11 From Desert Farm to Fork

Value Chain Development for Innovative Salicornia-Based Food Products in the United Arab Emirates

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CONTENTS

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11.1 INTRODUCTION

Climate change projections show an increase in average temperature by 1.1–5.4°C, a decrease in precipitation of more than 20%, and an increased incidence of prolonged droughts on a global scale (IPCC 2013). These are bad omens for agricultural production and farmers' livelihoods in hot and dry areas. On top of that, aggravating stresses such as heat, drought, and salinity worsen the situation even more. There is an urgent need to adapt agriculture to the adverse impacts of climate change especially in areas with existing environmental constraints. Conventional farming should be reassessed in salt-affected areas and the utilization of the available saline land and water resources should be explored for the implementation of biosaline agricultural systems. In desert environments, saline water resources must be desalinated in order to sustain agricultural production. However, the reject brine, a dense saline concentrate produced throughout the desalination process when disposed of in the environment, may have detrimental impacts on its attributes (Morillo et al. 2014; Giwa et al. 2017). At the world scale, inland and coastal desalination plants produce 141.5 million m^3/day of brine; most of this quantity (70.3% or 100 million m^3/day) comes from the Middle East and North African regions (Jones et al. 2019). The safe disposal of the brine remains a key environmental issue since it has more inorganic salts than brackish water and can contaminate groundwater resources when disposed of inland (Jones et al. 2019). Interesting solutions on brine management have been proposed adding economic value to its use by growing salt-tolerant plants and marine species such as fish and algae that can tolerate saline and hypersaline conditions following the integrated production systems approach (Crespi and Lovatelli 2010; Morillo et al. 2014; Sanchez et al. 2015; Giwa et al. 2017; Jones et al. 2019). This integrated farming model constitutes an effective management strategy that ensures efficient disposal and reuse of the reject brine to produce food, forage, and other valuable products. Such multi-component farming schemes can minimize external inputs, thereby decreasing the ecological footprint and promote biodiversity through growing a variety of crops, while producing high crop yields. The resource-saving practices of such schemes, allow the by-product of one system to become the input for another. These systems minimize the adverse effects of intensive farming and maximize the use of the available water resources through recycling. These combined farming systems could enhance food, nutrition, and livelihood security especially in hot and dry regions.

11.2 LANDSCAPE ANALYSIS OF INTERNATIONAL PROJECTS ON BIOSALINE AGRICULTURE

There have been various successful biosaline farming projects launched around the world. For example, the SalFar project is implemented in the North Sea Region and focuses on bringing into production degraded lands due to salinization (https://northsearegion.eu/salfar/). The main cause for increased salinization in the area is the continuous rise in sea levels which further aggravates seawater intrusion into inland farming zones affecting agricultural productivity. Without taking the appropriate measures to counteract the increasing salinity, this will lead to significant production losses, and severe damage will be caused to the local coastal economies.

The project is applying innovative methods of biosaline agriculture across selected coastal areas in the North Sea Region. It is a multidisciplinary project encompassing various disciplines such as agronomists, climate experts, farmers, entrepreneurs, chefs, etc. Apart from demonstrating alternative methods of farming under saline conditions, the project is also focusing on creating new value chains and business opportunities for local coastal communities using local salt-tolerant vegetation.

Coastal desert areas are barren lands that can be used for unconventional farming using seawater for halophytes (salt-loving plants) irrigation. The Seawater Energy and Agriculture System (SEAS) that was developed by the Masdar Institute in Abu Dhabi in the United Arab Emirates (UAE) (https://www.ku.ac.ae/the-seawater-energy-and-agriculture-system-seas-gets-an-upgrade) has been targeting coastal zones in hot and dry areas. SEAS combined an integrated system of aquaculture, halo-agriculture, and mangrove silviculture to produce sustainable biofuels for aviation and other by-products such as seafood. Based on the system's operation, seawater is pumped to supply shrimp and fish ponds and the water from the aquaculture then flows to the halophytes section.

Regarding inland desalination and the use of the reject brine for integrated farming, there has been a national program in Brazil, the so-called "Aqua Doce" program, that implemented the Integrated Agri-Aquaculture System (IAAS) approach using the reject brine from desalination for marine species farming and the aquaculture effluents were utilized for the irrigation of halophyte forage shrubs such as *Atriplex* spp. (Sanchez et al. 2015). The program launched in 2004 and has benefitted more than 150,000 inhabitants of the semi-arid region in the north-east part of Brazil. Several small-size reverse osmosis (RO) desalination plants were built to serve the local rural communities to reinforce the supply of freshwater, however, the brine produced was a problematic environmental issue. The IAAS scheme succeeded in turning an environmental problem (brine disposal in inland areas) into a source of new economic activities for the cultivation of fish and halophytes. In addition, due to its characteristics and good performance in arid regions and saline waters, the cultivation of a microalgae species (*Spirulina* sp.) was proposed as an alternative to fish farming within this production scheme.

