays used as special crop plants.

The objective of the present research was to find the suitability for use in salads as substitute of salt and which temperature to apply in storage of two halophytes (*Salicornia ramosissima* and *Sarcocornia perennis*) which grow naturally in the Ria Formosa salt marsh wetland in Algarve, Portugal, according to the time needed in the chain from harvest to consumption. The knowledge on correct temperature for the appropriate storage period of those halophytes will assist energy efficiency in post-harvest and consequently sustainability as well as, the benefit of using marginal land and saline wasteland, unproductive to be farmed by traditional crops, for halophyte food production.

II. Materials and Methods

A. Plant material and treatments

The experimental side is located in Ria Formosa wetland. The Ria Formosa extends 60 km along the southern coast of Portugal (the Algarve) covering approximately 18,400 hectares. Consisting of a line of sand dunes, barrier islands and sandy peninsulas, all stretching parallel to the coast, the Ria Formosa is a unique lagoon system in a state of permanent change, due to the continuous movement of winds, currents and tides. Endowed with some exceptional natural and geographical characteristics, this wetland area enjoys a fully justified international reputation as a valuable and privileged habitat for all kinds of fauna and flora. Amongst the vegetation, attention is drawn to the typical marshland plants, adapted here to the excessive salinity of the salt marshes.

Salicornia ramosissima and *Sarcocornia perennis* plants, which grow naturally in the salt marsh wetlands of Algarve were harvested in May-June and immediately transported to the Postharvest lab at the University of Algarve. Tips of 6-8 cm youngest fully expanded branches were separated, washed with tab water and left to dry for about 2 hours at room temperature. Then they were stored in polystyrene expanded trays, adequate for food storage, and covered with a 10 µm thick PVC film. After that, trays were stored in cold rooms at 1, 4 and 9 ºC for up to 21 days. At 0, 7, 14 and 21 days quality evaluation was performed for each replication (total of 3) and temperature treatment (Fig. 2).

B. Measurements

Weight loss was calculated by weighting always the same samples and expressed as the percentage of the initial weight.

Colour was measured, over the tips the placed in the trays, with a Chroma meter CR-300 series (CE Minolta, Japan) and quantified in the CIE L*, a*, and b* colour space. The L* value indicates lightness (black=0 and white=100), a* changes from green (negative values) to red (positive values), and b* from blue (negative values) to yellow (positive values) [13].

Electrolyte leakage measurements were made as described by [15] with some modifications. Five fresh tips with 5-8 cm, weighing in total 2g, were cut into 3 equal parts and subsequently placed into 20 ml of distilled water. After 6 hours at room temperature the electric conductivity (Ci) of the solution was measured with a conductivity benchtop meter ORION 3 STAR (Thermo electron corporation, USA). After that the solution was frozen and unfrozen twice and measured again the electric conductivity (Ct). Results were express as percentage of total conductivity (% electrolyte leakage = 100×Ci/Ct).

Fig. 2. *Salicornia* and *Sarcocornia* tips in polystyrene expanded trays and covered with a 10 µm thick polyethylene film.

C. Statistical analysis

Statistical analyses were carried out with a SPSS 16.0 computer program (SPSS Inc.). Two-way analyses of variance (ANOVA) tests at ($P<0.05$) for comparisons among treatments over time were conducted.

III. Results and Discussion

A. Weight loss

Weight loss was reduced by temperature decrease in both species (Figs. 3A and B). Till 7 days there were not significant differences among temperatures. However, after 14 days weight loss was lower at 1 and 4ºC than at 9ºC in *sarcocornia* (Fig. 3A), while in *salicornia* were higher at 4 and 9ºC than at 1ºC (Fig. 3B). It is noticeable that at 1ºC, *salicornia* maintained lower values of weight loss till 21 days of storage, similar to those of 7 days, in contrast to *sarcocornia* which increased its values from 14 to 21 days at the same temperature.

Weight loss is mostly dependent on the relative humidity surrounding the product, but can be also associated with a slight reduction in firmness [16], [17]. Weight loss is of great importance because is associated to shriveling and advance senescence, making the salad with a not fresh appearance.

