Received: 9 January 2009 Revised: 25 March 2009 Accepted: 31 March 2009

(www.interscience.wiley.com) DOI 10.1002/jsfa.3624

Effects of modified atmosphere packaging with different sizes of silicon gum film windows on *Salicornia bigelovii* Torr. storage

Dong-He Lu,[a,b] Min Zhang,[a]* Shao-Jin Wang,[c] Jin-Long Cai,[d]
Cheng-Pei Zhu[d] and Xiang Zhou[d]

Abstract

BACKGROUND: *Salicornia bigelovii* Torr. is a promising seasonal plant using seawater production but perishable with short shelf-life under ambient conditions. To develop a modified atmosphere packaging (MAP) for extension of *S. bigelovii* shelf-life, a nonselective polyethylene/polyamide (PE/PA) bag combining different sizes (0.6, 1.0 and 1.4 cm^2) of silicon gum film (SGF) windows was tested, and low-density polyethylene (LDPE) and perforated (1.0 cm^2) PE/PA bags were used as controls.

RESULTS: During 36 days of storage at 2 °C, the equilibrium compositions of O_2/CO_2 in LDPE, SGF1 (0.6 cm^2), SGF2 (1.0 cm^2) and SGF3 (1.4 cm^2) were 3.0–5.0/4.5–6.5 kPa, 0.5–1.5/8.5–19.0 kPa, 2.5–5.0/5.5–10.0 kPa, and 6.0–13.0/4.0–6.5 kPa, respectively. Passive MAP treatments improved the quality attributes of *S. bigelovii* during initial storage; however, the 0.6 cm^2 SGF package markedly accelerated deterioration over the latter storage. The 1.0 cm^2 SGF package was observed to provide the optimal condition for *S. bigelovii* storage.

CONCLUSION: The results show that passive MAP with optimized sizes of SGF windows could be an effective technique for prolonging shelf-life of *S. bigelovii*.

Keywords: MAP; halophytic plant; permeability; sensory quality; shelf-life

INTRODUCTION

Soil salinity has become a serious concern in recent years.[1] However, most fresh top crops consumed by people cannot tolerate salt.[2] Many scientists have started to focus on using seawater for crop cultivation along undeveloped coastal land.[3,4] *Salicornia bigelovii*, an edible halophytic plant,[5] contains high nutritive components, such as vitamins and minerals.[6,7] This plant has been recognized as one of the most promising crops in seawater[8,9] in many countries such as Mexico, the United Arab Emirates,[10] and China.[11] China, a country with a large population and limited land that is routinely ploughed, has seen a progressively increasing interest in the cultivation and consumption of *S. bigelovii* over recent years.[12,13] However, *S. bigelovii* gradually develops toughness, moisture and green loss, and normally has a shelf-life of 5–7 days under ambient conditions.

Fresh produce possesses the best possible quality at harvest, which cannot be improved but only maintained after harvest.[14–17] Refrigerated storage is a common method for minimizing postharvest quality losses,[18–20] while modified atmosphere packaging (MAP) is an effective complement to the optimum temperature for further preventing quality deterioration in a variety of produce.[21–24] Polymeric films such as polyethylene (PE),[25] low-density polyethylene (LDPE),[26] polypropylene (PP)[27] and perforated PP[28] have been widely used in MAP. On the other hand, a successful MAP results in an ideal barrier property for packaging,[29] but insufficient permeability of the packaging film may result in acceleration of quality deterioration.[30] Because respiration rates of different types of produce vary in a wide range, a given polymeric film can only be used in certain produce under specific conditions.[31,32] Generally, developments in material sciences have not fully met the MAP requirements for various fresh produce.[22,33] To extend the potential application of MAP, a scheme using a selective membrane and a nonselective material in parallel has been proposed.[34] For its particularly selective permeability, the silicon membrane has been developed successfully in chamber,[35] jar[36] and tray[37] MAP systems. However, the extensive use of these systems has been hindered by the substantial cost and facility available when compared with the bag system, especially at the retail scale in developing countries such as China.

---

* Correspondence to: Min Zhang, School of Food Science and Technology, Jiangnan University, 214122 Wuxi, China. E-mail: min@jiangnan.edu.cn

a State Key Laboratory of Food Science and Technology, Jiangnan University, 214122Wuxi, Jiangsu, China

b Agricultural Products Process Research Center of Fujian Agriculture Science Academy, 350013 Fuzhou, China

c Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164-6120, USA

d Jinagsu Jinglong Marine Industry Development Co. Ltd, 224145, Dafeng, China

There are no published reports on bag storage of *S. bigelovii*. Our previous work revealed that *S. bigelovii* is not chilling sensitive and the optimum stored temperature is about 2 °C (Lu DH, unpublished). Preliminary experiments demonstrate that different sizes of silicon gum film (SGF) windows could result affect shelf-life of *S. bigelovii*. It is also observed that the 0.9 cm^2 SGF window in a tray MAP system improves shelf-life of *Agrocybe chaxingu*.[37] The primary objectives of the present study were to determine the O_2 and CO_2 partial pressures in different packaging bags, to evaluate the effect of passive MAP with different sizes of SGF windows on the quality and shelf-life of *S. bigelovii* at 2 °C, and to develop an effective and small-scale MAP system that would be readily accessible by farmers.

