LWT - Food Science and Technology 43 (2010) 519–524

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Nutritional characterization and changes in quality of *Salicornia bigelovii* Torr. during storage

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ARTICLE INFO

Article history:
Received 17 January 2009
Received in revised form
11 September 2009
Accepted 22 September 2009

Keywords:
Salicornia bigelovii Torr.
Nutritional characterization
Quality degradation
Storage

ABSTRACT

Salicornia bigelovii Torr. (sea-beans or drift seeds in English, sea-asparagus in Chinese) is an oil-seed plant tolerant to seawater irrigation and perishable with a shelf life of only about 6 days at ambient temperature (25 °C). To provide a potential food supplement, nutritional value of *S. bigelovii* were determined together with its postharvest quality as affected by storage temperatures (0 °C, 2 °C, 8 °C and 25 °C). Nutritional analyses showed that *S. bigelovii* contained high vitamins and minerals, which made it an ideal nutritional and diet supplement. Storing *S. bigelovii* at low temperatures could be a practical technique to extend storage life by reducing the quality degradation. After conducing sensory evaluations and determining ascorbic acid and chlorophyll contents, the optimal temperature for storing *S. bigelovii* was around 2 °C. This research will help to develop technically effective and energy efficient methods for prolonging the shelf life of *S. bigelovii*.

1. Introduction

Nowadays soil salinity has become an important issue in agriculture, which is also one of the most urgent global problems to provide enough water and land for meeting the world's food needs (Pfiser, 1999). Sodium in the soil adversely affects the growth and yield of most crop plants, which are highly salt-sensitive (glycophytes) (Bashan, Moreno, & Troyo, 2000). None of the top five plants consumed by people – wheat, corn, rice, potatoes and soybeans – can tolerate salt. It is estimated that about 15% undeveloped land in the world's coastal and inland salt deserts would be suitable for growing crops using saltwater, i.e., 1.3×10^8 ha of new cropland that could be potentially brought into human or animal food productions. Therefore, we need alternative sources of water and land to grow some special crops (Glenn, Brown, & O'Leary, 1998). An idea of using seawater for crop production along coastal deserts has been proposed over the past 30 years (Glenn et al., 1997). *Salicornia* has been recognized as one of the most promising halophytes. Korean has used *Salicornia herbacea* as a folk medicine to treat a variety of diseases. Moreover, the filed patents claim that *S. herbacea* is effective to improve inflammatory responses and prevent atherosclerosis, hypertension, and tumors. These claimed therapeutic applications are also reported based on the scientific research (Im, Kim, & Lee, 2006; Im et al., 2007). Millman (2003) reported that Epicureans have dined on *Salicornia bigelovii* for eons. *S. bigelovii* is an annual leafless, fast growing, succulent valuably halophyte, and salt-marsh plant, which is considered to be a promising crop for cultivation in subtropical coastal deserts (Attia, Alsobayel, Kriadees, AlSaiady, & Bayoumi, 1997; Glenn, O'Leary, Watson, Thompson, & Kuehl, 1991). Up to now, *S. bigelovii* has been successfully cultivated in Mexico, India, Eritrea, Saudi Arabia and the United Arab Emirates (Milan & Stanislav, 2002), as well as in Southeast China.

S. bigelovii is not only a perishable but also highly seasonal plant. Selecting efficient storage methods is of great importance to minimize postharvest losses (Kulamarva, Gariépy, Sosle, & Raghavan, 2004). Fresh fruits and vegetables, such as *S. bigelovii*, continue to respire after harvesting. The respiration rate and metabolic activity may be changed naturally, as the produce goes through the internal processes of ripening, maturity and senescence or artificially by altering the external environment of storage, i.e., temperature. Refrigerated storage can lower the rate of metabolic activity through temperature control by reducing the rate of substrate depletion and the associated heat release, which is

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doi:10.1016/j.lwt.2009.09.021

a major means of preserving freshness of postharvest produce (Paul & Clarke, 2002).

Up to now, nutritional and biochemical compositions of *S. bigelovii* and effective storage methods to prolong its postharvest shelf life have not been extensively studied. The objectives of this study were to evaluate the nutritional characterization of *S. bigelovii* and to determine effects of low storage temperatures on its quality.

