ACTA BIOLÓGICA COLOMBIANA
http://www.revistas.unal.edu.co/index.php/actabiol

Facultad de Ciencias
Departamento de Biología
Sede Bogotá

UNIVERSIDAD NACIONAL DE COLOMBIA

ARTÍCULO DE REVISIÓN / REVIEW ARTICLE

BOTÁNICA

SALT TOLERANT PLANTS AS A VALUABLE RESOURCE FOR SUSTAINABLE FOOD PRODUCTION IN ARID AND SALINE COASTAL ZONES

Plantas tolerantes a la sal como un recurso valioso para la producción sostenible de alimentos en zonas costeras áridas y salinasa

Ramón Jaime HOLGUIN PEÑA[1], **Diana MEDINA HERNÁNDEZ**[1], **Mojtaba GHASEMI**[2], **Edgar Omar RUEDA PUENTE**[2*]

[1]Departamento de Agricultura de Zonas Áridas, Centro de Investigaciones Biológicas del Noroeste, S.C., La Paz, Baja California Sur, México .

[2]Departamento de Agricultura y Ganadería, División de Ciencias Biológicas y de la Salud, Universidad de Sonora, Hermosillo, Sonora, México.

For correspondence: erueda04@santana.uson.mx

Received: 25th Septemder 2019, **Returned for revision**: 27th February 2019, **Accepted**: 18th May 2020.
Associate Editor: Magdi Abdelhamid.

Citation/Citar este artículo como: Holgín Peña RJ, Medina Hernández D, Ghasemi M, Rueda Puente EO . Salt tolerant plants as a valuable resource for sustainable food production in arid and saline coastal zones. Acta Biol Colomb. 2021;26(1):116-126. Doi: http://dx.doi.org/10.15446/abc.v26n1.82412

ABSTRACT
This review focuses on the potential of halophytes for food, fodder and biofuels production, as well as their impacts on the environment and societies. Moreover, to open new areas in production systems using novel technologies such as halophytes in a desert agriculture. We are faced with the crisis and the shortage of freshwater in arid, semi-arid and desert regions. For this reason, we have to apply sustainable systems for human food, fodder and biofuels. Halophytes are naturally resistant to salt and develop on the coastal coast and arid-saline areas. We present a complete summary of the current situation of human population growth and food demand, a sustainable alternative such as halophilic crops of agro-industrial importance compared with conventional crops and how they can be incorporated into agriculture sustainable in arid, desert and coastal areas, basing the above on success stories.

Keywords: bioprospecting, halophyte, seawater.

RESUMEN
Esta revisión se centra en el potencial de las halófitas para la producción de alimentos, forrajes y biocombustibles, así como en sus impactos en el medio ambiente y en las sociedades. Asimismo, en las nuevas áreas que buscan sistemas de producción utilizando tecnologías novedosas como las halófitas en agricultura en el desierto. Nos encontramos ante una crisis de escasez de agua dulce en regiones áridas, semiáridas y desérticas. Por esta razón, tenemos que aplicar sistemas sostenibles para alimento humano, forraje y biocombustibles. Las halofítas son naturalmente resistentes a la sal y se desarrollan en litorales costeros y zonas árido-salinas. Presentamos un resumen completo de la situación actual del crecimiento de la población humana y de la demanda de alimentos, de los cultivos halófilos de importancia agroindustrial como una alternativa sustentable, comparados con los convencionales, y de la forma como se pueden incorporar en una agricultura sustentable en zonas áridas, desérticas y costeras, fundamentando lo anterior con casos de éxito.

Palabras clave: agua de mar, bioprospección, halófita.