In the case of the present work, the weight loss was not of significant importance till 14 days storage at 4 and 9ºC for *salicornia* and till 21 days for *sarcocornia* at 4ºC, since it did not reach 3%. Usually, horticultural products lose their fresh appearance when they have more than 3% weight loss [18].

The fact that the tips of both species were packed and wrapped with a film that created a modified atmosphere (MAP) helped to decrease the weight loss, since it is known to be efficient in reducing water loss by fresh horticultural products as well as respiration rate [19]. This fact helped to increase storage life capacity at a given temperature and in addition give protection against pathogen spoilage.

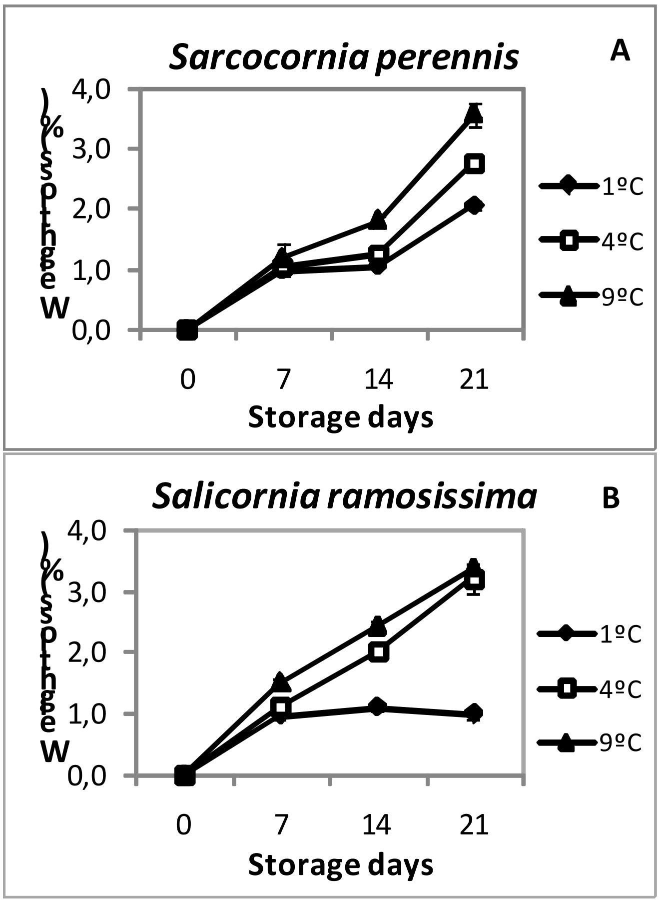

Figure 3. Weight loss of fresh branch tips of *sarcocornia* (A) and *salicornia* (B) stored for 21 days at 1, 4 and 9 ºC.

B. Colour

Colour did not have a significant change through 21 days at 1 and 4 ºC for *sarcocornia* (Figs. 3 A, B C). However, at 9 ºC, there is an increase in a* and b* values becoming slightly higher than at 1 and 4 ºC after 21 days storage (Figs. 3 A, B). The decrease in L* is more pronounced at 9 ºC being significantly different from treatments at 1 and 4 ºC after 21 days storage, meaning that *sarcocornia* tips become darker (Fig. 4C).

The decrease in L* and the increase in a* indicates browning of the tissues [20], [21], as well as b* increase indicates yellowing [22], indicating loss of freshness. This means that *sarcocornia* at 9 ºC lost freshness mainly from 14 to 21 days.

Salicornia fresh tips followed the same patern as *sarcocornia*, but in this case differences in colour parameters after 21 days are higher for a* and L* values (Figs. 5 A, B, C). In *salicornia*, from 14 to 21 days storage, the decrease in a* and the increase in L* are highly significant, indicating loss of the green colour and darkening of the tips, respectively. This indicates a higher susceptibility of *salicornia* to deterioration than of *sarcocornia* [23].

C. Electrolyte leakage

Sarcocornia fresh tips present an increase in electrolyte leakage from harvest to 21 days of storage for all storage temperatures (Fig. 6A). Electrolite leakage was significantly higher at 9 and 4ºC than at 1ºC. However, after 21 days there were significant differences among all temperatures being the higher electrolyte leakage values for the higher temperatures.