Since 2014 the International Center for Biosaline Agriculture (ICBA) has been implementing an IAAS using the reject brine from desalination to grow fish and the aquaculture effluents (rich in nutrients) are directed to grow halophytes in an open field and hydroponically (saline aquaponics) (Robertson et al. 2019). More than 15% of farmers in the Gulf region are currently using RO-units to produce freshwater for the farming of vegetables (https://www.biosaline.org/projects/integrated-aqua-agriculture-enhanced-food-and-water-security); it is therefore crucial to explore the potential of the brine by-product from desalination for food and feed production. In a desert environment where there is a lack of replenished freshwater resources, it is imperative to tap into the use of alternative water sources for food production. Biosaline farming schemes therefore constitute a good alternative for agriculture in desert areas. The IAAS developed at ICBA was funded by the EXPO LIVE program (https://www.expo2020dubai.com/en/programmes/expo-live) in two phases. The first phase focused on the improvement of the production components (fish and halophytes) of the inland and coastal integrated farms

(https://www.biosaline.org/projects/inland-and-coastal-modular-farms-climate-change-adaptation-desert-environments); the second phase targeted to create a range of halophyte-based products for human consumption and animal feed produced from inland IAAS (https://www.biosaline.org/projects/expo-live-project-phase-ii-desert-farm-fork-value-chain-development-innovative-halophyte). Coastal IAAS can also offer a wide portfolio of halophytic and fish products (Lyra et al. 2019). Apart from the cultivation of halophytes and fish in local farms in the UAE, the program has included activities related to different stages of the value chain such as the development of halophytic products and public awareness campaigns on halophytes and biosaline farming. The EXPO LIVE project constitutes a multidisciplinary project comprising a consortium of prominent national and international partners such as the Abu Dhabi Agriculture and Food Safety Authority (ADAFSA), the Khalifa Fund for Enterprise Development (KFED), the Environmental Agency in Abu Dhabi (EAD), the Max Planck Institute (MPI) in Germany and Global Food Industries/Healthy Farm, the food company that is developing the halophyte-based food products.

The various characteristics of the four projects mentioned above have been summarized in Table 11.1.

TABLE 11.1
Characteristics of the Biosaline Farming Systems Implemented by ICBA and the Masdar Institute in the UAE, the Aqua Doce Program in Brazil, and the SalFar Project in North Sea Region

	IAAS Developed at ICBA (UAE)	SEAS at Masdar Institute (UAE)	Aqua Doce Program (Brazil)	SalFar Project (North Sea Region)
Inland and coastal IAAS developed	Inland/Coastal	Coastal	Inland	Coastal
Marine species cultivation (fish, algae, cockles, shrimps, etc.)	+	+	+	+
Use of aquaculture effluents for halophytes irrigation	+	+	+	−
Modular farms include vegetable farming	+	−	+	−
Seawater use for halophytes farming	+	+	-	+
Use of reject brine from desalination	+	−	+	−
Halophytes cultivation for human consumption	+	−	−	+
Halophytes use as forage	+	−	+	−
Halophytes cultivation for biofuel production	−	+	−	−
Multipurpose halophytes used (i.e. Salicornia)	+	+	−	+
Training of farmers	+	−	+	+
Policy development for proper use of saline water	+	−	+	+
Value chain development for halophytic products	+	−	−	+
Halophytic cuisine	+	−	−	+

11.3 OBJECTIVES OF THE EXPO LIVE PROJECT – PHASE II

The EXPO LIVE project entitled "From Desert Farm to Fork: Value Chain Development for Innovative Halophyte-Based Food Products" had the overarching goal of developing the value chain of Salicornia-based food products and increasing consumers' knowledge on desert farming and the nutritional aspects of halophytes. Three specific objectives were addressed: (a) adding value to the reject brine from desalination growing Tilapia fish and Salicornia, (b) development of food products using fresh tips from *Salicornia bigelovii* as the main ingredient, and (c) environmental and economical assessments looking into the sustainability of the IAAS and biosaline component.

11.4 MATERIALS AND METHODS

11.4.1 Farms' Profile for the IAAS Implementation

Eight farms were selected in Abu Dhabi Emirate, as shown in Figure 11.1. The selection criteria for the farms were the following: (a) desalination units should be installed within the farms, (b) the salinity level of the reject brine from desalination should be higher than 20 dS/m, (c) the selected farms should be relatively close to one another, and (d) the farmers should be collaborative. The characteristics of the farms are presented in Table 11.2. In half of the farms only the Salicornia component

FIGURE 11.1 The locations of the eight farms in Al Khatim and Al Khazna villages in Abu Dhabi Emirate where the IAAS approach was implemented.

TABLE 11.2
The Characteristics of the Eight Farms in Abu Dhabi Emirate. EC_{GW} Is the Electrical Conductivity of the Groundwater; $EC_{RO\text{-}BRINE}$ Is the Electrical Conductivity of the Reject Brine from RO-desalination