INTRODUCTION

World population and food

The world population is estimated to grow from over 9.7 billion to 2050, which means more than doubled in the past 50 years and represents an annual rate of 1.2 % (PRB, 2017). If we take as reference 2001 (6.1 billion) in comparison to the estimated population for 2050, we have an increase of 62.8 %; there is an unfavorable projection in the increases of the poverty indices indicating that 1.2 million people lived in extreme poverty with pessimistic expectations for 2050 (Ravallion, 2013; Rougoor and Marrewijk, 2015). In addition, the expectations of growth of the rural population by 2020 are estimated at 300 million people, while the urban population could be expected at 3.4 billion. With the rapid global growth, the expectations regarding the availability of food in terms of food security are becoming more critical (Fedoroff *et al.*, 2010). In the last thirty years, concepts of food security have evolved and now takes into account not only physical and economic access (Thornton, 2010), but also considered a human right and new concepts related to food availability, food access and food utilization (Schmidhuber and Tubiello, 2007; Wheeler and Von Braun, 2013). However, one of the most constant concerns in the international development institutions is about the availability of food with nutritional quality and stability, so that this does not represent a risk in accessing food (Burchi and de Muro, 2016). This is, of the 3500 kilocalories per day (kcal day^{-1}) recommended to be considered with food quality status, poor countries only have access to 2000 kcal day^{-1}, representing a deficit of 18 %. Also, the nutritional sources in poor countries derive from agriculture and are generally deficient in essential micronutrients and amino acids indicating that more than 850 million people are suffering from chronic malnutrition (FAO, 2002). One of the main concerns in that while the population is focused on the immediate benefits of food security policies, current research is more focused on how to measure it (Webb *et al.*, 2006; Barret, 2010).

This review aims to address the question of whether halophytes have the potential for the development of sustainable agriculture that feeds livestock in arid and coastal areas, taking into account the sections on food security, regional economic development, poverty and social welfare. In addition, we present a case study on combined production systems for desert agricultura in arid coastal areas, where aquaponic systems with tilapia and hydroponic systems with halophytes in Sonora state and Baja California Peninsula, Mexico, stand out as a model of agricultura.

¿Could the conventional agricultural systems supply the food demand?

With the rapid growth global population, arable lands and restriction of freshwater for agricultural use have deep implications to satisfy this century's demands for food (Kearney, 2010). But certainly, this growth has involved a complex interaction between anthropogenic activities, global warming, contamination risk in food, energy supplies for industry, and transportation, among other aspects (Van Wesenbeeck *et al.*, 2009). One of the alternatives contemplated in the ONU Millenium Project in 2005 is the production in small scales or farming systems focused on the sustainable production systems. One of the opportunities for this type of production units is the use of relatively salty water or poor-quality water, considering also salts, which could affect productivity. This type of agriculture, called bio-saline, could be the best sustainable production strategy for the next 50 years, the most interesting model being the use of halophytes (Ladeiro, 2012).

Recently, the bioprospecting in arid, desert and coastline áreas (Antartic: 13 829.430 km²; Artic: 13 726 937 km²; Sahara: 9 065 253 km²; Arabic: 2 300 000 km²; Australia: 1 371 000 km²; Gobi: 1 300 000 km²; Kalahary: 930 000 km², Patagonic: 670 000 km²; Siria: 409 000 km²; and Sonora = Arizona: 362 600 km²) can be led no only to uncovering new desert plant species. Dry arid and deserts zones have over 20 000 native plant species, apart from animal, marine and microbial diversity, with potential for the discovery of new drugs, new chemical compounds with pharmaceutical use, in sustainable agriculture or in the market of metabolites, where it is considered an added value in desert agriculture. The concept of bioprospecting includes the exploration and investigation of indigenous knowledge related to the utilization and management of biological sources that involve three stages: collecting, analysis and commercialization (Quezada, 2007; Stanley, 2008).