2. Materials and methods

2.1. Plant material

Fresh samples of *S. bigelovii* Torr. (sea-beans or drift seeds in English, sea-asparagus in Chinese) were supplied by the Jiangsu Jinglong Marine Industry Development Co. Ltd. (Yancheng, China) and transported to the laboratory within 1 day after harvest. The samples had the offshoots in 13–15 cm long. About 5–6 cm of youngest fully expanded branch tips were selected used in all experimentations. These fresh samples were kept under the ambient air at 25 °C for less than 2 h prior treatments.

For nutritional characterization, *S. bigelovii* samples were first washed with deionized water. Sample homogenates were then obtained using a common kitchen homogenizer and finally stored at −70 °C prior to further uses.

To determine the quality degradation during storage, each 150 g *S. bigelovii* samples were randomly selected and packaged in low-density polyethylene perforated bags, and stored in the dark at 0 °C, 2 °C, 8 °C, or 25 °C, respectively. All experiments were conducted in triplicate.

2.2. Nutritional characterization analyses

2.2.1. Proximate composition analyses

Moisture content was determined by drying the sample in an oven at 105 °C for 3 h until a constant weight was obtained (AOAC, 1990). Crude protein content was calculated from total nitrogen content determined by the Kjeldahl method (AOAC, 1990) using a conversion factor of 6.25. Total lipids were determined according to the Soxhlet extraction methodology (AOAC, 1990). Crude fiber content was determined using the neutral detergent reagent method described by Guevara, Yahia, de la Fuente, and Biserka (2003). Ash content was determined by burning the sample in a muffle furnace at 500 °C for 5 h. Total carbohydrate content was estimated by difference between 100 and the sum of the percentages of moisture, crude protein, total lipid, and ash contents (Enujiugha, 2003).

2.2.2. Mineral analyses

Mineral elements were analyzed using a Varian Spectra Atomic Absorption Spectrophotometer (Model 220, Varian, USA) after drying ash. Sodium (Na) and potassium (K) contents were determined by emission photometry (AOAC, 1990). Contents of magnesium (Mg), calcium (Ca), iron (Fe), zinc (Zn) and copper (Cu) were determined by flame atomic absorption spectrophotometry. Plumbum (Pb), cadmium (Cd) and chromium (Cr) contents were determined by electrothermal atomic absorption spectrometry (AOAC, 1990). Phosphorus (P) content was measured by a UV–visible spectrophotometer (Model U2001, Hitachi Co., Tokyo, Japan) according to the method described by AOAC (1990).

2.3. Biochemical composition determination

β-Carotene was measured by the UV–visible spectrophotometer according to the methodology described by Reyes, Villarreal, and Luis (2007). Chlorophyll was determined using the spectrophotometric method (Vernon, 1960); procedures used were the same as described by Charles, Guillaume, and Gontard (2008).

Ascorbic acid was determined by the indophenol titration method (AVC, 1966). A 10 g sample was grounded in a mortar with 20 g L^{-1} oxalic acid solution. The 10 g L^{-1} oxalic acid solution was used to wash the paste into a 100 mL volumetric flask. About 10 mL filtered solutions were titrated with 2, 6-dichlorophenol indophenols solution until the faint pink color persisted for more than 5 s.

2.4. Amino acid analysis

The dried *S. bigelovii* sample was hydrolyzed with 6.0 mol L^{-1} HCl in a sealed tube at 110 °C for 24 h. An Agilent 1100 HPLC (Agilent, USA) was used with a 4.0 × 125 mm Hypersil ODS C18 column for separating amino acids. Amino acid content was presented as g kg^{-1} fresh weight (FW). The solvents and gradient conditions were used as described elsewhere (Henderson, Ricker, Bidlingmeyer, & Woodward, 2000). The detection wavelengths were set at UV 338 nm. The identity and quantity of the amino acids were assessed by comparison with the retention times and peak areas of the standard amino acids (Sigma–Aldrich, China).