Farms with Salicornia and Tilapia Component

Farm 453

EC_{GW} = 22.3 dS/m
$EC_{RO\text{-}BRINE}$ = 40.2 dS/m

Farm 17

EC_{GW} = 28.7 dS/m
$EC_{RO\text{-}BRINE}$ = 30.0 dS/m

Farm 79

EC_{GW} = 20.2 dS/m
$EC_{RO\text{-}BRINE}$ = 24.9 dS/m

Farm 168

EC_{GW} = 12.9 dS/m
$EC_{RO\text{-}BRINE}$ = 28.6 dS/m

Farms with Salicornia Component Only

Farm 211

EC_{GW} =26.8 dS/m
$EC_{RO\text{-}BRINE}$ = 36.8 dS/m

Farm 658

EC_{GW} = 12.7 dS/m
$EC_{RO\text{-}BRINE}$ = 20.8 dS/m

Farm 136

EC_{GW} = 21.5 dS/m
$EC_{RO\text{-}BRINE}$ = 31.0 dS/m

Farm 364

EC_{GW} = 20.0 dS/m
$EC_{RO\text{-}BRINE}$ = 21.7 dS/m

was added (farms 211, 658, 136, and 364); Salicornia was directly irrigated with the reject brine from desalination. In the other four farms both Salicornia and fish were incorporated (farms 453, 17, 79, and 168); in this case, Salicornia was irrigated with the effluents from aquaculture. The lowest and highest groundwater salinity (EC_{GW}) values ranged from 12.7 dS/m (farm 658) to 28.7 dS/m (farm 17), and the lowest and highest salinity values of the reject brine ($EC_{RO\text{-}BRINE}$) were between 20.8 dS/m (farm 658) and 40.2 dS/m (farm 453). The salinity levels of the groundwater and reject brine were prohibitive for the growth of conventional vegetables and crops, so halophytes were considered for the production of food and forage.

11.4.2 Salicornia and Fish Components

Salicornia bigelovii was sown at a rate of 0.5 g/m^2 in all eight farms between 16 December 2019 and 8 January 2020, as shown in Table 11.3. The actual area of cultivated land ranged from 410 m^2 to 820 m^2. Bubblers were used for irrigation, trying to simulate the tidal and flooding effects observed in Salicornia's natural habitats (tidal marshlands, mangrove swamps, etc.). Leaching fractions were also considered for the water calculations.

An affordable and simple to operate Recirculating Aquaculture System (RAS) was installed and operated 24/7 throughout the experimental period (from January till June) at the four farms (453, 17, 79, and 168). The fish species that was cultivated was Tilapia (*Oreochromis niloticus*). The fish were cultured in two circular polypropylene tanks with a total water volume of about 7.2 m^3 each. Three more tanks were used: one sedimentation tank for the removal of solid particles and wastes;

TABLE 11.3
Various Data Collected from the Eight Farms Related to Sowing Date of Salicornia, Surface Area Cultivated, Water Consumption for the Whole Salicornia Growth Cycle (from Sowing till Forage Harvest), Yield of Fresh Tips and Forage Biomass Yield

	Farm	Actual Land Cultivated (m^2)	Salicornia Sowing (Date)	Water Consumption for Whole Growth Cycle (from Sowing till Forage Harvest) (m^3)	Fresh Tips Yield (kg per m^2)	Dry Forage Biomass (kg per m^2)
Salicornia and Tilapia component	Farm 453	410	16-12-2019	3296	0.19	5.2
	Farm 17	820	26-12-2019	8311	0.06	2.6
	Farm 79	605	26-12-2019	4866	0.05	3.5
	Farm 168	512	08-01-2020	3743	0.03	0.4
Salicornia component only	Farm 211	710	17-12-2019	5440	0.06	3.6
	Farm 658	780	31-12-2019	4175	0.04	0.7
	Farm 136	512	17-12-2019	4377	0.15	4.0
	Farm 364	605	17-12-2019	3467	0.36	1.0

one biofilter tank full of cable hoses as bio-media for bio-filtration; and one water tank to pump the filtered water back to the fish tanks and for Salicornia irrigation. An air blower as a source of oxygen and two water pumps were also used to support the aquaculture system. All Tilapia systems operated using the reject brine from the RO-desalination plant and the aquaculture effluents were then directed to the Salicornia plots. To ensure that the system was functioning properly, the farm staff involved in the IAAS system were trained for the various aquaculture activities such as fish feeding; measurements of nitrite, nitrate, and ammonia; and the cleaning of the two fish and sedimentation tanks.

11.4.3 Soil and Water Monitoring

The electrical conductivity of the soil saturation extract (EC_e) was measured as an indicator of salinity in soil samples collected from Salicornia plots (0–30 cm depth) at the beginning (October 2019) and the end of the experiment (July 2020) using the reject brine from desalination and aquaculture effluents for Salicornia irrigation. Other soil parameters measured were soil texture, pH, Na, K, Ca, Mg, P, N, organic matter, and carbon content; these analyses are currently being assessed.

Detailed analyses were also conducted for all four water resources available at the farm level (groundwater, desalinated water, reject brine and aquaculture effluents) at two time intervals: (a) before starting the growing season and before using the reject brine for fish farming and Salicornia irrigation, and (b) at the end of the cultivating season. The results of these additional analyses are under assessment. Various group parameters were also analyzed such as: anions (fluoride, nitrate, nitrite, sulfate, etc.), metals (aluminium, arsenic, cadmium, etc.), BTEX compounds (benzene, toluene, ethylbenzene, and xylene), inorganic parameters (electrical conductivity, pH, etc.), pesticides, phenols and the microbiological load (total bacterial count, *Escherichia coli*, total coliform).

