Chapter 31
Use of Marginal Water for *Salicornia bigelovii* Torr. Planting in the United Arab Emirates

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Abstract Freshwater resources are not enough to meet the ever increasing demand of the agriculture sector to feed the growing population. Owing to this reason, agriculture scientists are exploring different ways to use saline water as an alternative source for crops. Samphire (*Salicornia bigelovii* Torr.) is one of the best candidates for such plants that can be grown using seawater. It has high culinary value and can be consumed either cooked or raw. The plant can also be used as feed for different domestic animals. Since its seed contains high-quality unsaturated oil (30%) and proteins (40%), it can be used to make biodiesel and as animal feed. At the Dubai-based International Center for Biosaline Agriculture (ICBA), a field experiment was conducted using five different lines of *Salicornia bigelovii* irrigated with seawater. In general, all of the Salicornia lines grew well and gave good results. To evaluate their performance, data were recorded on 50 individual plants from each line at maturity. Data on 12 different morphological characteristics of spikes and plants were collected. The range for plant height varies from 49.2 to 63.0 cm. Minimum of 65.8 g and maximum of 91.8 g plant dry weight were recorded. The lowest seed weight per plant was 6.39 g, and the highest was 9.17 g. The results indicate that highly valuable Salicornia can be grown successfully in arid regions using seawater for irrigation.

Keywords Arid region • Biodiesel • *Salicornia bigelovii* • Samphire • Seawater

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31.1 Introduction

Salicornia is a genus of tender halophytes with compressed succulent leaves that may be transformed into jointed, photosynthetic shoots (de Fraine 1912). It is a widespread genus which is found in all the continents except Antarctica (Shepherd et al. 2005). The genus belongs to subfamily Salicornioideae and family Chenopodiaceae (Short and Colmer, 1999). Salicornioideae contains some of the most salt-tolerant terrestrial plants that thrive well in salt marshlands, coastal areas, and among mangroves of different types (Wilson 1980; Davy et al. 2001). One of its species, *Salicornia bigelovii* can even be grown in hypersaline drainage water (Grattan et al. 2008).

The United Arab Emirates (UAE) which lies between 22°30′ and 26°10′ north latitude and between 51° and 56°25′ east longitude is located southeast of Arabian Peninsula with an area of 83,600 km^2. The UAE has two coastlines; on the Arabian Gulf, it has 650-km long shoreline, while on the Gulf of Oman, its coast length is about 100 km. Most of the country is comprised of desert with sand dunes, gullies, and oases. South and west of the country have deserts that are part of a vast sandy desert called Rub' al Khali or Empty Quarter. In the north, Al Hajar Mountains elevate at some places to more than 2,000 m. The UAE, where the soils usually are poor in nutrients, have four main landforms: sand, salt flat, gravel, and mountains. The line of the Tropic of Cancer passes across the UAE, making the weather in the UAE hot and sunny. During winter, the average daytime temperature in Dubai is 25°C. In the coastal areas, humidity is between 80 and 85% (Table 31.1). While throughout summer, the weather in Dubai is very hot and humid, with temperatures reaching up to 40°C, even the sea temperature can go up to 37°C, with humidity averaging more than 59% (Table 31.1) which may occasionally reach 90%. The rainfall in Dubai is intermittent and low and mostly occurs during winter (Table 31.1) in the form of showers and sometimes as thunderstorm.

Salicornia bigelovii Torr. is an annual halophyte, with erect, succulent, photosynthetic stem (Fig. 31.1a), which grows in coastal estuaries (Rodriguez-Medina et al. 1998) and salt flats (Rueda-Puente et al. 2007) of Mexico's northwestern states of Baja California and Sonora. Many scientists consider it to be the most salt-tolerant vascular plant in the world (Ayala and O'Leary 1995). *S. bigelovii* which is commonly known as samphire is used in salads and appetizer platters as a pickled sea vegetable. Raw samphire, with its sea savor, is ideal as side dish with seafood and fish. The foliage of the halophyte can also be used as an alternative to fodder crops such as alfalfa (Abdal 2009) and Rhodes grass (Glenn et al. 1991) for livestock like sheep and goats.