2.5. Sensory quality assessment

The samples were monitored every 2 days during storage at 25 °C, and every 4 days at 0 °C, 2 °C and 8 °C, respectively. A panel of 10 trained judges evaluated the sensory quality characteristics of all the *S. bigelovii* samples from each bag. Before the experiment started, the typical characteristics of the *S. bigelovii* and the possibilities of deterioration were learnt. The sensory tests (general appearance and color) were performed in a special taste room with separated boxes. General appearance was evaluated on a scale from 9 to 1, where 9 represents excellent without any rotten, 7 represents good without any rotten, 5 represents fair and limit marketability with less than 1% rotten, 3 represents poor and limit usability with 1–5% rotten, and 1 represents very poor and inedible with more than 5% rotten. Color was evaluated using attributes on the same scale, where 9 represents "dark green", 7 represents "green", 5 represents "light green", 3 represents "pale green" and 1 represents "yellow". Generally, the high scores represent good qualities and low scores represent bad ones, the other scores (8, 6, 4, and 2) for each index represent the relatively middle qualities. When the scale of plant material reached 5, the sample was considered as the end of its shelf life (Li, Zhang, & Wang, 2007).

2.6. Color and weight loss measurement

The L^* (lightness), a^* (green–red) and b^* (blue–yellowness) color values of samples were objectively measured with a portable colorimeter (CR-400, Konica Minolta, Tokyo, Japan) concurrently with subjective assessment. The instrument was standardized using a white ceramic plate ($L^* = 97$; $a^* = 0.14$, $b^* = 1.64$). Weight loss was determined by weighing each sample at the beginning and each withdrawal and expressed as the percentage of the initial sample weight.

2.7. Statistical analysis

The average and standard deviation values were over three replicates and used in the analysis. All data were evaluated by one-way analysis of variance (ANOVA) using SAS (Windows XP) with temperature as main effects. To determine effects of storage temperatures on quality changes, significant differences between treatments were separated at a level of 0.05 using Duncan methods.

3. Results and discussion

3.1. Nutritional characterization

3.1.1. Proximate and biochemical compositions

The proximate and biochemical compositions of *S. bigelovii* are summarized in Table 1. Moisture represented the largest single content among the proximate compositions of *S. bigelovii* tissue (fresh weight). It was evident that, among dry biomass, carbohydrate was in the biggest proximate compositions in the *S. bigelovii* tissues, followed by ash. While compared to corresponding data for several local common vegetables reported by Yang, Wang, and Pan (2002), the protein level in *S. bigelovii* was lower than that in celery leaf (2.6%) and spinach (2.6%), and similar to that in lettuce (1.3%) and Chinese cabbage (1.4%). Although the lipid content was relatively low, it was characterized by a high degree of unsaturation mainly for the sake of alpha-linolenic and linoleic acids (data not shown here) (Tikhomirova, Ushakova, Tikhomirov, Kalacheva, & Gros, 2008). Biochemical compositions of the *S. bigelovii* tissue showed high values of β-carotene, ascorbic acid and total chlorophyll (Table 1). *S. bigelovii* was rich in β-carotene, which made the plant a good source of Vitamin A. Hence, *S. bigelovii* as the vegetable plant can serve as the source of several biochemical substances and fatty acids indispensable for human being.

3.1.2. Mineral contents

Mineral contents of *S. bigelovii* on the basis of fresh weight are listed in Table 2. Contents of Na, K, Mg, Ca, P and Fe were observed as major minerals, followed by Zn and Cu were established at minor levels, while the values of contaminants Cd, Pb and Cr were found at the lowest level in the samples. Sodium and its concentration predominated in the plant mineral composition and amounted to about 1% of fresh weight, which was the reason why *S. bigelovii* would not be directly used as a staple food source. However, Zhu, Zhang, Zhuo, and Cai (2007) reported that the sodium chloride content of the fresh material can be reduced to 0.8–1.2% (fresh weight) when it was water-soaked for 36 h followed by hot water rinsing at higher than 90 °C. From a nutritional point of view, *S. bigelovii* may be considered as a good source of minerals, especially magnesium, iron and calcium.

3.1.3. Amino acid composition

The results of the amino acid composition of *S. bigelovii* are listed in Table 3. The total amino acid content was 10.86 g kg^{-1} · FW, in which the sample contained a considerable diversity of amino acid compositions. Among the amino acids analyzed herein, the content of glutamic acid and asparagine tended to predominate in *S. bigelovii*. From the data, we can also find that *S. bigelovii* contained remarkably substantial amounts of essential amino acids, suggesting that this plant is desirable for a staple food source. The lower content amongst the sulfur-containing amino acids (methionine and cysteine) appeared to be the least abundant compound within the tissue of all compositions. The crude protein content was a little higher than the total amino acid content, which was probably caused by some non-protein nitrogen, such as urea, resulting in an overestimate of the crude protein content.