Salicornia fresh tips behaved quite differently showing no significant changes and differences among temperatures and storage time for up to 14 days (Fig. 6B). However, after 21 days of storage, salicornia tips at 1ºC had significantly lower electrolyte leakage than the other temperatures.

Electrolite leakage refers to membrane permeability which, in fruit such as kiwifruit, usually increases as temperature decreases as a response to chilling stress [15]. Also, electrolyte leakage can be considered an indirect measure of symptoms of fruit senescence stage [16]. In leaves of Egeria densa Planchon sulfhydryl-binding reagents induce a temporary increase in nonmitochondrial respiration (ΔQO2) that is inhibited by diphenylene iodonium and quinacrine, two known inhibitors of the plasma membrane NADPH oxidase, and are associated with a relevant increase in electrolyte leakage [24].

In the present work it seems that *sarcocornia* is more susceptible to membrane leakage than *salicornia*. This is visible by higher values of electrolyte leakage at higher temperature and at the end of storage.

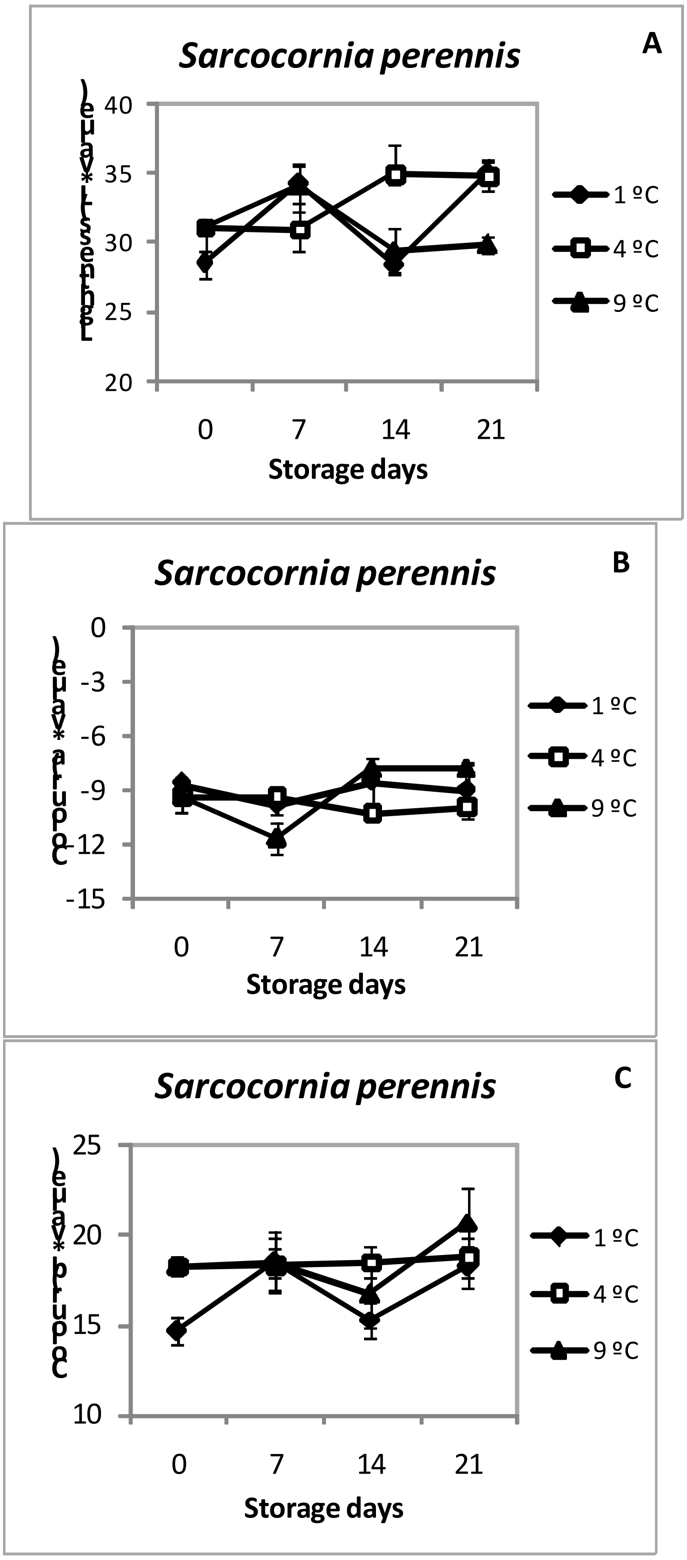

Figure 4. Colour parameters (L*, a* and b*) of fresh branch tips of *sarcocornia* stored for 21 days at 1, 4 and 9 ºC.