Salicornia bigelovii Torr. has immense potential to be used as an oilseed crop in the coastal areas of deserts and wastelands, using seawater for irrigation (Glenn et al. 1991). It has been evaluated as an oilseed crop in the desert coastline of Mexico (Troyo-Dieguez et al. 1994). The sandy regions that line Indian Ocean, Gulf of California, Red Sea, and Arabian Gulf can be used to cultivate this halophyte as an oilseed crop (Glenn et al. 1998). Its seed has high contents of oil (30%) and lower

Table 31.1 Mean monthly temperatures, precipitation, and relative humidity in Dubai, UAE

	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Temperature Mean value	°C	18.7	19.3	22.3	26.1	29.9	32.2	34.4	34.4	32.1	28.7	24.3	20.6	26.92
High temperature Mean daily value	°C	24.0	24.6	27.9	32.4	36.8	38.8	40.6	40.4	38.7	35.1	30.5	26.2	33.00
Low temperature Mean daily value	°C	13.7	14.5	17.0	20.1	23.5	26.1	28.9	29.3	26.3	22.7	18.3	15.4	21.32
Relative humidity Mean value	%	65.0	65.0	63.0	55.0	53.0	58.0	56.0	57.0	60.0	60.0	61.0	64.0	59.75
Relative humidity Mean daily maximum value	%	83.0	85.0	84.0	79.0	76.0	82.0	79.0	78.0	84.0	84.0	82.0	84.0	81.67
Relative humidity Mean daily minimum value	%	44.0	43.0	40.0	32.0	29.0	32.0	32.0	34.0	31.0	34.0	38.0	44.0	36.08
Precipitation Mean monthly value	mm	11.3	35.7	22.4	7.6	0.7	0.0	0.0	0.0	0.0	0.0	1.8	14.3	7.82

Fig. 31.1 Young *Salicornia bigelovii* plant (**a**), *Salicornia bigelovii* experimental plot at ICBA (**b**), at flowering (**c**) spikes near maturity (**d**), and *Salicornia bigelovii* seeds (**e**)

concentration of salt (less than 3%), which makes it the most promising oilseed halophyte crop for the future (Glenn et al. 1998). Its oil is considered to be of good quality that contains high amount of linoleic acid (75%), an unsaturated fatty acid essential for human diet, and linolenic acid (2%), an omega-3 fatty acid, which helps fight coronary heart disease (Anwar et al. 2002; Covington 2004). Its meal contains high contents of protein (42–45%) which can be used as an animal feed

(Glenn et al. 1991). Keeping its importance in view, *Salicornia bigelovii* Torr. breeding program has been started in Eritrea and the United States of America for its improvement (Zerai et al. 2010). The Salicornia oil can also be converted into biodiesel. According to one report, Salicornia planted in one hectare of land can produce 225–250 gallons of biodiesel (unpublished data).

The BEHAR (Arabian Saline Water Technology Company Limited) of Saudi Arabia had been working on different halophyte plant species and developed many *Salicornia bigelovii* Torr. lines for vegetable, fodder, and oilseed purposes. They sent seed of some promising Salicornia lines to ICBA to assess their performance in the United Arab Emirates.

31.2 Materials and Methods

The experiment was conducted at the facilities of ICBA (Fig. 31.1b), Dubai, United Arab Emirates, about 23 km from the Arabian Gulf. Details of flowering and spikes at maturity can be seen in Fig. 31.1c, d, respectively. Overall view of matured Salicornia seeds is shown in Fig. 31.1e.

The soils at ICBA experimental fields are sandy in texture, that is, fine sand (sand 98%, silt 1%, and clay 1%), calcareous (50–60% $CaCO_3$ equivalents), porous (45% porosity), and moderately alkaline (pH 8.22). The saturation percentage of the soil is 26 and has very high drainage capacity, while electrical conductivity of its saturated extract (ECe) is 1.2 dS m^{-1}. According to American Soil Taxonomy (Soil Survey Staff 2010), the soil is classified as Typic Torripsamments, carbonatic, and hyperthermic (Shahid et al. 2009).