Table 1
Proximate and biochemical compositions of *Salicornia bigelovii* Torr.[a]

Proximate composition (g·100 g^{-1} FW)[b]		Biochemical composition (mg kg^{-1} FW)	
Moisture	88.42 ± 1.36	Total chlorophyll	569.1 ± 9.10
Crude protein	1.54 ± 0.10		
Total lipids	0.37 ± 0.01	β-carotene	159.0 ± 5.74
Crude fiber	0.83 ± 0.13		
Total carbohydrate	4.48 ± 0.46	Ascorbic acid	58.4 ± 1.39
Ash	4.36 ± 0.37		

[a] Values were mean ± S.D. over three replicates.
[b] FW, fresh weight.

Table 2
Mineral elements content of *Salicornia bigelovii* Torr.[a]

Element	Content (mg g^{-1} FW)[b]	Element	Content (μg g^{-1} FW)
Na	9.98 ± 0.71	Zn	4.05 ± 0.14
K	1.76 ± 0.08	Cu	0.91 ± 0.14
Mg	1.18 ± 0.06	Cd	0.01 ± 0.00
Ca	0.62 ± 0.02	Pb	0.02 ± 0.01
P	0.18 ± 0.01	Cr	<0.01
Fe	0.01 ± 0.00		

[a] Values were mean ± S.D. over three replicates.
[b] FW, fresh weight.

3.2. Physiology of postharvest senescence

3.2.1. Sensory quality, color and weight loss

It is well known that storage of fruit and vegetables at low temperatures from harvest until consumption is an effective means for preserving quality and nutritional value (Concellón, Añón, & Chaves, 2007; Kader, 2002), while the negative effect of extreme low temperature on the shelf life of fruits and vegetables, especially for tropical plants and commodities has been explored since at least the eighteenth century. Storage recommendations for produces are generally the minimum temperature that provides the maximum shelf life (Paull, 1999).

Fig. 1 shows a general trend of general appearance and color for *S. bigelovii* at four temperatures. There were significant differences in the general appearance scores between ambient environment and refrigerated treatments after 4 days of storage (Fig. 1a). The general appearance scores of *S. bigelovii* stored at 25 °C decreased faster than those at chilling temperatures. The general appearance scores of *S. bigelovii* stored at 0 °C decreased slowly before the 12th storage day, and then decreased quickly because of chilling injury (water-soaked appearance).

The score changes for color during storage are shown in Fig. 1b, and all of them decreased gradually with a prolonging storage time, which indicated that there were obvious color changes during the storage period. Significant differences ($p < 0.05$) in scores of color were also observed between the ambient temperature (25 °C) and the chilling temperature (0 °C) storages from the 4th day, and between 2 °C and 8 °C after 16 days storage, respectively. The changes in L^*, a^* and b^* values were in agreement with those of color score changes. The increase in L^*, a^* and b^* values indicated a decrease in dark green color, the loss in green color and an increase in yellowing, respectively (Fig. 2).

Table 3
Amino acid composition of *Salicornia bigelovii* Torr.[a]

Amino acid	Content (g kg^{-1} FW)[b]	Amino acid	Content (g kg^{-1} FW)
Asparagine	1.16 ± 0.02	Cysteine	0.03 ± 0.00
Glutamic acid	1.63 ± 0.03	Valine	0.59 ± 0.05
Serine	0.68 ± 0.02	Methionine	0.09 ± 0.00
Histidine	0.26 ± 0.01	Phenylalanine	0.55 ± 0.01
Glycine	0.53 ± 0.01	Isoleucine	0.47 ± 0.02
Threonine	0.55 ± 0.01	Leucine	0.94 ± 0.01
Arginine	0.68 ± 0.02	Lysine	0.73 ± 0.01
Alanine	0.69 ± 0.02	Proline	0.83 ± 0.10
Tyrosine	0.44 ± 0.01	Total	10.86

[a] Values were mean ± S.D. over three replicates.
[b] FW, fresh weight.