EXPERIMENTAL

Plant material

S. bigelovii (*Salicornia bigelovii* Torr.), 5–6 cm of the youngest fully expanded branch tips used in this study, was obtained from Jiangsu Jinglong Marine Industry Development Co. Ltd (Yancheng, China). The materials were transported to the laboratory within 8 h after harvest. Materials without visual defects were randomly used in all experiments.

Modified atmosphere packaging

A commercial nonselective polyethylene/polyamide (PE/PA, 30 cm length × 20 cm width) bag was used together with a high-permselectivity silicon gum film (SGF, FC-8, Lanzhou Institute of Chemical Physics, CAS, Lanzhou, China). The permeabilities of PE/PA and SGF for O_2/CO_2 were $4.08 \times 10^{-9}/12.24 \times 10^{-9}$ mol s^{-1} m^{-2} Pa^{-1} and $5.20 \times 10^{-13}/6.31 \times 10^{-13}$ mol s^{-1} m^{-2} Pa^{-1} at 20 °C and 90% RH, respectively. This packaging was used for *S. bigelovii* to obtain a versatile membrane system in passive MAP treatments. In the present study, three sizes of window of 0.6 cm^2 (SGF1), 1.0 cm^2 (SGF2) and 1.4 cm^2 (SGF3) were cut in the central part on one side of the PE/PA bags and covered with SGF. A commercial low-density polyethylene (LDPE) bag (35 μm thickness, 30 cm length × 20 cm width) with a permeability of 3.74×10^{-12} mol s^{-1} m^{-2} Pa^{-1} for O_2 and 14.17×10^{-12} mol s^{-1} m^{-2} Pa^{-1} for CO_2 at 20 °C and 90% RH was used for comparisons. PE/PA bags with a 1.0 cm^2 window kept uncovered were used as a control (PERF). For each packaging, about 300 g *S. bigelovii* samples were randomly loaded and sealed. For each treatment, 27 bags were packaged based on three replicates with nine times measurements during the entire storage period. All packages were stored at 2 °C and 75% RH for 36 days.

Gas analysis

Gas compositions (O_2 and CO_2) in the sealed bags were measured before opening using a gas analyzer (CYES-II, Xuelian Analytical Instrument Co. Ltd, Shanghai, China) by placing the needle directly into the package and recording every 4 days during storage. Analyses were carried out in a storage room (2 °C with 85% RH) using a 10.0 mL gas sample.

Sensory quality assessment

Similar methods employed by Li *et al.*[38] were used to evaluate the sensory quality. A panel of 10 trained judges evaluated the sensory quality characteristics, including general appearance, firmness and color, which were weighted with 40%, 30% and 30%, respectively, for all the *S. bigelovii* samples from each bag on a scale from 9 to 1. Score 9 represents excellent quality without any rotting, very firm and dark green. Score 7 represents good quality without any rotting, firm and green. Score 5 represents fair and limited marketability with less than 1% rotten, moderately firm and light green. Score 3 represents poor quality and limited usability with 1–5% rotten, soft and pale green. Score 1 represents very poor and inedible, with more than 5% rotten, very soft and yellow. The sample was considered unmarketable when the score was lower than 5.

Respiration rate and weight loss

Respiration rate was determined by static methods.[39] Samples taken from the package were first exposed to ambient conditions in the storage room for 30 min. 200 g of the samples were then put into a gas-tight container (260 mm) with 10 mL of 0.4 mol L^{-1} NaOH in a Petri dish, and placed at 2 °C for 30 min. The Petri dish was then taken out and the NaOH was immediately titrated with 0.2 mol L^{-1} oxalic acid. The respiration rate was estimated as CO_2 μg kg^{-1} s^{-1}. Weight loss was determined by weighing each sample at the beginning of each withdrawal and expressed as percentage of initial sample weight.

Ascorbic acid, total chlorophyll and crude fiber content

Ascorbic acid was analyzed by the indophenol titration method according to the procedures described by Li *et al.*[37,38] A 10 g sample was ground in a mortar with 10 mL of 20 g L^{-1} oxalic acid solution. The homogenate was made up to 100 mL with 10 g L^{-1} oxalic acid solution. 10 mL filtered solutions were titrated with 2,6-dichlorophenol indophenol solution until the distinct light rose-pink color persisted for more than 5 s. Charles' method with some modifications was used to evaluate the total chlorophyll.[41] 5 g samples with 0.3 g calcium carbonate were homogenized in a mortar with 5.0 mL of 800 mL L^{-1} acetone solution. The filtered homogenate was made up to 100 mL with 800 mL L^{-1} acetone solution. Absorbencies at 665 and 649 nm were measured using a UV-visible spectrophotometer (Model U2001, Hitachi Co., Tokyo, Japan). Crude fiber was determined using the neutral detergent reagent method described by Guevara *et al.*[42] 1 g dry sample was mixed with 100 mL of cold laurel sodium sulfate, adjusted to pH 6.9–7.1, and mixed with 2 mL decahydronaphthalene and 0.5 g sodium sulfite. It was left at 110 °C for 60 min, filtered and washed first with hot water and acetone, and finally dried on a filter paper at 100 °C for 80 min.