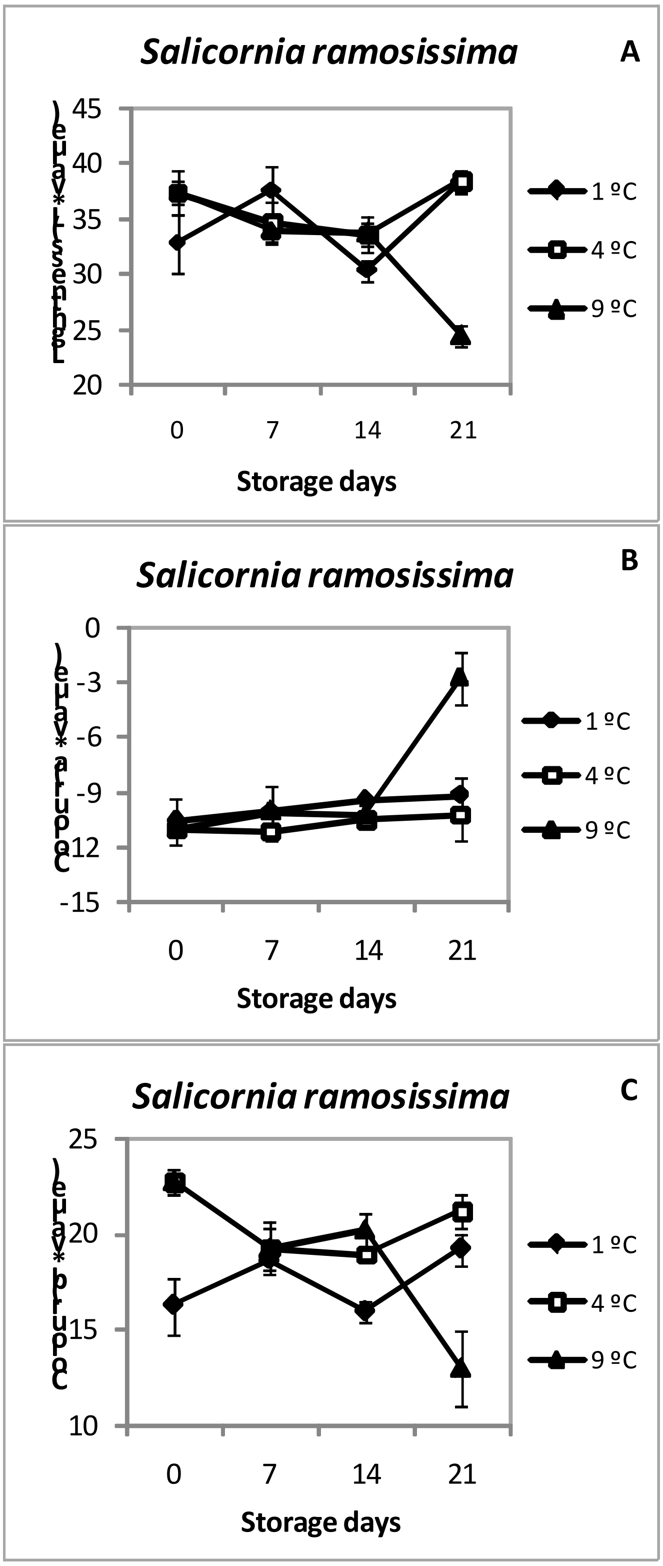

Figure 5. Colour parameters (L*, a* and b*) of fresh branch tips of *salicornia* stored for 21 days at 1, 4 and 9 ºC.