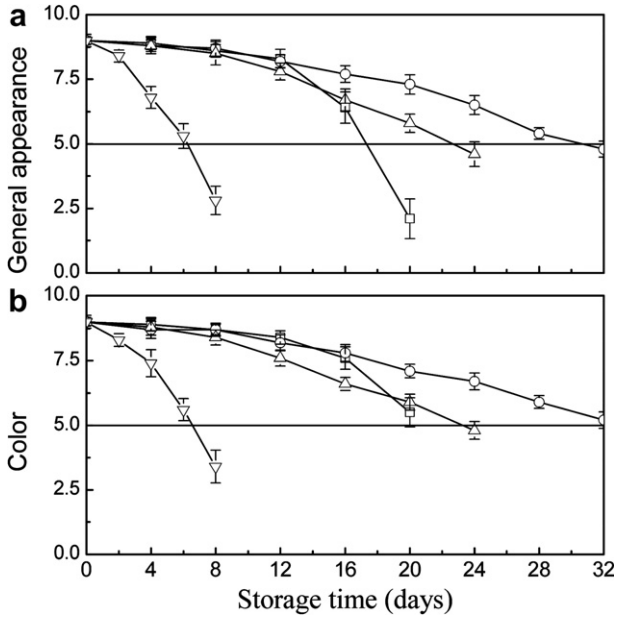

Fig. 1. Changes in scores (mean ± S.D. for three replicates) of general appearance (a) and color (b) for *Salicornia bigelovii* Torr. stored at different temperatures. (□) 0 °C, (○) 2 °C, (△) 8 °C, and (▽) 25 °C. The scores above 5 suggest acceptable quality.

Fig. 3 shows the changes in weight loss of *S. bigelovii* at different temperature storages. *S. bigelovii* stored at 0 °C, 2 °C, 8 °C and 25 °C represented an accumulating weight loss of about 1.7%, 4.4%, 3.15% and 7.45%, respectively, in the tested duration. Stored temperature had a significant effect on the weight loss ($p < 0.05$). The high-temperature (8 °C and 25 °C) storage resulted in high physiological metabolize and rapid senescence, which in turn resulted in the *S. bigelovii* great weight loss and made the sample tissue wilting.

Harvested *S. bigelovii* showed a senescence state, browning and wilting, for all four temperatures storages. The postharvest life at 0 °C, 2 °C, 8 °C and 25 °C, defined as the maximum storage period with nearly 99% of marketable vegetable, was 18, 30, 23 and 6 days, respectively. At ambient temperature (25 °C), the storage life of *S. bigelovii* was relative short. A storage temperature of 8 °C (typical supermarket cabinet temperature) can extend storage life by approximate 3 times for *S. bigelovii.* At 2 °C, the storage life of *S. bigelovii* was significantly extended by approximate 4 times. However, when stored at 0 °C, the sensory evaluation scores decreased slowly during prophase storage, but after decreased quickly, which may be caused by chilling injury. The advantage of storage at the optimal temperature in comparison to ambient temperature included improving the organoleptical attributes (low weight loss) and visual properties (color and general appearance).

Based on the sensory evaluation, color and weight loss measurement, the stored temperature had a significant effect on qualities (and hence storage life). Generally, lower temperature (above 0 °C) resulted in a longer storage life and the optimal temperature for storing *S. bigelovii* was 2 °C.

3.2.2. Ascorbic acid content

Fig. 4 illustrates the changes of ascorbic acid content in *S. bigelovii* as a function of time and storage temperature. *S. bigelovii* stored at different temperatures showed a gradual decrease in the ascorbic acid content from the initial value of 58.4 mg kg^{-1} FW. However, there was no significant difference between ascorbic acid contents of *S. bigelovii* after 12 days storage at temperatures among 0 °C, 2 °C and 8 °C, although 2 °C was more effective in controlling loss of ascorbic acid. Among the four storage temperatures, the slowest decreasing rate for the ascorbic acid contents of the *S. bigelovii* appeared at 2 °C and the sharpest decreasing rate was at 25 °C (Fig. 4). At 8 °C, a significant decrease was observed in the middle of the storage (day 12). At 0 °C, the decrease observed after 8 days was significant and represented 56% ascorbic acid loss after 20 days storage.