The sands at ICBA represent the soils of different regions of the UAE, especially some sandy areas close to the seashore. These sandy soils near the coasts are considered to be the most suitable for halophytes including Salicornia farming, using seawater as sole source of irrigation. Keeping these similarities in view, the Salicornia experiment was carried out at ICBA which may provide a guideline for future Salicornia production in the UAE.

The Saudi company of BEHAR provided ICBA with the seed of five prominent lines of *Salicornia bigelovii* Torr. developed by them. The lines were G8/28, SH, LP, K plant, and R12.

Before the sowing, compost was applied at the rate of 40 tonnes per hectare (t ha^{-1}) in the area selected for experiment. The seed of each experimental line was planted in two-row plot of 4-m length with row to row distance of 50 cm. The seed rate was 2 g per plot. The seed was hand-planted in the first week of November 2002 into furrows in sand that had earlier been irrigated with seawater from Arabian Gulf (Table 31.2) and was covered lightly. Irrigation with seawater (41 dS m^{-1}) was started immediately after sowing and continued throughout the crop duration. Irrigation was scheduled to maintain wet soil surface condition during germination and early growth and adjusted later according to crop growth and temperatures to maintain moist soil condition but avoid water logging or wilting of plants. Beginning

Table 31.2 Arabian Gulf water analysis

Units	mg L^{-1}	meq L^{-1}	RSC (meq L^{-1})	SAR (mmoles L^{-1})$^{0.5}$
Cations				
Sodium (Na^{+})	13,044	567	–	65
Magnesium (Mg^{+2})	1,500	125		
Calcium (Ca^{+2})	520	26		
Anions				
Chloride (Cl^{-1})	23,000	648		
Sulfate (SO_4^{-2})	3,100	65		
Bicarbonate (HCO_3^{-1})	171	3		
Carbonate (CO_3^{-2})	24	1		
EC	41 dS m^{-1}			
pH	8.2			
Specific gravity	1.031 g cm^{-3}			

approximately 6 weeks after sowing, plant stands were adjusted to 100 plants per row by thinning and transplanting into gaps.

After 30 days of sowing, daily application of urea at the rate of 0.3 g m^{-1} of row and compound fertilizer at the rate of 0.1 g m^{-1} of row was started. The fertilizer was dissolved in water and applied using watering can for uniform application.

In the middle of June 2003, different morphological characteristics like plant height, plant dry weight, plant biomass, distance between first spike and plant base, number of branches per plant, number of spikes per plant, spike length, spike weight, number of seeds per spike, number of seeds in one gram, seed weight per plant, and seed-to-plant weight ratio were recorded. Both for plant and spike traits, 50 samples from each plot were studied. For dry weight of plants, the samples were dried in oven at 80°C for 48 h.

The data were analyzed using standard statistical methods to ascertain the significant differences among the Salicornia lines for the 12 different morphological characteristics.

31.3 Results and Discussion

Table 31.3 illustrates data of different plant parameters. Data show (Table 31.3) that Salicornia line R12 is the tallest (63.0 cm) followed by LP (59.8 cm), while SH is the shortest (49.2 cm). In case of plant dry weight, R12 again is on the top with 91.8 g of weight, and second in line is LP whose dry weight is 81.0 g, while LP with 65.8 g has the least biomass. For both of the above-mentioned characters, a sizeable variation exists among the five Salicornia lines. Though LP is second in height (59.8 cm), its dry weight and biomass is the least among the five Salicornia lines observed, indicating that plant height is not related to either plant dry weight or biomass. On the other hand, data reveal that there is a direct correlation between

Table 31.3 Twelve different morphological characteristics of five lines of *Salicornia bigelovii* studied in field at ICBA during 2002–2003

