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

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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 cm²) of silicon gum film (SGF) windows was tested, and low-density polyethylene (LDPE) and perforated (1.0 cm²) PE/PA bags were used as controls.

RESULTS: During 36 days of storage at 2 °C, the equilibrium compositions of O₂/CO₂ in LDPE, SGF1 (0.6 cm²), SGF2 (1.0 cm²) and SGF3 (1.4 cm²) 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 cm² SGF package markedly accelerated deterioration over the latter storage. The 1.0 cm² 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. However, most fresh top crops consumed by people cannot tolerate salt. Many scientists have started to focus on using seawater for crop cultivation along undeveloped coastal land. *Salicornia bigelovii*, an edible halophytic plant, contains high nutritive components, such as vitamins and minerals. This plant has been recognized as one of the most promising crops in seawater in many countries such as Mexico, the United Arab Emirates, and China. 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. 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. Refrigerated storage is a common method for minimizing postharvest quality losses while modified atmosphere packaging (MAP) is an effective complement to the optimum temperature for further preventing quality deterioration in a variety of produce. Polymeric films such as polyethylene (PE), low-density polyethylene (LDPE), polypropylene (PP) and perforated PP have been widely used in MAP. On the other hand, a successful MAP results in an ideal barrier property for packaging, but insufficient permeability of the packaging film may result in acceleration of quality deterioration. 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. Generally, developments in material sciences have not fully met the MAP requirements for various fresh produce. To extend the potential application of MAP, a scheme using a selective membrane and a nonselective material in parallel has been proposed. For its particularly selective permeability, the silicon membrane has been developed successfully in chamber and tray 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.
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 cm² SGF window in a tray MAP system improves shelf-life of *Agrocybe chaxingi*. The primary objectives of the present study were to determine the O₂ and CO₂ 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 O₂/CO₂ were 4.08 × 10⁻⁹/12.24 × 10⁻⁹ mol s⁻¹ m⁻² Pa⁻¹ and 5.20 × 10⁻¹³/6.31 × 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, there were three sizes of window of 0.6 cm² (SGF1), 1.0 cm² (SGF2) and 1.4 cm² (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 O₂ and 14.17 × 10⁻¹² mol s⁻¹ m⁻² Pa⁻¹ for CO₂ at 20 °C and 90% RH was used for comparisons. PE/PA bags with a 1.0 cm² window were kept uncovered was 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 (O₂ and CO₂) 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. 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 1 to 9. 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. 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 CO₂ 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. 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. 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). Crushed fiber was determined using the neutral detergent reagent method described by Guevara et al. 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 O₂ and CO₂ 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 O₂ and lowest CO₂ partial pressures were observed in SGF3 treatment throughout the tested storage time, mainly due to the highest exchange area (1.4 cm²). These results also suggested that the SGF windows had a higher
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 SGF1 and SGF2 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.

### 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, the initial result is similar to that of green asparagus spears during MAP storage.\(^{44} \) 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 µg 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 \( S. \) bigelovii.
Ascorbic acid content

The content of ascorbic acid, one of the most important vitamins for the human body, of *Salicornia 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.\(^{48}\) 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
Effects of MAP on S. bigelovii storage

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

<table>
<thead>
<tr>
<th>Storage time (days)</th>
<th>Packaging</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PERF</td>
</tr>
<tr>
<td>0</td>
<td>8.3 ± 0.29AE</td>
</tr>
<tr>
<td>4</td>
<td>8.7 ± 0.33aDE</td>
</tr>
<tr>
<td>8</td>
<td>9.2 ± 0.37aD</td>
</tr>
<tr>
<td>12</td>
<td>9.9 ± 0.31aC</td>
</tr>
<tr>
<td>20</td>
<td>10.9 ± 0.37bA</td>
</tr>
<tr>
<td>28</td>
<td>12.2 ± 0.46aA</td>
</tr>
<tr>
<td>36</td>
<td>12.2 ± 0.42aA</td>
</tr>
</tbody>
</table>

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 cm²) film; LDPE, package with low-density polyethylene; SGF1, package with 0.6 cm² silicon gum film window; SGF2, package with 1.0 cm² silicon gum film window; SGF3, package with 1.4 cm² silicon gum film window.

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.

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 CO₂ (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 (O₂ and CO₂), 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 O₂ and CO₂ 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 O₂ (<1.5 kPa) and/or high CO₂ (>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.

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REFERENCES