Statistical analysis

The mean and standard deviation values were obtained over three replicates. Data analysis was carried out by analysis of variance (ANOVA). The mean values were separated by Duncan's multiple range tests at a significance level of 0.05.

RESULTS AND DISCUSSION

Gas partial pressures

Both of the headspace O_2 and CO_2 partial pressures in MAP treatments were clearly affected by the packaging method, changing sharply over the first 4 days and progressively during the latter storage, except for the perforated packaging kept under ambient conditions (Fig. 1). The highest O_2 and lowest CO_2 partial pressures were observed in SGF3 treatment throughout the tested storage time, mainly due to the highest exchange area (1.4 cm^2). These results also suggested that the SGF windows had a higher

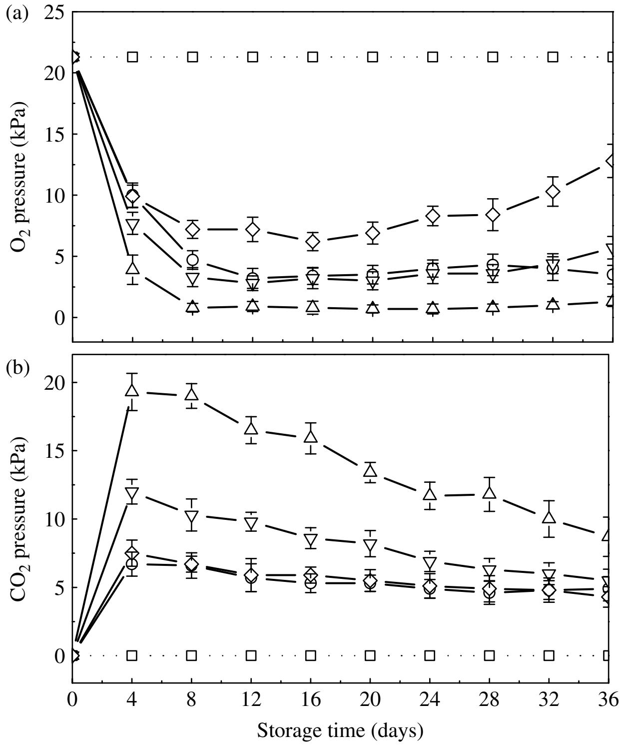

Figure 1. Changes of O_2 (a) and CO_2 (b) partial pressures (mean ± SD over three replicates) in packages for *Salicornia bigelovii* Torr. stored at 2 °C for 36 days: (○) package with low-density polyethylene (LDPE); (△) package with 0.6 cm^2 silicon gum film window (SGF1); (▽) package with 1.0 cm^2 silicon gum film window (SGF2); (◇) package with 1.4 cm^2 silicon gum film window (SGF3); (□) package with perforated (1.0 cm^2) film (PERF).

permeability to O_2 and CO_2 than the other packages, and the size of SGF windows would clearly affect the headspace gas partial pressures in packages. However, a contrary result could be observed in SGF1 packaging due to the small exchange area (0.6 cm^2). On the other hand, the trend showed that the O_2 partial pressure in LDPE treatment was slightly higher than that of SGF2, while the CO_2 partial pressure was similar to that of SGF3 (Fig. 1). This result could be caused by the slightly higher permselectivity for CO_2 of the LDPE film when compared with that of SGF film.

The O_2 partial pressure decreased abruptly from the initial value (21 kPa) to a level lower than 10 kPa in MAP treatments during the initial 4 days and changed slightly during the following storage (Fig. 1(a)). A steady state of 2.5–5.0 kPa O_2 could be noted in both SGF2 and LDPE treatments after 8 days of storage. However, the values in SGF1 treatment were lower than 1.5 kPa. The O_2 partial pressures in SGF3 treatment reached the lowest level on the 16th day, followed by a progressive increase.

The CO_2 partial pressure accumulated obviously over initial days, and reached a peak around the 4th day, followed by various decreases with MAP treatments (Fig. 1(b)). A significant drop was observed in SGF1 and SGF2 treatments, while the changes in LDPE and SGF3 treatments were not so obvious over the latter storage time.

The aim of MAP is to obtain a desirable equilibrium atmosphere in packages since the low limit of O_2 partial pressure for most vegetables is about 1.0 kPa.[43] In this study, the O_2 partial pressures in MAP treatments, except for SGF1, were above 2.5 kPa and the CO_2 partial pressures were also at sound values which appeared to be beneficial for maintaining the quality and extending the shelf-life of *S. bigelovii*. These results showed that both SGF and LDPE packaging systems could be used for *S. bigelovii* MAP.