	Lines				
	G8/28	SH	LP	K plant	R12
Characteristics	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Plant height (cm)	58.3 ± 0.6	49.2 ± 0.57	59.8 ± 0.57	58.6 ± 0.58	63.0 ± 0.64
Plant dry weight (g)	80.0 ± 0.27	74.1 ± 0.26	65.8 ± 0.26	81.0 ± 0.29	91.8 ± 0.29
Plant biomass ($g\ m^{-2}$)	4001 ± 178	3704 ± 169	3290 ± 169	4048 ± 173	4588 ± 192
1st spike height (cm)	11.2 ± 3.56	10.3 ± 3.43	11.6 ± 3.39	11.4 ± 3.43	11.0 ± 3.84
No. of branches per plant	16.5 ± 0.19	15.9 ± 0.18	15.7 ± 0.18	16.3 ± 0.18	17.1 ± 0.20
No. of spikes per plant	151.9 ± 7.2	146.6 ± 6.9	70.0 ± 6.8	131.8 ± 7.0	147.3 ± 7.7
Spike length (cm)	6.9 ± 1.16	6.8 ± 1.05	8.1 ± 1.27	7.8 ± 1.17	7.9 ± 1.16
Spike weight (g)	0.32 ± 0.01	0.34 ± 0.01	0.51 ± 0.01	0.39 ± 0.01	0.39 ± 0.01
No. of seeds per spike	59.52 ± 1.38	54.74 ± 1.33	61.91 ± 1.13	57.23 ± 1.34	53.93 ± 1.49
No. of seeds per gram	942.7 ± 22.2	904.3 ± 22.2	778.3 ± 21.1	795.6 ± 21.6	830.2 ± 23.9
Seed weight per plant (g)	8.46 ± 0.40	9.33 ± 0.39	6.39 ± 0.38	8.67 ± 0.39	9.17 ± 0.44
Seed-to-plant weight (%)	11.55 ± 0.57	12.97 ± 0.57	10.26 ± 0.54	10.85 ± 0.55	10.19 ± 0.61

plant dry weight and plant biomass. The more a plant has dry weight, the higher will be its biomass. The larger biomass yield of some of the lines, especially R12, points out their suitability to be grown as fodder for livestock and vegetable for human consumption in the UAE. Though the UAE produces different types of fodder crops (Rhodes grass, alfalfa), it is not enough for its livestock. Currently, Rhodes grass has been banned in Abu Dhabi emirate to save precious groundwater resources.

The country depends heavily on the imported fodder, which for its cost restricts further increase in animal production. The UAE coastal areas comprised of salt flats (Shahid et al. 2004; Abdelfattah and Shahid 2007), while the inland region is mostly desert (Melamid 1997; Shahid 2007; Shahid and Abdelfattah 2008). Here, the salt flats (coastal and inland sabkha) contain 30% or more of salts. To reduce the salt contents in the soil, the salt flats have to be flooded with seawater and water collected in evaporation ponds for salt harvesting. After the reduction in salt contents, the soil can be used to propagate Salicornia, which is again highly unlikely to happen in salt-rich sabkha of the UAE, due to water table usually within 1–2 m from soil surface, and near-surface groundwater EC is more than 250 dS m^{-1}. Salicornia cultivation is only possible in the coastal area of the UAE where sand is accumulated to more than 2 m depth, and these areas have the potential for Salicornia cultivation using seawater. These soils are similar to sandy soils at ICBA where present study was conducted. Such areas have been delineated by Shahid et al. (2004). Planting of Salicornia and other halophytes in the coastal areas rather than inner regions reduces the cost of seawater transportation. In different experiments, Salicornia has successfully been grown as fodder in the coastal regions of Mexico (Glenn et al 1997) and Kuwait (Abdal 2009).

As the results demonstrate, biomass yield of the studied *Salicornia bigelovii* genotypes ranges from 3.3 kg m^{-2} (LP) to 4.6 kg m^{-2} in R12 (Table 31.3), which is higher than the experiments conducted in Mexico where the average yield was 1.7 kg m^{-2} (Glenn et al. 1998). Perhaps this difference is due to Salicornia being grown in coastal area than in clean sandy soil (Abdal 2009). For this trait, R12 is on the top, whereas LP is at the bottom. The outcome of the study is encouraging for *Salicornia bigelovii* planting in the UAE and similar other regions, where seawater is available and freshwater is scarce, to feed the livestock.