Halophytes as a promise

Halophytes are a group of plants that are capable to complete their life cycle in a substrate rich in NaCl or other elements at concentrations where most and conventional plants (glycophytes) are unable to tolerate. They have been grouped according to their physiological response in their tolerance to salinity in: i) halophiles, which are those that need salt like Salicornia (*Salicornia* spp.), suaeda (*Suaeda*), *Limonium* spp., and *Atriplex* spp., among others; ii) the preferential halophiles or macrophytes, that are those that prefer the salt like seaside bulrush (*Scirpus maritimus*); and iii) the subsistence halophiles, that is, those tolerant to the salt like as common reed (*Phragmites* spp., Grigore and Toma, 2017). These are classified as naturally salt-loving plants due to the ability of their leaves to excrete Na and Cl ions (Flowers *et al.*, 2010; Shabala and Mackay, 2011). Approximately 99 % of plants used in agriculture are salt sensitive species and represent at most 2 % of earth herbal variety (Flowers *et al.*, 2010); the other 98 % are plants that growths in areas richs in salts. Since centuries ago, halophytes have been utilized as food, oilseed crop, forage, fodder, biofuel and for medicinal goals (Davy *et al.*, 2001). For example, perennial saltgrass (*Distichlis palmeri*) as a food crop by the indigenous at South Americans, who lived along the lower Río Colorado in Mexico (Bermúdez, 2005; Panta *et al.*, 2014). Approximately 50 species are seed-bearing with high potential for edible oil and protein sources, but also being highly valued as biofuels source, mainly for biodiesel, bio-ethanol, and fuelwood (Qadir *et al.*, 2008; Flowers *et al.*, 2010; Panta *et al.*, 2014).

Some of the main advantages of these plants are their hight values of crude protein and contained digestible fiber (Master *et al.*, 2007). Another advantage of this type of plants is their good adaptability in the arid coastal regions and that can be used to revegetate saline lands (Panta *et al.*, 2014). Nevertheless, the provision of scientific information related to the nutritional values of some halophytes or desertic plant shrubs is still limited, whether for agricultural use or forage and livestock production (Masters *et al.*, 2007).

On the other hand, in some arid areas of the world new alternatives are required to satisfy the food needs of livestock; due to its climatology and diminute availability of water, it is a problem for the production of quality and quantity of food for humans and forage for livestock. Evidence indicates that some halophytes could be a contribution to the livestock system. In addition, the edible Chenopodaceae have a singular importance as a source of protein, essential for feeding animals; halophytes such as *Atriplex* spp., *Salicornia* spp. and *Distichlis palmeri* have been identified and applied as alternative crops for forage and feed in saline lands (Masters *et al.*, 2007). In the field of medicine, *Ipomoea pes-caprae* has been used for treating fatigue, strain, arthritis, rheumatism, and menorrhagia (Panta *et al.*, 2014). Also, this type of plants has been used to desalinate brackish waters, and carbon sequestration (Körner, 2013; Gunning *et al.*, 2016).

Another big problem into the arid zones close to coastal areas is the saline intrusión, which is the movement of saline water into freshwater aquifers, which can lead to groundwater quality degradation, including drinking water sources, and other consequences. Saltwater intrusion can naturally occur in coastal aquifers, owing to the hydraulic connection between groundwater and seawater. As an example, Hermosillo, Sonora, Mexico is located near the coast of the Gulf of California; the area between the coast and the city of Hermosillo is called the Costa de Hermosillo. It is one of the most important agricultural districts in Mexico country. The exploitation of coastal groundwater began in 1945 with 15 wells. In 1950 there were 258 wells pumping water, and in 1955 there were 484 (Flores-Márquez *et al.*, 1998). There are currently more than 550 wells in operation. This withdrawal of water far exceeds the natural recharge and upsets the natural balance between fresh and salt water. Severe problem and seawater intrusion evidences have been seen in several wells. Near the coast there are high concentrations of salt, and the wells should be abandoned. As this aquifer represents the only source of irrigation water, the size of irrigation areas is decreasing. In this sense, due the capacity to abosorb salts and concentrate them into their tissues, the halophytes have a high potential for desalination and phytoremediation of polluted soils (Padmavathiamma *et al.*, 2014).