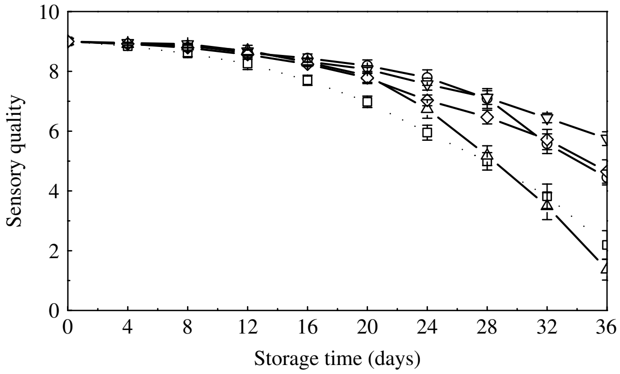

Figure 2. Changes in scores (mean ± SD for three replicates) of sensory quality for *Salicornia bigelovii* Torr. stored in different packages at 2 °C for 36 days: (○) package with low-density polyethylene (LDPE); (△) package with 0.6 cm^2 silicon gum film window (SGF1); (▽) package with 1.0 cm^2 silicon gum film window (SGF2); (◇) package with 1.4 cm^2 silicon gum film window (SGF3); (□) package with perforated (1.0 cm^2) film (PERF).

Sensory evaluation

The sensory quality scores of *S. bigelovii* in different packages decreased progressively during storage at 2 °C (Fig. 2). Higher scores could be detected in SGF2, SGF3 and LDPE treatments, because all these treatments provided scores higher than 5 until 32 days of storage. However, in the final experiment, only the SGF2 treatment was above 5. A faster decrease during the entire period and a sharp drop in the latter period can be found in scores of the PERF, SGF1 and LDPE treatments, respectively, when compared with data found in the other treatments. Both the PERF and SGF1 treatments produced unacceptable results (scores below 5) around the 28th day. The effect of packaging methods on sensory quality would be mainly due to the different gas compositions (Fig. 1). The moderate reduction in O_2 and increase in CO_2 observed in SGF2, SGF3 and LDPE could be associated with extending senescence.[44] The results showed that ideal packaging permeability could effectively improve the quality of postharvest *S. bigelovii*, while insufficient permeability may result in accelerated deterioration.

Respiration rate

The respiration rates of *S. bigelovii* stored in different packages at 2 °C are listed in Table 1. The initial respiration rate was particularly high (CO_2, 21.20 $\mu g\ kg^{-1}\ s^{-1}$), which was most probably dominated by stress resulting from the harvesting process and transportation just before storage. The respiration rate dropped abruptly during the first 8 days – extraordinarily in the first 4 days, followed by a steady level in all treatments. This result is similar to that of green asparagus spears during MAP storage.[45] The value for PERF treatment was significant higher than those for MAP treatments during 4–12 days' storage. On the other hand, the respiration rate in SGF1 was obviously lower than in other packages during the entire storage period, particularly in the initial days, which could result from the low O_2 and/or high CO_2 partial pressures in the packaging (Fig. 1(a)).[23] During the final period, slight increases could be observed in PERF, LDPE and SGF3 treatments, which may be due to sample senescence. The results indicated that MAP could result in a lower respiration rate for *S.*

Table 1. Changes in respiration rate of *Salicornia bigelovii* Torr. stored at 2 °C for 36 days (CO_2 µg kg^{-1} s^{-1})

	Packaging				
Storage time (days)	PERF	LDPE	SGF1	SGF2	SGF3
0	21.20 ± 1.039aA				
4	12.04 ± 0.711aB	9.28 ± 0.617bB	7.76 ± 0.469cB	8.93 ± 0.625bB	9.27 ± 0.622bB
8	8.81 ± 0.683aC	6.30 ± 0.494bcC	5.33 ± 0.378cC	6.16 ± 0.589bcC	6.86 ± 0.519bC
12	6.99 ± 0.519aD	5.14 ± 0.372bcD	4.51 ± 0.353cC	5.06 ± 0.392bcC	5.54 ± 0.522bD
20	4.48 ± 0.456aE	3.93 ± 0.464abE	3.57 ± 0.272bD	3.87 ± 0.419abD	4.21 ± 0.411abE
28	4.36 ± 0.383aE	3.91 ± 0.503abE	3.35 ± 0.261bD	3.58 ± 0.667abD	3.88 ± 0.483abE
36	5.48 ± 0.767aE	4.68 ± 0.621aDE	3.06 ± 0.400bD	3.37 ± 0.400bD	4.50 ± 0.589aDE

Values are mean ± SD over three replicates. Means in the same column followed by different capital letters indicate significant difference ($P < 0.05$) between days of storage, while different small letters in the same row indicate significant difference between treatments ($P < 0.05$) using Duncan's test. PERF, package with perforated (1.0 cm^2) film; LDPE, package with low-density polyethylene; SGF1, package with 0.6 cm^2 silicon gum film window; SGF2, package with 1.0 cm^2 silicon gum film window; SGF3, package with 1.4 cm^2 silicon gum film window.

