Respiration Rate and Some Physicochemical Characteristics of Salicornia bigelovii as a Leafy Green Vegetable

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ABSTRACT: Salicornia is a valuable halophyte annual plant in the most species. This salinity tolerance plant that grows in salt water marshes are found all over the world. Since salinity is a major stress factor, Salicornia is a priceless edible vegetable, considered to be a favourable resource for cultivation in arid and semi-arid coastal zones. However, the important thing is that its properties should be well known especially as a leafy vegetable. On the other hand, Salicornia bigelovii is a perishable vegetable, with short storage life under ambient conditions. Thus, knowing its characteristics can be a great help to preserve it longer. Accordingly, the physicochemical properties, chemical composition and respiration rate of Salicornia bigelovii grown in Aq-Qalla Salinity Research Station, Golestan Agricultural and Natural Resources Research and Education Center, Iran were investigated in this paper. The results showed that the moisture content, total soluble solids content, pH, titratable acidity, ascorbic acid content, salinity content, respiration rate, maximum force, displacement, and color indices (L*, a*, b*) of S. bigelovii are 89.67%, 15.83%, 6.11, 0.05%, 0.03%, 56ds/m, 26.80 mgCO₂/kg.hr, 1.4 N, 1.47 mm, and 23.69, -6.77, 15.73, respectively. With respect to S.bigelovii plant as a leafy green vegetable, this plant is considered as a high respiration vegetable group.

Keywords: Quality Characteristics, Respiration Rate, Salicornia bigelovii.

Introduction

As the world’s population grows and freshwater stores become more precious, researchers are looking to the elected crops like Salicornia that do not need fresh water to irrigate (Glenn et al., 1998). Salicornia is a wild and annual (biennial, in some species) halophytic plant from Chenopodiaceae family that grows near salt marshes and salted wetlands or the vicinity of coastal areas in Asia, North America, and the Middle East. It is also grown in semi-arid areas of Iran such as Isfahan, Fars, and Yazd provinces (Akhani, 2003). Salicornia varieties are often multipurpose (Al-Oudat and Qadir, 2011) and it is very rich in vitamins, minerals and highly unsaturated oils (Raposo et al., 2009). Salicornioideae species are also rich in dietary fiber and many bioactive substances, such as phytosterols, polysaccharides, and phenolic compounds mainly flavonoids and phenolic acids (Choi et al., 2014). Salicornia is a great greenhouse crop for niche markets as well (Schalke, 2015) and its young leaves and stems are cooked or pickled (Tanaka, 1976). However, there are considerable studies on the Salicornia’s seed. Some of these valuable articles are summarized in the

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papers of Glenn et al. (1991), Clark (1994), Hassan El-Mallah et al. (1994), Bashan et al. (2000), Anwar et al. (2002), Grattan et al. (2008), Kang et al. (2011), Choi et al. (2014), and Isca et al. (2014). Ahmadi et al. (2016) also evaluated the extracted oil from Salicornia persica Akani plant using gas chromatography. They suggested that this oil is suitable to use in the food industry due to its proper oxidative stability. Furthermore, there are other sporadic studies on salicornia. For example, Zerai et al. (2010) compared S. bigelovii lines produced in two breeding programs with wild germplasm in greenhouse trials on brackish water (10 ppt NaCl) irrigation. They concluded that S. bigelovii has sufficient genetic diversity among wild accessions and cultivars to support a crop improvement program. In addition, the effects of adding glasswort (Salicornia herbacea L.) hydrate containing a non-meat ingredient (carboxymethyl cellulose, carrageenan, isolated soy protein, sodium caseinate) on the quality characteristics of reduced-salt, reduced-fat frankfurters were evaluated by Lim et al. (2015). They indicated that the use of the above substance improves the quality characteristics of reduced-salt, reduced-fat frankfurters.

The Salicornioideae family includes almost 15 genera and 80 species. The commonly found Salicornia species are S. ramosissima, S. indica, S. brachiata, S. bigelovii, S. herbacea, S. perennis, S. fragilis, S. nitens, S. pusilla, and S. disarticulate (Choi et al., 2014; Isca et al., 2014). However, there are not many studies on salicornia plant as an edible vegetable.

Salicornia bigelovii Torr., an annual salt marsh plant is a species from Salicornia genus, Salicornioideae subfamily, Chenopodiaceae (Amaranthaceae) family, and Caryophyllales order, in the scientific classification. The taxonomic classification of this genus is extremely difficult and may impossible for non-specialists. However, the taxonomic key for identification of the species of Salicornia is based on molecular genetic research (Kadereit et al., 2007; Kadereit et al., 2012).