11.5 RESULTS AND DISCUSSION

11.5.1 Salicornia Cultivation

The water consumption values for the whole growth cycle from sowing until the harvest of the Salicornia biomass to be used as forage (early July 2020) were between 3296 m^3 and 8311 m^3 (Table 11.3). It is apparent that significant quantities of water were consumed for Salicornia cultivation using bubblers for irrigation.

The harvest of fresh tips took place in early April 2020; this coincided with the strictest lockdowns in the UAE during the COVID-19 pandemic. The yield of fresh tips (the upper 10–15 cm of the Salicornia shoots) was not as high as expected and there were several challenges faced which are explained in Section 11.6. The yield ranged from 0.03 (farm 168) to 0.36 kg/m^2 (farm 364). Whole Salicornia plants were harvested at a later growth stage to be used as forage in early July 2020. The dry biomass yields were between 0.4 (farm 168) and 5.2 kg/m^2 (farm 453).

The Salicornia fresh tips were purchased by a food company (Global Food Industries/Healthy Farm) at 4.1 USD $/kg to develop Salicornia-based recipes, dishes, and products. The selling price of Salicornia forage was 354 USD $/ton at the farm gate. Salicornia forage was distributed to camel, sheep, and goat farms and was used at a rate of 30% due to its high salt content (De La Llata Coronado 1991; Glenn et al. 1992; Swingle et al. 1996; Al-Owaimer 2000).

11.5.2 Soil and Water Analyses

Regarding the starting soil salinity (samples collected in October 2019), farm 168 had the highest soil EC_e (33.8 dS/m) and farm 136 had the lowest EC_e (2.3 dS/m) (Table 11.4). By July 2020, there had been substantial (118–465%) increases in the soil salinity at four farms (farms 364, 453, 658, and 136), but lower increases (15 and 54%) at farms 168 and 211 respectively. By contrast, on farms 17 and 79 the soil salinity decreased by 34% and 2.6% respectively. Factors such as the soil properties, the leaching fractions used and the time of the soil sampling (before or after irrigation) were taken into consideration to evaluate the obtained results of the electrical conductivity. Sanchez et al. (2015) also observed that a progressive salinization of the land irrigated with the reject brine could not be prevented, even though there was a slight salt removal capacity observed by the halophytic forage cultivated. After running a 5-year study of continuous irrigation and drainage of the fields they noted that salinity progressively increased from 0.60 in 2000 to 8.2 dS/m in 2006. Proper management of the irrigation, appropriate cultivation techniques, and the use of liquid manure were imperative to improve the performance of the yield grown with the saline water. In addition, periodical flushing of the salts with freshwater was necessary to decrease the soil salinity and maintain an acceptable salt balance.

Results for water analysis are still under assessment. Overall, a microbiological load (*E. coli* – Total Coliform) was not detected in any water samples. Most of the results derived from the analyses of the inorganic parameters were characterized by lower values than the allowed detection limits.

TABLE 11.4
Electrical Conductivity of the Soil Saturation Extract (EC_e) Collected from the Top 30 cm in All Eight Farms

		EC_e (dS/m)		Increase or Decrease of EC_e
	Farm	October 2019	July 2020	between the two Samplings (%)
Salicornia and Tilapia component	Farm 453	16.8	47.4	182
	Farm 17	18.3	12.0	−34
	Farm 79	15.2	14.8	−2.6
	Farm 168	33.8	38.9	15
Salicornia component only	Farm 211	14.7	22.7	54
	Farm 658	14.2	43.6	207
	Farm 136	2.3	13.0	465
	Farm 364	5.6	12.2	118

TABLE 11.5
Tilapia Biomass (kg) Progress per Farm

	Tilapia Biomass Progress per Farm (kg)					
	Months					
Farms	Initial Stocking	February 2020	March 2020	April 2020	May 2020	June 2020 (Total)
Farm 453	78	Fish died	78 (Restocking)	88	124	167
Farm 17	85	116	155	189	221	288
Farm 79	82	92	130	114	116	152
Farm 168	78	112	147	185	220	227

11.5.3 Fish Farming

The fish was stocked at each farm in late January 2020 and the initial biomass produced ranged from 78 to 85 kg (Table 11.5). A second restocking was conducted on Farm 453 because the fish died due to a lack of oxygen caused by an electrical power outage. The fish biomass was measured at the end of every month (from February till the end of June) based on the average body weight of fish sampled. Although the initial biomass was similar in all farms, the final produced biomass varied significantly between farms and ranged from 152 (farm 79) to 288 kg (farm 17). This variation was attributed to the fact that in one farm (farm 453) restocking of new fingerlings (fish of smaller size and less weight) was done due to fish death and the lack of correct fish feeding in some others. The total fish biomass from all four farms was 834 kg at the end of the experiment. The maximum fish density was achieved in farm 17 and was 20.5kg/m^3.