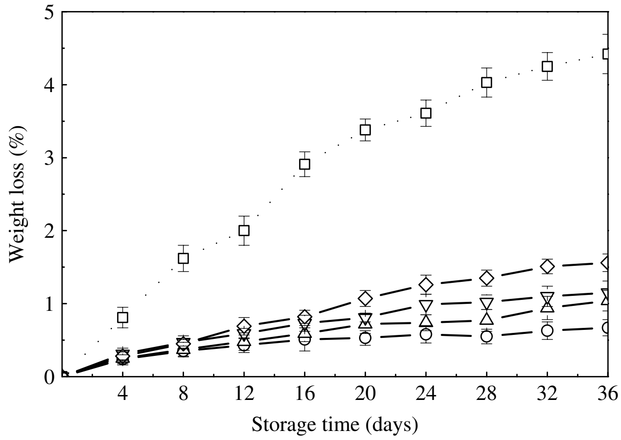

Figure 3. Changes in weight loss (mean ± SD for three replicates) of *Salicornia bigelovii* Torrr. stored in different packages at 2 °C for 36 days: (○) package with low-density polyethylene (LDPE); (△) package with 0.6 cm^2 silicon gum film window (SGF1); (▽) package with 1.0 cm^2 silicon gum film window (SGF2); (◇) package with 1.4 cm^2 silicon gum film window (SGF3); (□) package with perforated (1.0 cm^2) film (PERF).

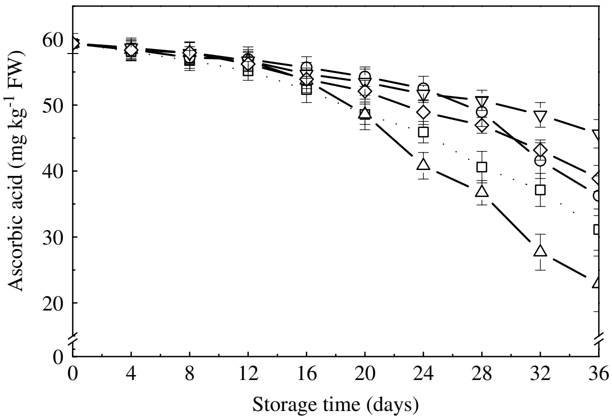

Figure 4. Changes in ascorbic acid content (mean ± SD for three replicates) of *Salicornia bigelovii* Torr. stored in different packages at 2 °C for 36 days: (○) package with low-density polyethylene (LDPE); (△) package with 0.6 cm^2 silicon gum film window (SGF1); (▽) package with 1.0 cm^2 silicon gum film window (SGF2); (◇) package with 1.4 cm^2 silicon gum film window (SGF3); (□) package with perforated (1.0 cm^2) film (PERF).

bigelovii during postharvest storage, which would be of benefit in maintaining its quality.

Weight loss

S. bigelovii stored in all MAP treatments represented an accumulating weight loss of less than 1.6% during the tested duration; however, the data for the PERF treatment were close to 4.5% (Fig. 3). There were marked differences between the PERF and MAP treatments, while the differences amongst different MAP treatments were not so clear. The lowest weight loss was found in the LDPE treatment, which was factually attributed to its lowest permeability for moisture. The low moisture permeability of LDPE packaging could possibly result in microbial growth and ultimately affect the product quality (Fig. 2).[32]

Ascorbic acid content

The content of ascorbic acid, one of the most important vitamins for the human body,[46] of *S. bigelovii* at harvest is about 60 mg kg^{-1} fresh weight, which showed an obvious decrease during the postharvest storage, which was similar to some other fresh produce.[47] There were no clear differences ($P < 0.05$) amongst different packages during the first 16 days of storage, although the PERF treatment showed the least potency in controlling decomposition of ascorbic acid (Fig. 4). Surprisingly, a sharp decrease in ascorbic acid content could be noted from the 12th day in the SGF1 package, and from the 24th day in the LDPE package, respectively. During 36 days storage, the accumulating loss of ascorbic acid represented approximately 50% with SGF1 packaging, most probably due to the excessively low O_2 and/or high CO_2 partial pressure in the package (Fig. 1).[48] On the other hand, the lower ascorbic acid decomposition rate in SGF2 packaging throughout the storage period, and in LDPE packaging during the initial period, can be attributed to the ability of both these treatments to offer conditional O_2 and/or CO_2 partial pressures, which retarded the postharvest senescence of *S. bigelovii* tissue.

Total chlorophyll content

Changes in total chlorophyll content of *S. bigelovii* were very similar to those of ascorbic acid, which decreased progressively during postharvest storage (Fig. 5). The degradation of chlorophyll could

Table 2. Changes in crude fiber content of *Salicornia bigelovii* Torr. stored at 2 °C for 36 days (g kg^{-1} fresh weight)

	Packaging				
Storage time (days)	PERF	LDPE	SGF1	SGF2	SGF3
0	8.3 ± 0.29aE	8.3 ± 0.29aD	8.3 ± 0.29aD	8.3 ± 0.29aF	8.3 ± 0.29aE
4	8.7 ± 0.33aDE	8.6 ± 0.31aCD	8.6 ± 0.31aCD	8.5 ± 0.35aEF	8.6 ± 0.32aDE
8	9.2 ± 0.37aD	8.9 ± 0.27aBC	8.9 ± 0.34aBCD	8.9 ± 0.28aDE	9.1 ± 0.31aCD
12	9.9 ± 0.31aC	9.1 ± 0.34bBC	9.2 ± 0.31bABC	9.4 ± 0.31abCD	9.5 ± 0.34abC
20	10.9 ± 0.37aB	9.4 ± 0.35cAB	9.6 ± 0.37bcA	9.9 ± 0.32bcBC	10.2 ± 0.40bB
28	12.2 ± 0.46aA	9.8 ± 0.41cdA	9.5 ± 0.43dAB	10.3 ± 0.38bcAB	10.9 ± 0.39bA
36	12.2 ± 0.42aA	9.6 ± 0.47dAB	9.4 ± 0.40dAB	10.5 ± 0.26cA	11.4 ± 0.33bA