Salicornia bigelovii produces seed oils, protein meal, fresh salad greens and forages on seawater irrigation (Lu et al., 2010; Zerai et al., 2010). It is growing to 0.3 m and is in flower from August to September. The seeds then ripen from September to October. The flowers are hermaphrodite and are pollinated by wind. It cannot grow in the shade and prefers moist soil (Anon, 2012). It is considered to be the best prospect of development and utilization of halophytes, has been successfully cultivated at home and abroad, and begin large-scale production (Lu, 2009). Nutrients and toxic trace element content of S. bigelovii Torr. was measured by Lu et al. (2010). The results showed that it has a higher nutritional value in terms of amino acid composition, vitamins, some functional ingredients and a wealth of mineral elements, which made it an ideal nutritional and diet supplement.

Since, S. bigelovii is perishable with a short shelf life of only about 6 days at ambient temperature (Lu et al., 2009; Lu et al., 2010), it is necessary to know its physiological characteristics like respiration rate as well as physicochemical properties. Thus, this paper may be an interesting article on the use of Salicornia bigelovii as a fresh leafy vegetable grown in Iran as commercial food crops due to the plants’ native habitat will give some idea about its application needs.

Materials and Methods

- Plant material

Fresh samples of Salicornia bigelovii were supplied from Aq-Qalla Salinity Research Station, Golestan Agricultural and Natural Resources Research and Education Center, Iran (Figure 1). As is shown in Figure 1, the Salicornia bigelovii has stem and leaves, as the same other leafy
vegetables. Thus, it was harvested and transported to the laboratory less than one day after harvesting in the cool of the night. The samples had the offshoots in 13–15 cm long. About 5–6 cm of youngest fully expanded branch tips were selected to be used in all the experimentation. These fresh samples were first washed and subjected to analyses for their characterization.

**Fig. 1.** A whole plant of *Salicornia bigelovii* from Aq-Qalla Salinity Research Station

- **Proximate analyses**
  All the experiments for analyses were conducted in triplicate order.

- **Moisture content**
  The moisture content was determined by drying the sample in an oven at 105± 5°C for about three hours until a constant weight was obtained (AOAC, 2005a). It was then calculated using Equation 1.
  \[ \text{Moisture content} = \left( \frac{M_2 - M_1}{M_0} \right) \times 100 \]  
  Where:
  - \( M_0 = \) sample mass inside the plate (g)
  - \( M_1 = \) mass of plate and sample (g)
  - \( M_2 = \) mass of plate and sample after incubation (oven) and mass stabilization (g)

- **Total soluble solids (TSS)**
  The total soluble solids (TSS) were measured by a refractometer (Atago model, Japan). In this test, the device was first calibrated using distilled water (set to zero). A few drops of *Salicornia* leaves solution (20 g of salicornia leaves with 40 ml of distilled water, mixed in a blender and then filtered) was placed on the charter of the refractometer at 20°C. Then, the TSS content was expressed as a percentage (AOAC, 2005a).

- **pH**
  The pH of the samples was determined with a pH meter (Metrohm- model 691, Switzerland), and the value was recorded (Maftoonazad et al., 2008).

- **Titratable acidity**
  Titratable acidity was calculated using Equation 2 (AOAC, 2005a). In order to calculate the titratable acidity in each product, the dominant acid of the product should be known that showed the equivalent factor (E) in Equation 2. Equivalent factor for a number of organic acids such as malic, citric, tartaric, oxalic, acetic, and lactic are 67, 70, 75, 45, 60, and 90, respectively (Toivonen, 2016). Patel (2016), in the evaluation of *Salicornia* as a food and medicine, pointed to the presence of oxalate. Therefore, oxalic acid was considered the dominant acid when the acidity of *Salicornia* was calculated.
  \[ \text{Acid} \% = \left( \frac{N \times E \times V}{100} \right) / \text{grams of sample} \]  
  Where:
  - \( N = \) Normality of NaOH (0.1 N)
  - \( E = \) Equivalent factor of the dominant acid
  - \( V = \) mls NaOH used

- **Ascorbic acid content**
  Ascorbic acid was determined by the indophenol titration method (AOAC, 2005b). 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. Finally, the ascorbic acid content was calculated using Equation 3.

\[
\text{Ascorbic acid} = \frac{(V_0 - V_1) \times m_1}{m_0} \times 100
\]  

Where:
- $V_0$ = The volume of colored solution used for sample titration (ml)
- $V_1$ = The volume of colored solution used in the control test (ml)
- $M_0$ = Sample mass used in the titration test (g)
- $M_1$ = The mass of ascorbic acid which is equivalent to one milliliter of colored solution (mg)

- Salinity content
The salinity content was measured by an electrical conductivity meter (Jenway model 4510, UK). In order to carry out this, 20 grams of *Salicornia* leaves were mixed with 40 milliliters of water and then filtered. The salinity content of the filtered samples was reported in dS/m.