In another sense, and considering the accelerated growth of the population worldwide and, consequently, its greater demand for energy, the devastating effects of climate change, as well as the reduction and increasing difficulty of access to fossil fuel deposits, have raised the need for society to seek alternative sources of energy to meet their needs and reduce palpable damage to the environment. In recent years, various countries have oriented efforts and public policies in this regard, exploring alternatives for the generation of energy for self-consumption and exports with a sustainable approach. The effects of climate change require increasing the efforts of nations to generate alternative energies such as biofuels, so as to ensure a sustainable use of the great biodiversity that exists, while promoting conditions that guarantee food supply and caring for the environment. The interest of some halophytes like *Salicornia bigelovii* (*TORR*) as a bioenergetic crop arises from the need to take advantage of coastal resources such as saline soils and brackish waters to produce food or products of commercial interest. The salicornia plant was proposed as an oilseed crop due to the properties of its seed that contains up to 30 % oil, similar to compound crops such as soybeans. Different authors mention it as the most promising species for the profitable use of coastal salt flats with a bioenergetic interest (Gleen *et al.*, 1998), with the production potential of up to 230 gallons of biodiesel per hectare cultivated (Shahid *et al.*, 2013), thus considering it an alternative for the aviation industry (Hari *et al.*, 2015) and automotive transport. The oil obtained from the seed of *Salicornia* can be converted into biodiesel through transesterification since its properties are very similar to the oils currently used for this purpose. On the other hand, the production of this halophyte generates a high percentage of lignocellulosic biomass (90 %) that can be converted into biofuel through enzymatic hydrolysis and microbial fermentation. Fit in mention that other non-edible halophytes that could be used as oilseed trees and alternatives for bioenergy production, have extensively documented, like *Calophyllum inophyllum*, *Azadirachta indica*, *Terminalia catappa*, *Madhuca indica*, *Pongamia pinnata*, and *Jatropha curcas*, and especially because they bring a wide range of welfare benefits to rural areas (Gerber, 2008).

Recently, the bioprospecting in arid, desert, and coastline areas can be led to uncovering new desert plant species. There are over 20 000 native plant species, apart from animal, marine and microbial diversity, with potential for the discovery of new drugs, new chemical compounds with pharmaceutical use, in sustainable agriculture or in the market of metabolites, where it is considered an added value in desert agriculture. The concept of bioprospecting includes the exploration and investigation of indigenous knowledge related to the utilization and management of biological sources that involve three stages: collecting, analysis and commercialization (Quezada, 2007; Stanley, 2008).

As we can see, the halophytic plants have many advantages from economic, social, and environmental approaches, but in addition, the social and environmental advantages of halophyte crops are a strong support to the agribusiness economy- with high impact on regional development; thus, production of forage and oilseed on a large-scale basis can be a profitable option.

Freshwater disponibility to agriculture

The freshwater is one of the scarcest and finite resources in the world, particularly the freshwater directed for agriculture sector (Koehler, 2008; Pimentel *et al.*, 2004). Currently, there are sites in special dry arid zones where it is scarcer. Several paths and approaches have been explored, especially those related to agronomic management and considering environmental aspects to reduce water degradation (Sullivan, 2002; Bates *et al.*, 2008). Nowadays, it is known that population growth, water scarcity, and land destruction in the arid and semi-arid zones are related to causing education difficulties for populations, poverty, environmental problems, and social and environmental insecurity (Brown and Funk, 2008). It is registered that freshwater is mainly available in the countries of the northern part of the world at ample amounts, while it is scarce especially in developing countries, where about 40 % of the world's population lives. Water consumption has increased by more than 600 % during the last century and over 70 % of water worldwide is consumed for irrigation (Koyro *et al.*, 2011). The area of irrigated land has increased from 1966 to 1998 from 1.5 to 2.7 million km^2. This means that it is increasing twice as fast as population growth. Therefore, it is expected that 50 % of humankind will experience scarcity of freshwater by the year 2025 (Koyro and Lieth, 2008).

In Mexico, as in other underdeveloped countries in arid and semi-arid regions in the world (Tanzania, Sudan, Egypt), there is a growing migration due to problems of availability of water for agricultural activities (Webb *et al.*, 2006). Also, there are some products derived of the techonology where the yield estimated in some crops like maize in standard conditions in irrigated systems is 3.5 times compared with those in dryland crops (27.3 versus 7.8 metric tons per hectare) (Von Grebmer *et al.*, 2012). Still, the introduction of new irrigation systems is helping to obtain a good management of the scarce freshwater resource. However, in the arid regions (specifically those world desert rings dedicated to agricultural sector and producing 75 % of human food), farming methods and other options have proven not to be a healthy option in terms of food sacurity. For that reason, it is very important enlarge the knowledge concidering other type of natural resources like the agroindustrial halophytes, which are growing in those rings and could be incorporated into the agricultural sector.