Feed conversion ratio (FCR) is the efficiency in terms of how much feed is required to produce 1 kg of fish. FCR is calculated as the ratio of feed given/fish weight gain. A good FCR is close to 1. Based on the results presented in Table 11.6, the best FCR was achieved on Farm 17 with FCR values ranging from 1.21 to 1.94 throughout the farming cycle. Farm 453 also had a good FCR but in order to be compared to the other farms, two more months of rearing would have been needed. Farm 79 had

TABLE 11.6
Feed Conversion Ratio (FCR) of Tilapia Fish per Farm

	Feed Conversion Ratio of Tilapia Fish				
	Months				
Farms	February 2020	March 2020	April 2020	May 2020	June 2020
Farm 453	Fish died	0.70	3.36	1.10	1.65
Farm 17	1.21	1.72	1.94	1.51	1.24
Farm 79	1.59	1.75	-2.61	17.67	0.47
Farm 168	1.03	1.80	1.43	1.92	14.76

the worst FCR (big and negative values) due to fish spawning. As a result, the fish population increased by 25% (newborn fish) which significantly affected the consumption of feed.

11.6 MAIN CHALLENGES ADDRESSED DURING THE SALICORNIA VALUE CHAIN DEVELOPMENT

Several challenges impeded some activities during the project (Figure 11.2). Some of these were aggravated by the lockdowns imposed by the COVID-19 pandemic.

- *Salicornia fresh tips harvest:* The harvest of fresh tips was conducted manually, and a high number of workers were utilized for this purpose (Figure 11.2 – photo A). Unfortunately, there are no harvesting machines in the market customized for Salicornia tips, which means that more working hours are needed for the farm staff to harvest sufficient quantity of Salicornia fresh tips to sell. This impacted on overall productivity and profitability. In addition, Salicornia fresh shoots can range in length from 5 to 25 cm, based on the requirements and specifications each company has for its food products, thus, the final yield of fresh tips might change. Proper specifications are therefore needed to be defined in advance to characterize the proper length of Salicornia tips based on the food use either as fresh or processed. Moreover, the lack of uniform height of Salicornia plants in the field meant that the cuttings of fresh tips were of uneven length (Figure 11.2 – photo B). This lack of uniformity was attributed to the cross-pollinating nature of Salicornia and to the fact that there is no actual variety developed with more stable characteristics.
- *Quality control and sanitization process for Salicornia fresh tips:* In order for Salicornia to be used as ingredient in food products, specific protocols based on HACCP (Hazard Analysis Critical Control Points) principles (FAO/WHO Codex Alimentarius Commission 2003) and procedures should be followed. As a result, an audit was conducted on the abilities of the farms to comply with the quality protocols. Analyses were carried out to determine the presence of heavy metals and pesticide residues in Salicornia grown in the different farming environments. In addition, before bringing in Salicornia fresh tips to the processing facilities of the food company, they needed to have been washed to minimize cross-contamination issues. Salicornia was therefore cleaned and sanitized at a hygienically designed facility near to harvesting sites using clean potable water and chlorine tablets (Figure 11.2 – photos C and D). After sanitization, the Salicornia shoots were placed in clean disinfected perforated plastic crates (15 kg in a crate) and were immediately transferred into a chiller truck (4°C) (Figure 11.2 – photo E).
- *Weeds presence in Salicornia plantation:* A few farms had persistent weeds such as *Tribulus terrestris*, *Sesuvium portulacastrum*, and *Portulaca oleracea* (Figure 11.2 – photo F). As there are no herbicides registered for Salicornia cultivation, these weeds had to be removed by hand. This increased the overall expenses of production.