Values are mean ± SD over three replicates. Means in the same column followed by different capital letters indicate significant difference ($P < 0.05$) between days of storage, while different small letters in the same row indicate the significant difference ($P < 0.05$) between treatments using Duncan's test. PERF, package with perforated (1.0 cm^2) film; LDPE, package with low-density polyethylene; SGF1, package with 0.6 cm^2 silicon gum film window; SGF2, package with 1.0 cm^2 silicon gum film window; SGF3, package with 1.4 cm^2 silicon gum film window.

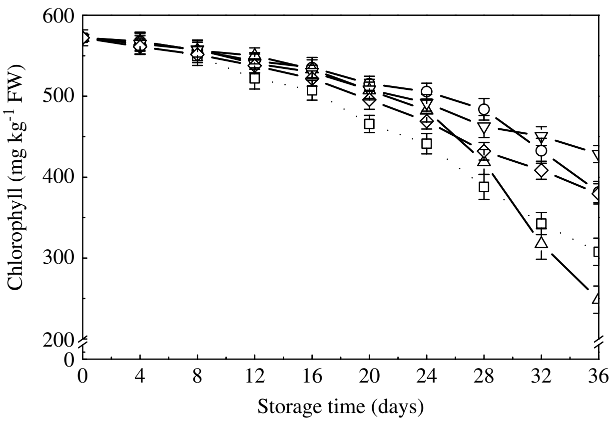

Figure 5. Changes in total chlorophyll content (mean ± SD for three replicates) of *Salicornia bigelovii* Torr. stored in different packages at 2 °C for 36 days: (○) package with low-density polyethylene (LDPE); (△) package with 0.6 cm^2 silicon gum film window (SGF1); (▽) package with 1.0 cm^2 silicon gum film window (SGF2); (◇) package with 1.4 cm^2 silicon gum film window (SGF3); (□) package with perforated (1.0 cm^2) film (PERF).

result in the loss of green color in *S. bigelovii*.[49] After 36 days' storage, the total chlorophyll contents in the PERF and SGF1 treatments were significantly ($P < 0.05$) lower than that of the other treatments, showing that the feasible MAP treatments had a favorable effect on chlorophyll content. The results confirmed the fact that chlorophyll breakdown occurred at high rates for senescing higher plants under conditions in which senescence was induced.[50]

Crude fiber content

Table 2 lists the crude fiber content of *S. bigelovii* in different packages during postharvest storage at 2 °C, which increased generally with storage duration. The changes in crude fiber content of *S. bigelovii* were similar to that of asparagus spears during postharvest storage.[51] The crude fiber accumulations in different packages remained at a comparatively high level during initial storage, and then had a relatively low increased rate. There were no significant differences between the PERF and diverse MAP treatments until the 12th day. The fastest increase was observed in the PERF treatment, followed by SGF3, then SGF2. All of them represented a significant increase in the tested duration. However, for the SGF1 and LDPE packages the data observed were obviously low in comparison with the other treatments (Table 2). In the SGF1 treatment, a certain decrease could even be observed during the final stage, which may have resulted from the fact that elevated partial pressures of CO_2 (Fig. 1(b)) could increase cell permeability and cause a disintegration of crude fiber.[52]

CONCLUSIONS

The packaging method resulted in significantly different in-package atmospheres (O_2 and CO_2), which clearly affected the product quality of treated *S. bigelovii* during storage. Passive MAP could be a practical technique for extension of shelf-life, and the recommended gas partial pressures of O_2 and CO_2 for preserving *S. bigelovii* were 2.5–5.0 and 5.5–10.0 kPa, respectively. On the other hand, *S. bigelovii* stored under extremely low O_2 (<1.5 kPa) and/or high CO_2 (>10.0 kPa) conditions may cause quality deterioration and reduce the shelf-life. In considering the control of SGF window sizes for the desired gas permeability, the passive MAP with a SGF window provided an effective method for *S. bigelovii* storage.

ACKNOWLEDGEMENTS

This work was funded by the Jiangsu Provincial Science and Technology Achievements Transformation Special Fund Programs (No. BA2006058).

REFERENCES

1 Pfiser RW, *Limits to growth of Salicornia bigelovii Torr. at suboptimal salinity*. PhD thesis, University of Arizona, Tucson (1999).
2 Bashan Y, Moreno M and Troyo E, Growth promotion of the seawater-irrigated oilseed halophyte *Salicornia bigelovii* inoculated with mangrove rhizosphere bacteria and halotolerant *Azospirillum* spp. *Biol Fertil Soils* **32**:265–272 (2000).
3 Glenn E, Miyamoto S, Moore D, Brown JJ, Thompson TL and Brown P, Water requirements for cultivating *Salicornia bigelovii* Torr. with seawater on sand in a coastal desert environment. *J Arid Environ* **36**:711–730 (1997).
4 Glenn EP, Brown JJ and O'Leary JW, Irrigating crops with seawater. *Sci Am* **279**:76–81 (1998).
5 Millman J, Trendy sprout thrives on water from the sea. *Wall Street J* **2**:1–3 (2003).
6 Lu AG, Zhang XL, Ju X and Yang YZ, Quality analysis of the vacuum freezing drying *Salicornia*. [In Chinese]. *Food Res Dev* **29**:111–114 (2008).