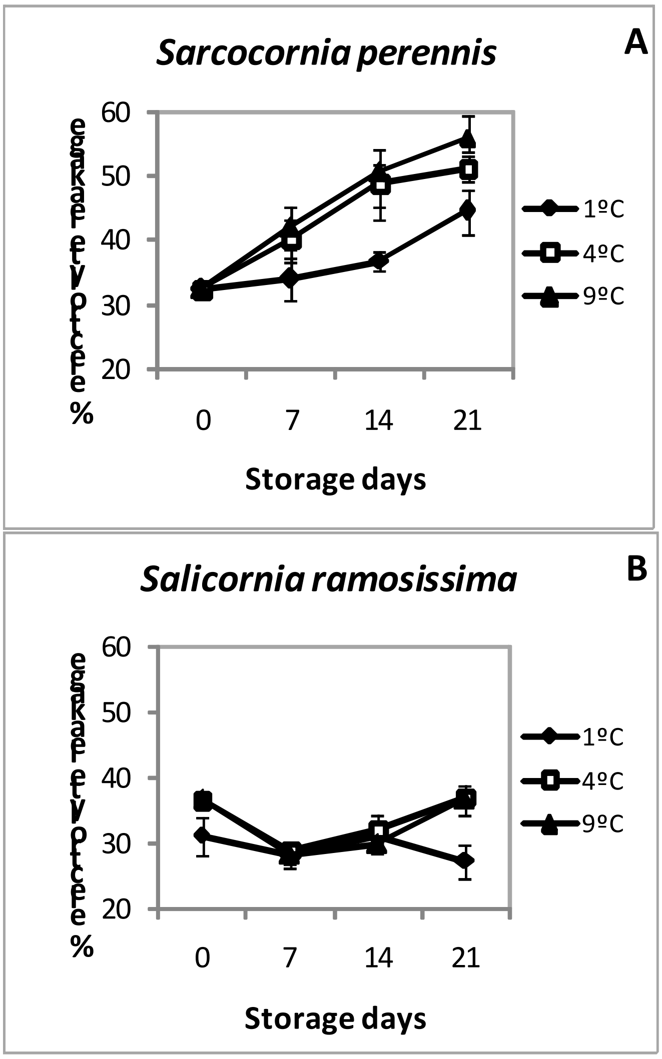

Figure 6. Electrolyte leakage of fresh branch tips of sarcocornia (A) and salicornia (B) stored for 21 days at 1, 4 and 9 ºC.

IV. Conclusions

Halophytes grow in saline habitats can be good source of food, fibre and bioenergy. Halophytes help combat salinisation, soil erosion, loss of biodiversity and bioproductivity. With the ever-increasing population and the need for increased crop production, the non-productive salt-affected lands have to be used for producing non-conventional crops of high economic value. Many halophytes combine high biomass and high protein or mineral levels with outstanding ability to a wide range of environmental stresses [25].

Halophytic plants, such as *Salicornia* ssp. and *sarcocornia* are consumed today in Europe as fresh or cooked gourmet foods. Several studies with many halophyte species reported their high nutritional content. However, the supply of these plants is limited because of low knowledge on their cultivation and postharvest handling and storage. As observed visually and from the data presented, either *Salicornia ramosissima* or *Sarcocornia perennis* showed a good acceptable quality for consumption up to 21 days at 1 and 4ºC. At 9ºC such quality was achieved only till 14 days (Fig. 7).

Salicornia keeps better through storage than *sarcocornia*.

Fresh horticultural products are highly perishable. Reduction of energy consumption for refrigeration in the chain from farm to consumption, enclose a good knowledge of the management of horticultural products. Preharvest adequate cultural practices are very important to give a quality product which keeps better in postharvest life. In addition, correct harvest measures provide reduction of postharvest losses.

Fig. 7. *Salicornia ramosissima* and *Sarcocornia perennis* tips after storage.

Those technologies as well as good management of energy in refrigeration through good insulation of storage rooms and good management of pre-cooling and cooling systems are of great importance for energy saving and consequently sustainable growth.

Postharvest technologies are of great importance, since some help to keep fruit quality through storage without additional energy consumption [8]. However, they should be applied in such way to avoid negative effects to human health and environment.

Usually, fresh horticultural products are stored at the lowest temperature which keeps them for long period with good quality, and are taken out from cold storage according to the market requirements. However, as it is in the case of the present research, energy saving, and consequently less harm to the environment, can be done by storing fresh horticultural products at higher temperatures in the case they are needed to be put in the market earlier. The products that will be commercialized later, should be the only ones stored at the lower temperatures.

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