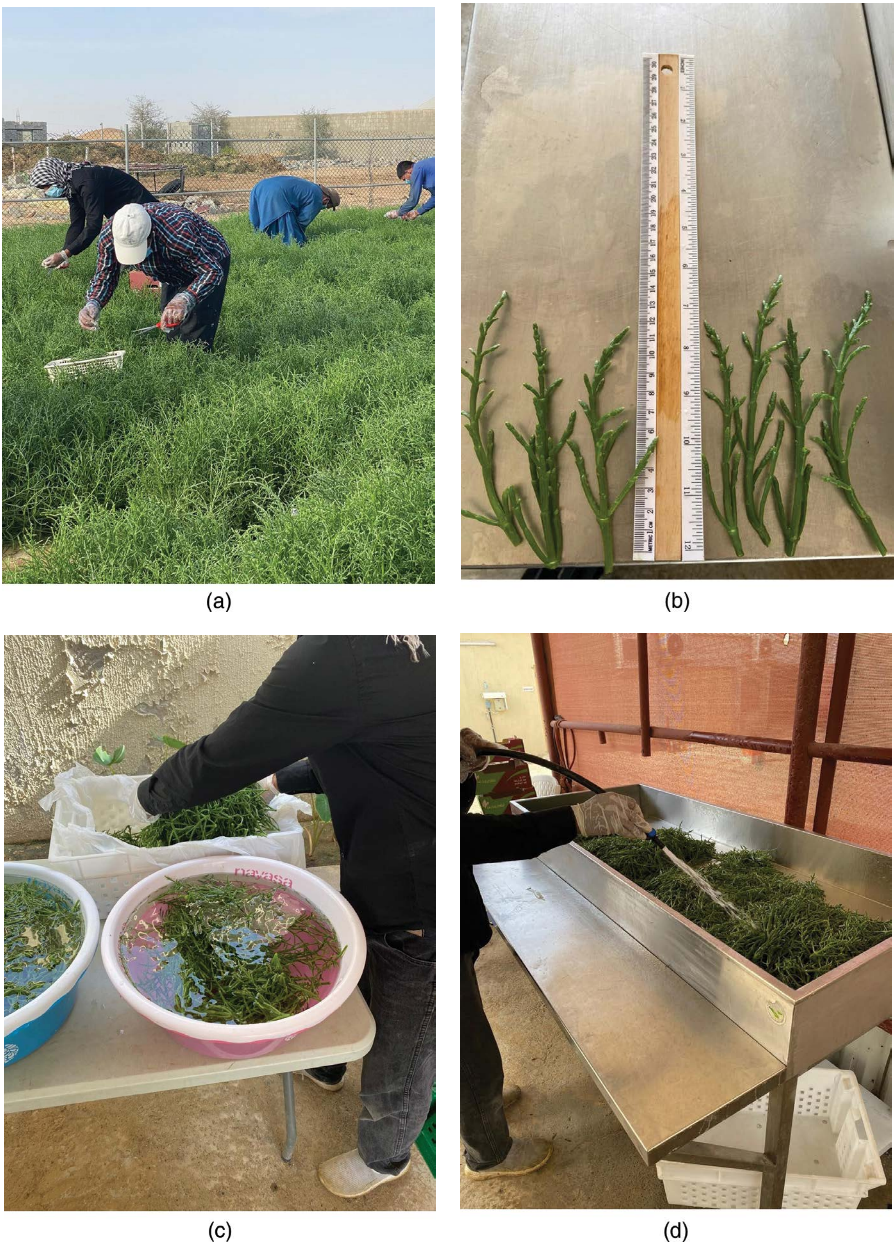

FIGURE 11.2 Manual harvest of Salicornia fresh tips on one of the eight farms in Abu Dhabi Emirate in April 2020 (a); uneven Salicornia fresh tips (b); sanitizing Salicornia fresh tips with chlorine tablets (c); washing Salicornia fresh tips (d); Salicornia shoots placed in clean and disinfected perforated plastic crates (e); and weeds in Salicornia plots (f).

(Continued)

(e) (f)

FIGURE 11.2 (Continued)

- Other challenges addressed had to do with the lack of workers at the farms especially during the COVID-19 outbreak, where social distancing and limited movement measures were imposed. Other challenges faced were the instability of the electrical supply, which resulted in fish death in one farm, and a lack of water supply at other farms which led to irregular Salicornia growth.
- *Lack of public's knowledge on halophytes, desert, and biosaline farming:* In order to increase the demand for Salicornia in the UAE, consumers should be aware of the opportunities that lie within the agricultural context in a desert environment, the nutritional benefits that halophytes have and how biosaline farming can contribute in fostering the food, nutrition, and security of livelihoods on a local level. Various halophytic crops that can be used for food and feed have great potential within such a marginal farming context.

11.7 INITIATIVES TO OVERCOME THE CHALLENGES

- *Salicornia breeding:* Improved high-yielding Salicornia varieties are needed with good, stable, and uniform characteristics that will guarantee a sustainable production of Salicornia for different uses in desert areas. As a result of the increasing number of national and international requests for technical back-stopping on Salicornia and after a 7 year of field selection of Salicornia germplasm (Lyra et al. 2016, 2020), ICBA is moving forward with a breeding program on this halophytic species which involves plant selection and the use of recombination breeding methodologies.

- *Mechanization of the fresh tips and seeds harvest*: ICBA is currently collaborating with manufacturing companies to develop customized equipment for the harvest of Salicornia fresh tips, the cleaning and collection of seeds since these are currently long, tedious processes.
- *Developing quality control and sanitization protocols for halophytic produce:* Designated areas need to be prepared for the proper auditing of the Salicornia produce when it is directed for the food industry so that cross-contamination is avoided. Sanitization protocols should be also developed and suitable facilities and equipment should be prepared for such use. In addition, heavy metals, pesticide residues, and the microbiological load should be analyzed to assess the safe use of the harvested material. Farm staff also need to be trained on good post-harvest handling practices of the fresh Salicornia produce.
- *Weeds management in halophytic cultivations:* When the weed load in Salicornia plantation is high, it is really challenging to control it manually. Because Salicornia consumes a lot of water, soil moisture is abundant, thus, weeds can emerge and spread quickly, especially when the Salicornia is at a young vegetative stage. Trials on the use of pre-emergent and post-emergent herbicides for broadleaf and grass weed species need to be conducted. Efficient weed control methods for Salicornia will contribute to the cleanliness of cultivation and its effective management.
- *Training programs for farmers and farm workers on IAAS and halophytes:* In order to avoid any hindrances on the operation of Salicornia cultivation and IAAS, farm staff should be trained properly to act proactively when an unexpected issue comes up such as a power outage, intermittent water supply, etc. ICBA is developing training modules translated into local languages (currently Arabic and Urdu) for farmers and farm workers to close the knowledge gaps that currently exist on Salicornia cultivation.
- *Initiatives to increase public knowledge on halophytes, desert and biosaline farming:* Public awareness campaigns have been launched to showcase the benefits of halophytic plants, their farming potential in desert environments, and their vital role in contributing to the national food security strategy plan in the UAE. Under the EXPO LIVE project, there is an initiative called "The Halophytic Kitchen Lab" (https://www.emiratessoilmuseum.org/education-programs/university-corporate-programs/halophytic-kitchen-lab) which is tailor-made for both students and adults. This initiative includes live interactive cooking sessions using halophytes (Salicornia, quinoa, etc.) as ingredients for recipes prepared by a chef with a nutritionist providing the necessary information on the nutritional value of halophytic crops. Creating dishes, recipes, and food products based on halophytes is effective in increasing the awareness of consumers and informing the public about halophytes' nutritional value, cooking, and farming potential, especially in areas dealing with soil and water salinity issues. Halophytes, with the contribution of chefs, can be included in the cuisines and dietary patterns of the local communities strengthening the food security component at the community, region, and country level.