Bio-saline agriculture as alternative

One impediment in dry arid and coastal zones where agriculture is working, is the saline intrusion and hights leves of salts in freswater from pumps (sub-soil 4-10 gr L^{-1}). The use of seawater or brackish water to grow crops has been applied in arid and saline areas as an alternative farming method to produce forages, human food and raw material to biofuel (Abideen *et al.*, 2014). This type of agriculture, based on plants that are capable of growing under saline conditions, can generate an economically viable market for salinity tolerant crops while expanding production to marginal lands and reducing the high pressure on the conventional water resources. Soil salinity and scarcity of freshwater resources are two of the principal threats for agriculture, and these limitations cause to reduce food production for the human population and their livestock. About more than 30 % of the irrigated agricultural lands have produced idle´s lands throughout the world (Koyro *et al.*, 2011). Salinity is one of the most important abiotic stress, which severely influences agricultural crop productivity through the accumulation of poisonous Na^{++} and Cl^{-} ions (Yamaguchi and Blumwald, 2005). There are several new technologies for use the seawater and brackish water for agricultural purposes that are related with arid, semi-arid and desert coastline zones and are focused mainly in three lines: i) the agriculture using halophytes or salt-tolerant (loving-salt) species, ii) the aquaculture combined with hydroponics, and iii) use of seawater in degraded soils. It is estimated that an additional 200 million hectares of new cropland will be required over the next 30 years just to feed the burgeoning populations of the tropical and subtropical regions. Although, only 93 million hectares are currently available and comfortably accessible (Rees and Wackernagel, 1996).

One of the challenges related to arid and desert areas is that most of these areas are coastlines and they include 41 % of the world's land surface and have two billion residents (Sternberg *et al.*, 2015). As the greatest biome, arid zones support 44 % of worldwide agriculture, half the world's livestock and are important for their biodiversity (D'Odorico *et al.*, 2013). However, identification of arid and desert areas and their extension has been inexact due to change climate and environmental factors (Thornton, 2010).

Salicornia, a promise as bioprospection

In terms of bio saline agriculture, *Salicornia* is one of the main halophytes with potential for commercial cultivation and is experimentally and semi-commercially grown on almost all continents (Jafari *et al.*, 2012). It is a promising plant resource in arid coastal zones due to its potential as food, fodder and as biofuel (Ksouri *et al.*, 2012). *Salicornia* species are the first halophyte selected for agricultural development and have been grown and harvested on demonstration plots and farms in Mexico, Egypt, The United Arab Emirates, Kuwait and Saudi Arabia (Rueda-Puente *et al*., 2017). However, until now the potential of *Salicornia* seeds has been for the extraction of high-quality oils for the cosmetology and aeronautical industry.

Being able to use a plant like *S. bigelovii* that tolerates high salinity conditions as forage is a point of special interest, especially in desert areas where livestock feed is usually scarce several months a year until the arrival of the rainy season. It would also open up the possibility of creating new farming and livestock production systems in areas where the coastal salt flats and other areas near the sea would not previously be considered.

The potential of this species as forage has been documented for decades. Riley *et al.* (1994) evaluated for several years the effect of feeding sheep and goats with various percentages of inclusion of *S. bigelovii*, finding that it can replace 50 % of conventional forages in sheep and 100 % in goats. Saoud *et al.* (2007), with a similar method, found that the sheep fed *Salicornia* gained more weight than in the control treatment, and although it could be thought that this weight difference is due to fluid retention due to the intake of salts contained in the plant, the authors discusses that this is not the case, but rather the ingested salts help to improve the digestion sheep, thus assimilating food better.

Other studies also highlight the potential of using the seeds of *S. bigelovii* and the by-product of oil extraction from them to feed species of aquaculture importance such as shrimp (Alam *et al.*, 2017) and tilapia (Ríos-Duran *et al.*, 2013), demonstrating that conventional diets can be partially or totally substituted by a low-cost one with the same benefit.

On the other hand, the effect of including the by-product of salicornia oil extraction for fattening chickens was also analyzed by Attia *et al.* (1997); these authors revealed by means of different percentages of inclusion of this protein-rich by-product (34 %) that it can replace the conventional chicken diet as long as cholesterol is added.