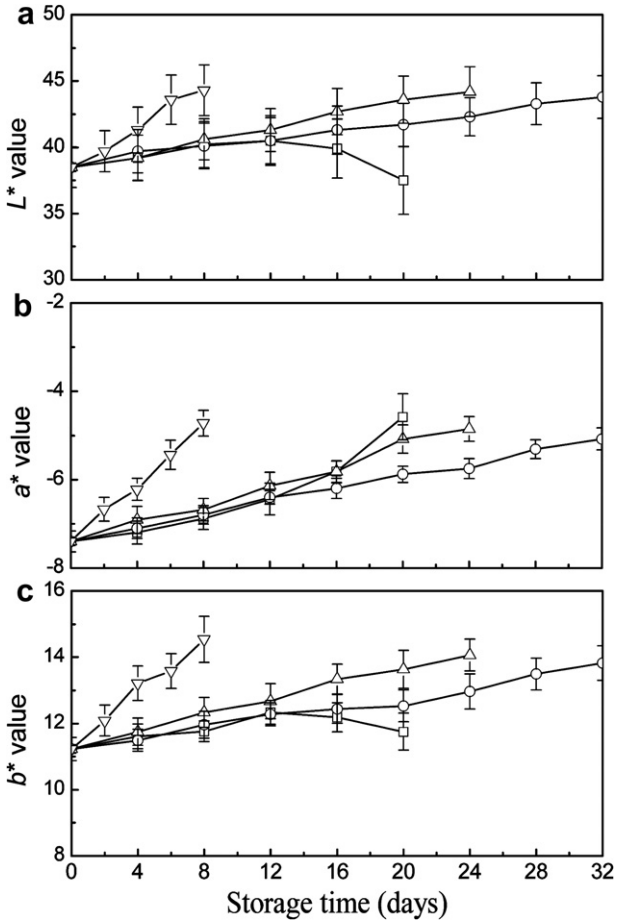

Fig. 2. Changes in L^* (a), a^* (b) and b^* (c) color values (mean ± S.D. for three replicates) of *Salicornia bigelovii* Torr. stored at different temperatures. (□) 0 °C, (○) 2 °C, (△) 8 °C, and (▽) 25 °C. FW, fresh weight.

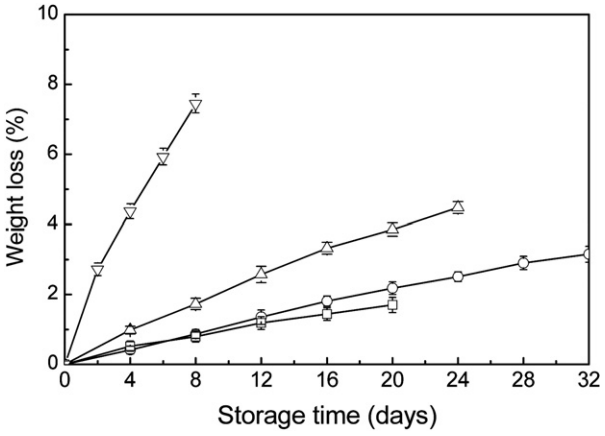

Fig. 3. Changes in weight loss (mean ± S.D. for three replicates) of *Salicornia bigelovii* Torr. stored at different temperatures. (□) 0 °C, (○) 2 °C, (△) 8 °C, and (▽) 25 °C.

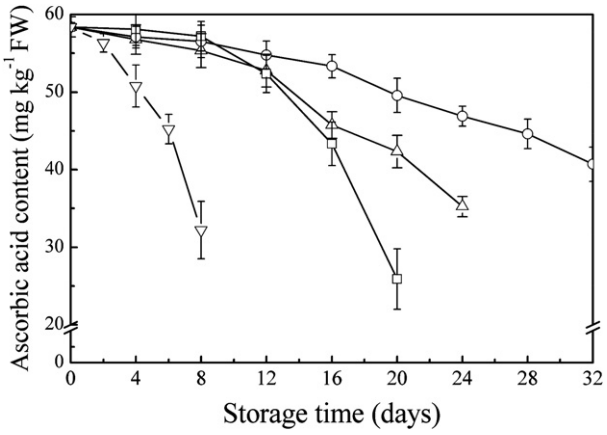

Fig. 4. Changes in ascorbic acid content (mean ± S.D. for three replicates) of *Salicornia bigelovii* Torr. stored at different temperatures. (□) 0 °C, (○) 2 °C, (△) 8 °C, and (▽) 25 °C. FW, fresh weight.