11.8 INNOVATIVE SALICORNIA-BASED FOOD PRODUCTS

The Salicornia fresh produce collected from the eight farms was transformed through a collaboration with a food company (Global Food Industries/Healthy Farm) into innovative halophytic products marketed locally at an initial stage. Preliminary versions of the Salicornia-based products are presented in Figures 11.3 and 11.4. The

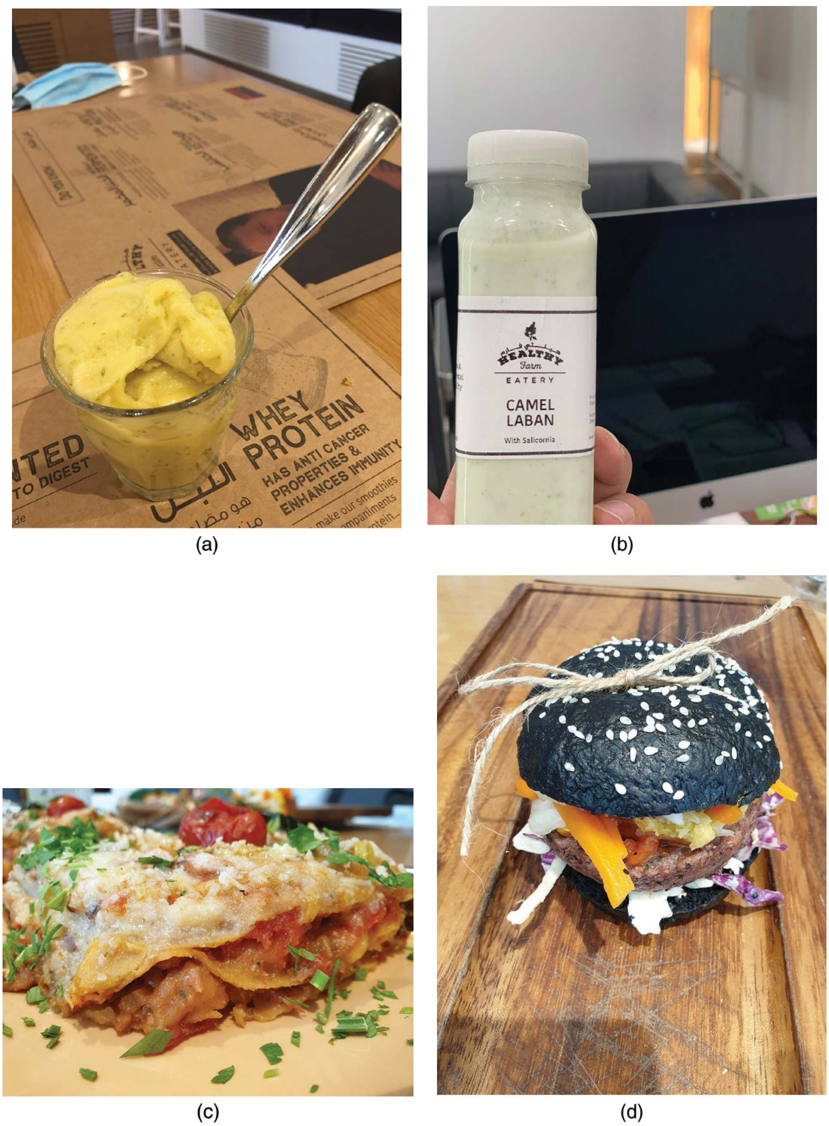

FIGURE 11.3 Sorbet with mango, banana and Salicornia (a); Camel Laban with Salicornia (b); Lasagna with Salicornia (c); Charcoal bread with vegan Salicornia burger (d). (All the food products and recipes shown in the photos were prepared by Healthy Farm team ©.)

ratio of Salicornia as an ingredient in the recipes ranged between 20% and 40% for all the products and recipes developed. Salicornia showed great versatility in cooking options and processing possibilities for both salty and sweet dishes, liquid and solid food products. The nutritional profile of Salicornia for food use has been investigated with promising results (Patel 2016). Salicornia is characterized by a high content of minerals and high Vitamin C, especially at a later growth stage, which in combination with Zn, Mg, and Mn make it a good candidate to boost the immunity system (unpublished data). Salicornia has also a good antioxidant profile, anti-aging properties, and fertility-boosting effects (Zhang et al. 2015). Overall, the vision is to