The mature *Salicornia bigelovii* plants irrigated with seawater contain 30–40% salt. The salt contents need to be reduced before being used as a feed. To achieve that purpose, it can either be mixed with other available fodders like Rhodes grass or soaked with seawater for some time that reduces the salt contents to a considerable level (Glenn et al. 1992).

The main objective of the experiment was to investigate the potential of the Salicornia genotypes as an oilseed crop. For this reason, nine different morphological characteristics related to seed production were studied in detail. These characteristics are first-spike distance from the plant base, number of branches per plant, number of spikes per plant, spike length, spike weight, number of seeds per spike, number of seed per gram seed weight per plant, and seed-to-plant weight ratio.

First-spike distance from the plant base has an important role in harvesting of Salicornia seed, as the plucking of the higher spikes will be easier than the lower ones. For this character, LP has a slight edge over the other lines (Table 31.3). Its spike is 11.6 cm above ground while the others have a range of 10.3–11.2 cm. The results show that there is relatively small variation among the lines for this trait; however, further investigation is required for statistical assessment.

For the number of branches per plant, small difference was found among the Salicornia lines (Table 31.3). The line R12 has the highest number of branches (17.1), while by means of 15.7, LP has the lowest number for the trait. For this characteristic, genetic variability among the lines is minute, but this is not the case with number of spikes per plant. A considerable variation exists between the lines for this trait (Table 31.3). With 151.9, G8/28 has produced more spikes than the other four genotypes, whereas with the lowest number of spike (70.0 spikes), LP was at the bottom. The difference between the two lines is more than two times for this plant character.

The length of a spike indicates the number of seeds it contains. The longer the length of a spike, the more seeds it encloses. Likewise, spike weight also correlates with seed production. Among the five Salicornia lines studied, LP shows the longest spike with 8.1 cm in length, while SH that has 6.8-cm long spike is the shortest (Table 31.3). The difference between the two lines for this characteristic is 16%. For spike weight, LP also has the heaviest spike (0.51 g); on the other hand, G8/28 produced the lightest spike of 0.32 g (Table 31.3). The variation between the two genotypes for this trait is more than 37% which is quite higher. As far as number of seeds per spike is concerned, the genotype LP has the maximum number of seeds (61.9) while the lowest seed number per spike was recorded in SH (54.7). For this character, the variation between the two Salicornia lines is around 12%. The line LP has given the best performance for all the three spike traits which play very important role in seed yield of a Salicornia plant. But for number of spikes per plant, it was the lowermost. In a Salicornia breeding program, the line can be incorporated for its three excellent spike traits to evolve improved varieties.

The number of seeds per gram points out the size of the seed. For this seed character, G8/28 and SH produced 947 and 904 seeds per gram, respectively, indicating that their seed is smaller in size. While LP has the largest seed among the Salicornia lines as it has 778 seeds per gram, that is more than 20% larger than G8/28. The results show that a sizeable variation is present for the seed size in the Salicornia lines (Table 31.3). For seed size, LP again has outperformed other lines. Large seed for an oilseed crops is a desirable character which is correlated with high oil and protein meal production compared to the smaller ones. For this superior seed trait, LP can be involved in Salicornia improvement projects to introduce cultivars with good oil yield.

Seed weight per plant is the most important character that defines the yield potential of a genotype. This character displays considerable differences among the five Salicornia lines (Table 31.3). The line SH with 9.33 g of seed gave the highest yield per plant, whereas the lowest yield was observed in LP (6.39 g). The difference between the two lines for this trait is more than 31%. The performance of line LP is the worst for this character, but for other traits like spike length, spike weight, number of seed per spike, and seed weight, it gave the best results. Its lowest yield for seed per plant seems to be due to its lower number of spikes per plant which were less than half of the top performer (SH).

For seed-to-plant weight ratio, SH has the highest percentage of 12.97; on the other hand, LP scores the lowest percentage of 10.26 for the character (Table 31.3). The difference between the two genotypes for this trait is around 21%, indicating the presence of large genetic variability. The data display that all the five Salicornia lines, especially SH, have the good yield potential of seed production in the UAE.