7 Tang WZ, Liu ZP, Zhu JH, Peng HX and Li HL, A study on the component content of two north American glasswort new species. [In Chinese]. *J Guangxi Agric* **11**:33–35 (2003).
8 Attia FM, Alsobayel AA, Kriadees MS, AlSaiady MY and Bayoumi MS, Nutrient composition and feeding value of *Salicornia bigelovii* Torr. meal in broiler diets. *Anim Feed Sci Technol* **65**:257–263 (1997).
9 Glenn EP, O'Leary JW, Watson MC, Thompson TL and Kuehl RO, *Salicornia bigelovii* Torr.: an oilseed halophyte for seawater irrigation. *Science* **251**:1065–1067 (1991).
10 Milan S and Stanislav Z, Vegetable lipids as components of functional foods. *Biomed Papers* **146**:3–10 (2002).
11 Jiang D, Li YX, Huang LF, Zeng FR and Zhang YK, Effects of salinity and temperature on introduction and cultivation of the Euhalophyte *Salicornia bigelovii* Torr. in the Xiamen ambient sea. *Chin Bull Bot* **25**:533–542 (2008).
12 Hong LZ, Ding Hr, Yang Zq, Wang Mw, Wang K and Zhu Xm, Research progress and prospects of halophytic vegetation *Salicornia bigelovii*. [In Chinese]. *Acta Agric Jiangxi* **20**:46–48 (2008).
13 Zhou F, Zhou QC, Hua C and Chen QZ, Effects of KCL and NaCl on growth and several antioxidative enzyme activities of *Salicornia bigelovii* Torr. *Plant Physiol Commun* **44**:51–54 (2008).
14 Li Y, Brackett RE, Shewfelt RL and Beuchat LR, Changes in appearance and natural microflora on iceberg lettuce treated in warm, chlorinated water and then stored at refrigeration temperature. *Food Microbiol* **18**:299–308 (2001).
15 Kader AA, Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technol* **40**:117–121 (1986).
16 Cao S, Zheng Y, Yang Z, Tang S and Jin P, Control of anthracnose rot and quality deterioration in loquat fruit with methyl jasmonate. *J Sci Food Agric* **88**:1598–1602 (2008).
17 Li H and Yu T, Effect of chitosan on incidence of brown rot, quality and physiological attributes of postharvest peach fruit. *J Sci Food Agric* **81**:269–274 (2001).
18 Paul DR and Clarke R, Modeling of modified atmosphere packaging based on designs with a membrane and perforations. *J Membr Sci* **208**:269–283 (2002).
19 Tulio AZ, Ose K, Chachin K and Ueda Y, Effects of storage temperatures on the postharvest quality of jute leaves (*Corchorus olitorius* L.). *Postharvest Biol Technol* **26**:329–338 (2002).
20 Sanz S, Olarte C, Ayala F and Echávarri JF, The response to lighting of minimally processed chard: influence on its shelf life. *J Sci Food Agric* **88**:1622–1631 (2008).
21 Wszelaki AL and Mitcham EJ, Effect of combinations of hot water dips, biological control and controlled atmospheres for control of gray mold on harvested strawberries. *Postharvest Biol Technol* **27**:255–264 (2003).
22 Rai DR and Paul S, Transient state in-pack respiration rates of mushroom under modified atmosphere packaging based on enzyme kinetics. *Biosys Eng* **98**:319–326 (2007).
23 Kader AA, Zagory D and Kerbel EL, Modified atmosphere packaging of fruits and vegetables. *Crit Rev Food Sci Nutr* **28**:1–30 (1989).
24 Remon S, Ferrer A, Marquina P, Burgos J and Oria R, Use of modified atmospheres to prolong the postharvest life of Burlat cherries at two different degrees of ripeness. *J Sci Food Agric* **80**:1545–1552 (2000).
25 Ding CK, Chachin K, Ueda Y, Imahori Y and Wang CY, Modified atmosphere packaging maintains postharvest quality of loquat fruit. *Postharvest Biol Technol* **24**:341–348 (2002).
26 Gonzalez G and Tiznado M, Postharvest physiology of bell peppers stored in low density polyethylene bags. *LWT Food Sci Technol* **26**:450–455 (1993).
27 Awad MA, Increasing the rate of ripening of date palm fruit (*Phoenix dactylifera* L.) cv. Helali by preharvest and postharvest treatments. *Postharvest Biol Technol* **43**:121–127 (2007).
28 Sanz C, Perez AG, Olias R and Olias JM, Quality of strawberries packed with perforated polypropylene. *J Food Sci* **64**:748–752 (1999).
29 Christie GBY, Macdiarmid JI, Schliephake K and Tomkins RB, Determination of film requirements and respiratory behaviour of fresh produce in modified atmosphere packaging. *Postharvest Biol Technol* **6**:41–54 (1995).
30 Jacxsens L, Devlieghere F, De Rudder T and Debevere J, Designing equilibrium modified atmosphere packages for fresh-cut vegetables subjected to changes in temperature. *LWT Food Sci Technol* **33**:178–187 (2000).