- Respiration rate
*Salicornia* leaves with known weights were placed in an airtight plastic container (10 × 20 × 20 cm$^3$) to measure their respiration rate using a CO$_2$-sensitive sensor (Testo AG-435-2, Germany). The CO$_2$ sensor of the instrument was placed inside the container to measure the CO$_2$ concentration. The device was programmed to measure the concentration of CO$_2$ for each sample at 1 minute intervals for 30 minutes. The respiration rate was calculated based on the regression slope of CO$_2$ concentration versus time and reported in mgCO$_2$/Kg.hr (Sahraei Khosh Gardesh et al., 2016).

- Texture analysis
The resistance of the *Salicornia* plant to the sheared force (i.e. firmness) was measured using an Instron Universal Testing Machine (Hounsfield, H5KS model, UK) with the following requirements:
- Shear blade specifications: length: 87.88 mm, width: 69.85 mm, thickness: 3.16 mm
- Load cell= 500 N
- Test speed= 5 mm/min
- End point= 2.5 mm
A test was replicated five times. The maximum force ($F_{max}$) and the displacement were obtained from force-deformation curves and the results were expressed in Newton and millimeter, respectively (Konopacka and Plocharski, 2004).

- Color measurement
The L* (lightness), a* (green–red) and b* (blue–yellowness) color indices were measured numerically for *Salicornia* leaves using a portable colorimeter (Konica Minolta, CR-400 model, Japan). The instrument was first standardized using a white ceramic plate (Lu et al., 2010). Samples test was replicated three times.

- Statistical analysis
The average and standard deviation values were calculated for three replicates (five for texture analysis) of all variables by excel software.

Results and Discussion
Some of the physicochemical properties of *Salicornia bigelovii* including moisture content, total soluble solids, pH, titratable acidity, Ascorbic acid, salinity content, respiration rate, maximum force and displacement, and color (L*, a*, b*) were measured in this study. The results of the above variables are shown in Table 1.
Table 1. Some of the physicochemical properties of *Salicornia bigelovii*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>89.67 ± 0.01</td>
</tr>
<tr>
<td>Total soluble solids (%)</td>
<td>15.83 ± 0.15</td>
</tr>
<tr>
<td>pH</td>
<td>6.11 ± 0.00</td>
</tr>
<tr>
<td>Titratable acidity (%)</td>
<td>0.05 ± 0.01</td>
</tr>
<tr>
<td>Ascorbic acid (%)</td>
<td>-0.025 ± 0.00</td>
</tr>
<tr>
<td>Salinity (ds/m)</td>
<td>56 ± 0.17</td>
</tr>
<tr>
<td>Respiration rate (mgCO₂/Kg.hr)</td>
<td>26.80 ± 10.09</td>
</tr>
<tr>
<td>Maximum force (N)</td>
<td>1.4 ± 0.20</td>
</tr>
<tr>
<td>Displacement (mm)</td>
<td>1.47 ± 0.27</td>
</tr>
<tr>
<td>L*</td>
<td>23.69 ± 0.85</td>
</tr>
<tr>
<td>Color a*</td>
<td>-6.77 ± 0.41</td>
</tr>
<tr>
<td>Color b*</td>
<td>15.73 ± 0.09</td>
</tr>
</tbody>
</table>

- Biochemical compositions

Several physiological variables are associated to the quality of leafy vegetables. According to Table 1, the results of the composition analyses of *Salicornia bigelovii* grown in north of Iran (Aq-Qalla Salinity Research Station) shows a considerable characteristics as a leafy green vegetable. These results are in good agreement with the results of Lu et al. (2010) for some nutritional analyses of *S. bigelovii*. They reported that it contains high vitamins and minerals, which made it an ideal nutritional and diet supplement. Therefore, the detailed results are discussed below point by point.

- Moisture content

The Moisture content of *Salicornia bigelovii* was reported 88.42% ± 1.36 by Lu et al. (2010) and it was 89.67% ± 0.01 in this study. In addition, the moisture content of the leaf, stem, and root of *Salicornia herbacea* is respectively reported as 90.9, 73.9, and 66.2% by Rhee et al. (2009). In general, the moisture content determines the crispness and juiciness of the leaves (Kader and Barrett, 2004).