Salicornia has long been included in the diet of human beings, mainly in Mediterranean countries, where it is used as a garnish to accompany fish and seafood. In recent years, interest in its consumption has increased not only for its pleasant taste but also for its high nutritional value, as it is rich in minerals and antioxidants such as vitamin C and B-carotene (Ventura *et al.*, 2011). It is estimated that in conditions of high salinity (500 mM) the plant has a yield of 15 ton/ha per year of fresh product, which has a shelf life of six days but can be prolonged with refrigeration (Zerai *et al.*, 2010). In addition to its nutritional value as food, it is attributed medicinal and therapeutic effects. *Salicornia* shows positive effects for health problems like obesity, hypertension, diabetes, asthma, arthritis, sepsis and cancer. It is also important to note that the seed oil of the *Salicornia* plant is rich in linoleum acid (about 70 %), an essential fatty acid for health since it cannot be produced naturally by the human body, which makes it an ideal and healthy edible vegetable oil compared to other edible oils on the market as it has excellent antioxidant and anti-aging properties (Ventura *et al*., 2013).

The cultivated *Salicornia* yields 2 ton ha^{-1} with a content in the seeds of 28 % oil and 31 % protein, similar to soybean yield, being a common raw material for biofuel and food in depressed countries (Stanley, 2008; Greenlee *et al.*, 2009). *S. bigelovii* cultivation in the United States of America and Mexico, has also been successful in Pakistan, Egypt, Saudi Arabia, and the United Arab Emirates (Anwar *et al.*, 2002; Lobell *et al.*, 2008; Zerai *et al.*, 2010).

Commercial development of *S. bigelovii* in Baja California Sur (BCS), Kino Bay and Santa Ana, Sonora, reveals yields of oilseed that range from 500 to 2500 kg ha^{-1} as compared to soybean that shows a minimum oilseed yield of 1000 kg ha^{-1} and a maximum of 2500 kg ha^{-1} (Rueda-Puente *et al.*, 2017). The best dates for cultivating Salicornia recommended in the peninsula of Baja California are the months of January to March for the seed and from September to May for the vegetable (Fig. 1), being able to obtain a production of biomass (dry matter) up to 22 000 kg ha^{-1} and of seed of 1500 to 2000 kg ha^{-1}, with the potential to extract 600 kg of oil per hectare (Rueda-Puente *et al.*, 2003).

Halophytes, aquaponics and combined agriculture

Historically, the most relevant research in aquaponics systems in saline environments have been carried out in Australia, Israel, North America and Abu Dhabi, commonly with shrimp, marine fish, sea urchin and crustaceans, seaweed and seagrass (Murray *et al.*, 2014). However, the aquatic component has been especially problematic at the industrial level is related to the dependence of wild species used in feeding fish (Zanella, 2009). This dependence can be reduced by the production of alternative resources such as leguminous grains, seagrass or other halophytes or salt-loving plants that can be produced in the same system (Himabindu *et al.*, 2016). For example, the cultivation of protein-rich marine grasses with mullet or rabbitfish in aquaponics systems can provide feed ingredients for fish species of commercial importance. In general terms, an aquaponics module can produce about 0.568 kcal L^{-1} water and 0.050 g (protein)/L water (Enduta *et al.*, 2011). This implies an acceptable yield in comparison with traditional systems of aquaculture or hydroponics. In addition, other advantages besides the efficient use of water or the food, is