31 Kim JG, Luo Y and Gross KC, Effect of package film on the quality of fresh-cut salad savoy. *Postharvest Biol Technol* **32**:99–107 (2004).
32 Teixeira GHA, Durigan JF, Alves RE and O'Hare TJ, Use of modified atmosphere to extend shelf life of fresh-cut carambola (*Averrhoa carambola* L. cv. Fwang Tung). *Postharvest Biol Technol* **44**:80–85 (2007).
33 Al-Ati T and Hotchkiss JH, Application of packaging and modified atmosphere to fresh-cut fruits and vegetables, in *Fresh-Cut Fruits and Vegetables: Science, Technology, and Market*, ed. by Lamikanra O. CRC Press, Washington, DC, 305–338 (2002).
34 Kirkland BS, Clarke R and Paul DR, A versatile membrane system for bulk storage and shipping of produce in a modified atmosphere. *J Membr Sci* **324**:119–127 (2008).
35 Stewart OJ, Raghavan GSV, Golden KD and Gariépy Y, MA storage of Cavendish bananas using silicone membrane and diffusion channel systems. *Postharvest Biol Technol* **35**:309–317 (2005).
36 Saxena A, Bawa AS and Raju PS, Use of modified atmosphere packaging to extend shelf-life of minimally processed jackfruit (*Artocarpus heterophyllus* L.) bulbs. *J Food Eng* **87**:455–466 (2008).
37 Li T, Zhang M and Wang S, Effects of temperature on *Agrocybe chaxingu* quality stored in modified atmosphere packages with silicon gum film windows. *LWT Food Sci Technol* **41**:965–973 (2008).
38 Li T, Zhang M and Wang S, Effects of modified atmosphere packaging with a silicon gum film as a window for gas exchange on *Agrocybe chaxingu* storage. *Postharvest Biol Technol* **43**:343–350 (2007).
39 Yang ZJ and Zhang HY, *A Laboratory Course Manual of Storage in Fruit and Vegetable*. [In Chinese]. Laiyang Agriculture College, Laiyang, China (2000).
40 Association of Vitamin Chemists, *Methods of Vitamin Assay*. Wiley, Chichester (1966).
41 Charles F, Guillaume C and Gontard N, Effect of passive and active modified atmosphere packaging on quality changes of fresh endives. *Postharvest Biol Technol* **48**:22–29 (2008).
42 Guevara JC, Yahia EM, de la Fuente EB and Biserka SP, Effects of elevated concentrations of CO_2 in modified atmosphere packaging on the quality of prickly pear cactus stems (*Opuntia* spp.). *Postharvest Biol Technol* **29**:167–176 (2003).
43 Saltveit ME, A summary of CA requirements and recommendations for vegetables, in *VIII International Controlled Atmosphere Research Conference*, ed. by International Society for Horticultural Science. *Acta Hortic* **600**:723–727 (2003).
44 Gonzalez-Aguilar GA, Buta JG and Wang CY, Methyl jasmonate and modified atmosphere packaging (MAP) reduce decay and maintain postharvest quality of papaya 'Sunrise'. *Postharvest Biol Technol* **28**:361–370 (2003).
45 An J, Zhang M, Lu Q and Zhang Z, Effect of a prestorage treatment with 6-benzylaminopurine and modified atmosphere packaging storage on the respiration and quality of green asparagus spears. *J Food Eng* **77**:951–957 (2006).
46 Podsedek A, Natural antioxidants and antioxidant capacity of Brassica vegetables: a review. *LWT Food Sci Technol* **40**:1–11 (2007).
47 Barth MM, Kerbel EL, Perry AK and Schmidt SJ, Modified atmosphere packaging affects ascorbic acid, enzyme activity and market quality of broccoli. *J Food Sci* **58**:140–143 (1993).
48 Pariasca JAT, Miyazaki T, Hisaka H, Nakagawa H and Sato T, Effect of modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage on the quality of snow pea pods(*Pisum sativum* L. var. *saccharatum*). *Postharvest Biol Technol* **21**:213–223 (2001).
49 Heaton JW and Marangoni AG, Chlorophyll degradation in processed foods and senescent plant tissues. *Trends Food Sci Technol* **7**:8–15 (1996).
50 Oberhuber M, Berghold J, Breuker K, Hortensteiner S and Krautler B, Breakdown of chlorophyll: a nonenzymatic reaction accounts for the formation of the colorless 'nonfluorescent' chlorophyll catabolites. *Proc Natl Acad Sci USA* **100**:6910–6915 (2003).
51 Zhang M, Zhan ZG, Wang SJ and Tang JM, Extending the shelf-life of asparagus spears with a compressed mix of argon and xenon gases. *LWT Food Sci Technol* **41**:686–691 (2008).
52 Nichols R and Hammond JBW, Storage of mushrooms in pre-packs: the effect of changes in carbon dioxide and oxygen on quality. *J Sci Food Agric* **24**:1371–1381 (2006).