Generally, fruits and vegetables show a gradual decrease in ascorbic acid content as storage temperature and/or duration increases (An, Zhang, Lu, & Zhang, 2006; Gil-Izquierdo, Gil, Conesa, & Ferreres, 2001; Piga, Caro, Pinna, & Agabbio, 2003). The loss of ascorbic acid content is most probably dominated by the presence of catalysts and oxidase enzymes, such as polyphenol oxidase (PPO) to catalyse the oxidation especially at high temperature (Gil-Izquierdo et al., 2001; Li, Zhang, & Wang, 2008; Mao, Que, & Wang, 2006). In this study, the storage temperature at 2 °C was the most effective for keeping the quality of *S. bigelovii.*

3.2.3. Total chlorophyll content

In plants, the green color is due to chlorophyll located in chloroplasts. Loss of green color is normally considered as the major consequence of chlorophyll degradation (Guevara, Yahia, & de la Fuente, 2001; Heaton & Marangoni, 1996). Most plants show chlorophyll content degradation during storage (Moreira, Roura, & del Valle, 2003; Roura, Davidovich, & del Valle, 2000). In this study, the level of *S. bigelovii*'s total chlorophyll content decreased during storage at each temperature (Fig. 5), which is similar to broccoli's storage (Costa, Civello, Chaves, & Martinez, 2005). From Fig. 5 we can also find that the total chlorophyll content measured from day 4 of ambient storage (25 °C) was significantly lower compared to those of refrigerated storage. *S. bigelovii* stored at ambient condition showed a rapid decline and more than 30% decrease after 8 days, while refrigerated treatment samples presented higher levels of total chlorophyll. Refrigerated treatment not only delayed the onset of chlorophyll catabolism but also slowed down the rate of degradation. In contrast, at 0 °C treatments, the total chlorophyll content showed a significantly decreased after 16 days.

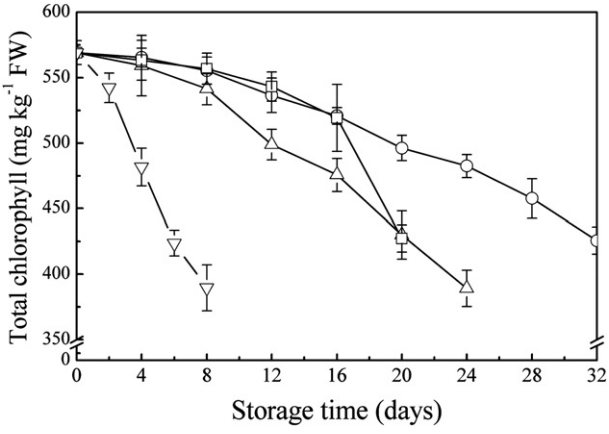

Fig. 5. Changes in total chlorophyll content (mean ± S.D. for three replicates) of *Salicornia bigelovii* Torr. stored at different temperatures. (□) 0 °C, (○) 2 °C, (△) 8 °C, and (▽) 25 °C. FW, fresh weight.

In senescing higher plants, under conditions where senescence induced, chlorophyll breakdown occurred with high rates (Brown, Houghton, & Hendry, 1991; Oberhuber, Berghold, Breuker, Hortensteiner, & Krautler, 2003). Thus, the question relating to *S. bigelovii* chlorophyll loss should not be focused specifically on chlorophyll catabolism, but on approaches to maintain cell membrane integrity.

4. Conclusions

Being a halophytic plant, *S. bigelovii* is one of the most promising halophytes and likely to provide a human foods supplement. *S. bigelovii* was perishable with a shelf life of only about 6 days at ambient temperature (25 °C). Refrigeration could be a practical technique for the extension of storage life, and the optimal temperature for preserving *S. bigelovii* was around 2 °C. However, high mineral element contents and certain untested compositions may cause safety problems. Therefore, the suitability of taking *S. bigelovii* as a human staple food source and efficientive methods to further prolong its postharvest shelf life than the refrigeration need to be thoroughly studied.

Acknowledgments

This research was supported by the Jiangsu Provincial Science and Technology Achievements Transformation Special Fund Programs (No. BA2006058) and "11th Five-year Plan" National Science & Technology Pillar Program of China (No. 2006BAD30B02).

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