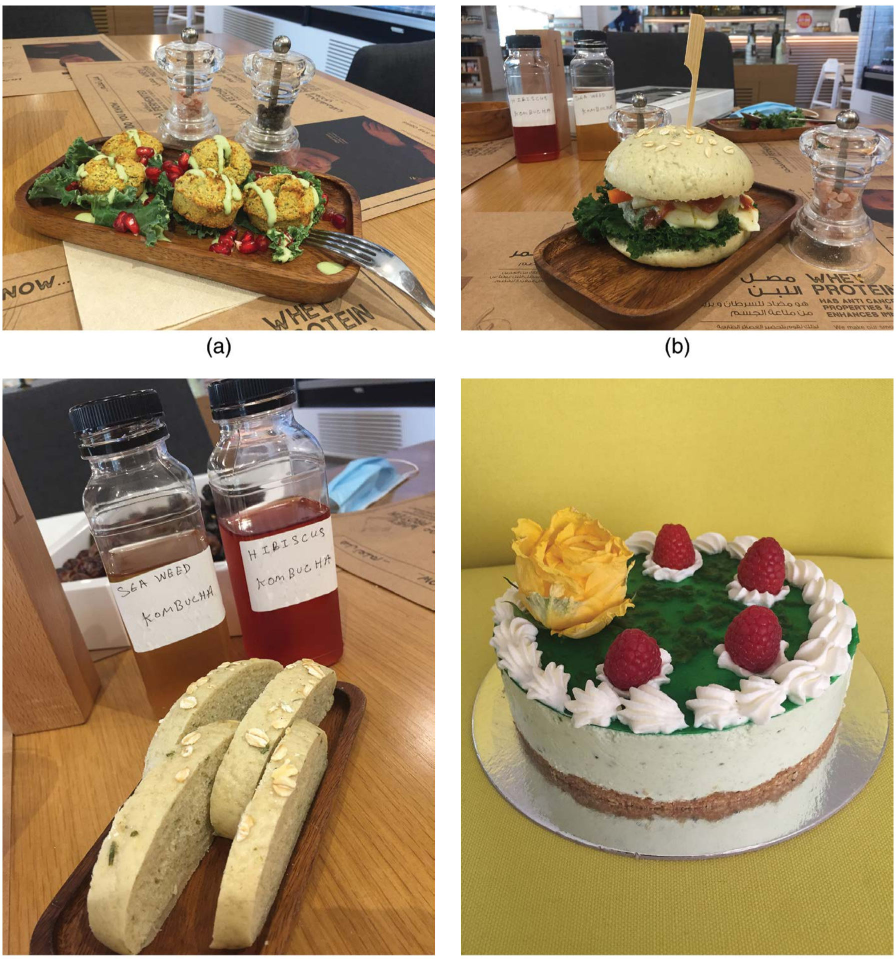

FIGURE 11.4 (a) Falafel with Salicornia, quinoa, chickpea and kale; (b) Vegan Salicornia burger; (c) Steamed Salicornia bread; (d) Camel cheesecake with Salicornia.

(Continued)

(e) (f)

FIGURE 11.4 (e) Charcoal pizza with Salicornia; (f) Vegan Salicornia, quinoa, peas balls. (All the food products and recipes shown in the photos were prepared by Healthy Farm team ©.)

create a halophyte-based food industry with local produce in a desert environment that could be replicated in similar climatic contexts and salt-affected areas.

11.9 CONCLUSIONS

Biosaline farming is a feasible solution in marginal, coastal, and salt-affected areas utilizing unconventional water resources such as seawater, brackish groundwater, and the reject brine from desalination. Various projects on biosaline farming have been implemented on a global scale applying a diverse range and combination of production components. One of these production schemes is the IAAS. The IAAS constitute climate-resilient systems that encompass different production modules (marine species and halophytic species for various uses) capable of enhancing the food and nutrition security of the local rural communities. Agricultural biodiversity is a direction that should be primarily adopted in vulnerable regions to make farm ecosystems more resilient to adverse climate change impact. IAAS can provide additional income-generation opportunities since both crops and fish can be produced for human consumption, as well as forage for animals. This combination provides an additional and diversified income to farm businesses. The EXPO LIVE project targeted to scale-up IAAS to eight farms in the UAE, looking into how value could be added to the reject brine from desalination by growing Tilapia and *Salicornia bigelovii*. Different challenges were faced during project implementation and initiatives to overcome these have been already launched. In order for the farming of halophytes to expand, there should be a gradual increase in their demand by consumers.

However, the public is not familiar with halophytes, their nutritional value and this knowledge need to be enhanced. Awareness campaigns need to be deployed to increase halophytic products' visibility and demand, so that halophytic products become more popular to consumers. Moreover, periodic soil and water monitoring should be conducted, so that the sustainability of such biosaline ventures could be guaranteed. As the requests on biosaline farming are increasing (ICBA is currently introducing IAAS and Salicornia at the Red Sea Governorate in Egypt and Morocco), it is imperative to adopt methodologies and directions that are primarily community-driven looking into all the value chain components and the local socioeconomic and climatic context. An impressive impact could be achieved for small-holder farmers in marginal, coastal, and salt-affected regions by implementing innovative, cost-effective, and low-consumption biosaline farming models that generate multisource food and income using brackish groundwater, seawater, and the reject brine from desalination. For such a purpose, research, governmental, academia, private sector should unite forces to make biosaline farming ventures feasible and sustainable. It is apparent that the vexing issue of the rising salinity levels should be confronted in a multidisciplinary way for more tangible and effective results.

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