As a whole, all the five Salicornia lines have performed well for both biomass and seed production. But the line SH has shown the best results for seed production and other related traits in the experiment. It seems to have good potential to be grown as an oilseed cultivar in the desert. While for biomass, R12 has given the best performance. Therefore, this line can be selected both for vegetable and fodder purposes in the UAE and other similar countries.

The seed yield of the studied Salicornia lines at ICBA is very high. At the rate of 20,000 plants per hectare, SH may give the yield of 18.66 t ha^{-1} followed by R12 with 18.34 t ha^{-1}. This seed yield is much higher than in Eritrea where an experimental farm produced Salicornia seed at the rate of 2 t ha^{-1} and Mexico where seed yield was 5 t ha^{-1} (unpublished data). The significant differences in Salicornia seed yield are believed to be due to the scale of experimental fields and locations, where small plots can be well managed and looked after compared to large fields. In Eritrea, the field size was 80 ha and it was close to the coastal area, whereas in Mexico, the Salicornia planting was done in 400-ha field and the plantation was also near the coast. In the case of ICBA, the experiment was conducted in sandy soils with compost supplement, and plot size for each line was 4 m^2 which is easy to look after and maintain.

In the coastal desert region of Sonora, Mexico, work has been started on 5,000-ha area to cultivate Salicornia for biodiesel production, protein meal, and fodder using seawater for irrigation. The objective was to encourage the use of nonconventional source of irrigation to save the precious freshwater. The work has shown that net profit from Salicornia oil is higher than corn ethanol and soybean oil which are being used to make biofuel. The Salicornia crop needs less fertilizer and pesticides, making it environmentally friendly.

The Masdar Institute of Science and Technology, UAE, with the backing of Boeing, Etihad Airways, and UOP Honeywell is working on a plan to grow Salicornia in Abu Dhabi to produce biofuel for aeronautics industry. For the project, only seawater will be used for irrigation to produce Salicornia seed oil. The purpose of the project is to decrease the use of fossilized oil which emits greenhouse gases that lead to climate change. The production of Salicornia seed oil at a reasonable price will decrease dependency on conventional energy sources, paving way to cleaner environment. ICBA is cooperating with Masdar in Salicornia project.

Since the soils at ICBA are porous with high drainage capacity, it does not tend to build salts when irrigated with salty water. At the center, there is good drainage system which helps in leaching salts. Soils irrigated with seawater for a cropping season reveals that there is about 5% decline in pH, that is, from 8.22 to 7.79, due to salt accretion at a depth of 50 cm (root zone of *Salicornia bigelovii*). But the salt concentration can be decreased by flushing soils with seawater (Duncan et al. 2000). Brine water farming has some problems, but it has many benefits. Arid coastal sandy desert farms have natural drainage system. Even after 10 years of seawater irrigation in the shoreline Salicornia farms, salts did not accumulate in the soils to harm plant growth (Glenn et al. 1998). The areas close to coast may be ideal for Salicornia cultivation as salts accretion due to brine water irrigation will be lower.

31.4 Conclusions

The preliminary research at ICBA demonstrated that Salicornia has the potential to be grown as oilseed, fodder, or vegetable crop in the UAE. As the results show, sandy soil and seawater do not curtail the growth of Salicornia plant. On the sandy areas close to shorelines, availability of seawater ensures the smooth farming of the crop. The country has more than 750-km long coastline, which can partially accommodate its cultivation at a large scale, where sandy soils such as Torripsamments are available. This will help in reducing the country's dependence on imported fodder, which costs foreign exchange.

Farming of Salicornia as an oilseed crop in the UAE not only boosts the edible oil production, but it will also help in establishing the biofuel industry. Use of biofuel instead of fossil fuel will lead to a better environment as it emits less particulates, carbon monoxide, and hydrocarbons which are injurious to health. After extraction of oil from Salicornia seed, its byproduct meal which contains more than 40% protein can be used as feed for poultry and fish farming. This will ultimately help in increase of meat production in the UAE.

Salicornia is a promising crop for the farmers of the UAE and other similar countries that live in desolate and saline region, providing precious oil and nutritious fodder where little else could endure. Extensive cultivation of Salicornia will not only provide different agriculture products, but it also assists in reducing global warming by sequestering the atmosphere carbon.

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