- Total soluble solids

The total soluble solids (TSS) of *Salicornia bigelovii* was measured about 15.83%. Since the TSS content is directly correlated with the preservation of a pleasant taste over time (Varoquaux et al., 1996; Martinez, 2010 as cited in Vargas-Arcila et al., 2017), this high quality attribute in *Salicornia bigelovii* might be contributed to good taste preservation.

- pH and titratable acidity

The pH and the titratable acidity of *Salicornia bigelovii* plant was obtained 6.11 and 0.05%, respectively. It is worth to note that vegetable taste depends on the content and combination of sugars, organic acids, etc (Vargas-Arcila et al., 2017).

- Ascorbic acid content

Biochemical compositions of the *S. bigelovii* tissue showed 0.025% ± 0.0 for the ascorbic acid that is a little lower than what Lu et al. (2010) found (i.e. 58.4 ±1.39 mg/100g fresh weight). Incidentally, the negative sign for ascorbic acid in Table 1 indicates that ascorbic acid of *Salicornia* is less than the standard solution in the test. Although ascorbic acid presents in low concentrations, the nutritional quality of the product might be regarded quite standard as it is consumed fresh (Acamovic-Djokovic et al., 2011).

- Salinity content

As cited in Grattan et al. (2008) work and Weeks (1986), it has been reported that the amount of salt for optimal growth of *Salicornia bigelovii* Torr. is about 170-200 mol/m³ with an electrical conductivity of 15-17 ds/m. The salinity of *Salicornia europaea* L. (syn. *S. herbacea* L.) is stated over than 56 ds/m by Al-Oudat and Qadir (2011). In addition, the amount of salt is reported 3.3% for *Salicornia herbacea* by Rhee et al. (2009). However, the salinity content of *Salicornia bigelovii* plant obtained 56 ds/m in this study. High salinity content in this plant may be used as an additive in some products as a substitute for common salt.
Respiration rate

The initial respiration rate of *S. bigelovii* was about 26.80mgCO$_2$/Kg.hr. In the classification of vegetables and fruits based on their relative respiration rate, they are divided into six categories: very low (less than 5), low (5-10), medium (11-20), high (21-40), very high (41-60) and extremely high (more than 60) at 5$^\circ$C. Leafy vegetables such as spinach and parsley with 45 and 60 mgCO$_2$/kg.hr respiration rate respectively is placed in the very high category (Mangaraj and Goswami, 2009; Gross et al., 2016). Since respiration rate of *Salicornia bigelovii* was measured about 26.80mgCO$_2$/Kg.hr, it is placed in the category with a high respiration rate. The higher respiration rate results in the less durability and shelf life. In fact, the two main goals of post-harvest technologies for fruits and vegetables are to preserve their quality in the production chain. In general, respiration is one of the most important metabolic activities of plants that breaks complex molecules such as starches, sugars and organic acids in cells and converts them into simple molecules such as H$_2$O, CO$_2$, and energy (Sharon and Martha, 2010). Upon completion of these resources, the product enters the senescence stage. Therefore, respiratory rate determines the amount of using organic matter, as a result, the shelf life of the product.

Texture analysis

From the force-displacement curve in the shear test for shearing the leaves of *Salicornia bigelovii*, the maximum force was obtained 1.4 N ± 0.20 at a displacement of 1.47mm ± 0.27. It should be noted that postharvest changes in texture of *S. bigelovii* strongly require basic information like the obtained results for many of the future applications.

Color analysis

In addition, the general color scores (mean ± S.D. for three replicates) for *S. bigelovii* as a leafy green vegetable in terms of L*, a*, and b* values were obtained 23.69 ± 0.85, -6.77 ± 0.41, 15.73 ± 0.09, respectively as is presented in Table 1. In general, variations in the color of the leaves is mainly resulting from chlorophyll degradation (Vargas-Arcila et al., 2017). Therefore, the color information of the *S. bigelovii* may help to its better applications such as packaging, storage, etc.

Conclusion

*S. bigelovii* is one of the most promising halophytes and is likely to provide human foods supplement. It was perishable with a shelf life of only about 6 days at ambient temperature (25$^\circ$C). Thus, knowing its characteristics could be a very useful and practical information in deciding how to increase the shelf life or processing of *Salicornia* as an edible vegetable. Therefore, the current results are potential beneficiaries for *Salicornia* growers, horticultural specialists, consumers and all actors of the production-distribution-sales chain of *Salicornia*.

References