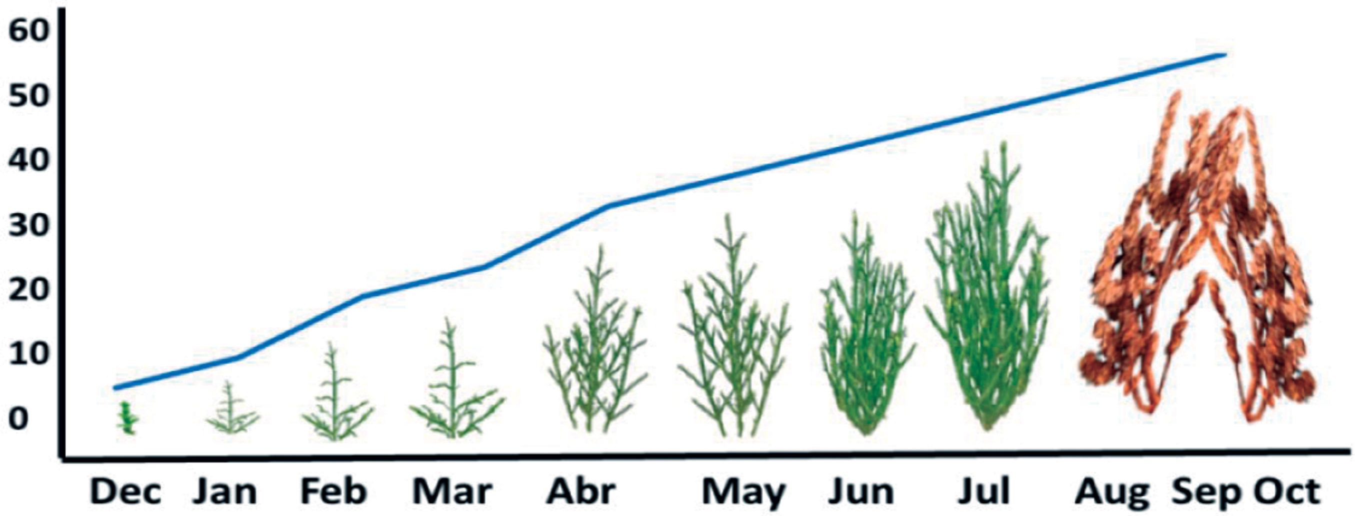

Figure 1. Average height (cm) of *Salicornia bigelovii* plants during their phenological description in the coastal area in Sonora, México.

the use of agricultural species that could have a high added value, either due to their components (fruit, leaf or root) or the use of secondary metabolites that increase the value of the product produced. Well-documented examples are the use of antioxidants, capsaicin, lycopene and other protein products derived (Raskin *et al.*, 2002). Also, the aquaponics systems may be a resource for obtaining marine products used in the pharmaceutical and biofuel industries (Klinger and Naylor, 2012).

Another important challenge and a problem still unresolved in the combined aquaponics systems is the constant increase in the conductivity and the handling of phosphorus that commonly put the efficiency of the system at risk (Savidov *et al.*, 2007). There are a small number of species that have a good response in the adaptability and efficiency of the system, and the commercial exploitation with the selected plants has been very inconsistent and there are not enough data to assess their success (Stankus, 2013). Some of the best-studied species are Murray cod (*Maccullochella peelii*) that integrated with green oak lettuce (*Lactuca sativa*) have had a good response in biomass gain in different hydroponic sub-systems as gravel bed, floating root and nutrient film technique (NFT), without differences in the constant of conductivity (Knaus and Palm 2017). In relation to the management of organic matter in a farm of fish operating a land-based recirculating aquaculture system (RAS), it was observed that polychaete assisted sand filters (*Hediste diversicolor*) combined with halophyte *Halimione portulacoides* remediate efficiently the organic matter generated (Marques *et al.*, 2017).

In Mexico, various models of RAS or NFT type have been carried out at the experimental level. Some has climbed at commercial level with several combinations, mainly catfish, shrimp and tilapia (Zetina-Cordoba *et al.*, 2006; Segovia-Quintero, 2011) combined with *Salicornia* spp. and *Gracilaria* spp. (Wade *et al.*, 2010). There is a model which it consists mainly in aquaponics systems and other with bio-filtration (SCB), in which principally loving-salt plants as Swiss chard, *Portulaca oleracea*, and aromatic plants as basil (*Ocimun basilicum*) (Buhmann *et al.*, 2015) has been explored. Some of the most successful production system are in Puerto Peñasco in Sonora and in Baja California Sur, México (Mariscal-Lagarda *et al.*, 2012). Efficient use of water in aquaponics in the northwest region of Mexico in the RAS hydroponics systems has not been fully tested at large scale because they have the same difficulties as always, such as the lack of initial funding for acquisition of infrastructure, experience and permanent training of technical personnel, in addition to high operating cost (Martínez-Porchas *et al.*, 2010; Klinger and Nailor, 2012). Moreover, there is a consideration that the critical aspects may change in each region or country according to electricity prices, heat availability, government policies, and the geographic environment and, consequently, there is no general optimal system, since this must be adjusted to environmental conditions (Lambin *et al.*, 2003; Ronzon-Ortega *et al.*, 2012).

Most of the aquaponics models experimented with integrated seawater in arid lands of Mexico are based on the combination of shrimp, hybrid tilapia, and *Salicornia* spp. (Rueda-Puente *et al.*, 2017; Klim, 2012; Mbaga, 2014; Bresdin, 2015). The crop system in Puerto Peñasco, Sonora in the north of Mexico with the seawater farm Eritrea Co. was the first integrated seawater farm in the world on a commercial scale (Zanella, 2009). The basis of the success of this farm is because it combines the extensive production of shrimps with *Salicornia*. Other alternatives for combined production with industrial potential have been the red algae (*Gracilaria algae*) for the agar industry (Cardozo *et al.*, 2007; Naylor *et al.*, 2009) or production of hydroponic green forage (Neori *et al.,* 2017). Segovia-Quintero (2011) cited that in

La Paz, at the south of the peninsula of California in Mexico, the aquaculture and hydroponic systems have shown an acceptable level of efficiency as in many places already documented in other arid regions in the world (Rakocy *et al.*, 2004; Graber and Junge, 2009), because particularly the climatic and orographic conditions of the peninsula, that could be extrapolated and serve as semi-commercial models to adapt in other arid and semi-arid regions of the world (Castellanos *et al.*, 2002; Cardona *et al.*, 2004; Geissler *et al.*, 2014; Rueda-Puente *et al.*, 2017). One of the most studied models due to its productive potential is the tilapia/basil model (Racoky *et al.*, 2004; Rodríguez-González *et al.*, 2015; Pérez-Fuentes *et al.*, 2016). The freshwater models, commonly consist in a bioflock model with tilapia and a variety of salt-loving plants, principally, those with high commercial value in international markets as basil, spinach (*Spinacea oleracea*), Swiss chard (*Beta vulgaris*), cebollin (*Allium schoenoprasum*), peppermint (*Mentha spicata*) and wild oregano (*Lippia palmeri*) (Bareño Rojas, 2006; SIAP, 2015). Also, this model explores the potential to use groundwater by linking the system to open-field cultivation with salt-tolerant crops as Jalapeño pepper (*Capsicum annuum*), habanero pepper (*Capsicum chinense*) and cherry tomato (*Solanum lycopersicon*) (Satreps, 2016). In Baja California Sur, Mexico, there are two aquaponics systems, one with bio-filtration (SCB) and another with water replacement (SRA). Both systems, have shown promising results with the combination of tilapia and acropolis lettuce. The growth time for tilapia and lettuce was 160 and 30 days, respectively, showing for tilapia the highest average growth values (364.64 ± 43.16 g), meanwhile, the lettuce grew better in SRA (11.74 ± 1.63 g) (Rodríguez-González *et al.*, 2015). Experiments with tilapia raised in a bio flock system under high density cultivation have shown that 10:1 C:N ratio provides good survival and growth of tilapia with no water exchange and seems to be a good strategy in areas where alkaline pH is a limiting factor for aquaculture activities, but the main finding was that application of biofloc technology (BFT) optimizes energy and resources during production. In the Centro de Investigaciones Biológicas del Noroeste S.C. (CIBNOR), in conjunction with the University of Tottori (Japan), are working on a project related to development of aquaponics combined with open culture adapting to arid regions for sustainable food production, in order to reduce the global impact of the food crisis by making efficient use of water resources, especially in sustainable open-field cultivation in arid zones (Satreps, 2016).

The theoretical plan is undoubtedly very important and necessary in long-term strategies for the production of foods, although to arrive at the commercial exploitation it is necessary to solve some operational difficulties such as maintaining balance in each of the phases and components, the cost, and the use of biological control (Rakocy *et al.*, 2004; Shi-Yang *et al.*, 2011; Okemwa, 2015). All of which require greater skills, knowledge and practice and, of course, evaluate the cost/benefit, integrating all possible aspects, including production, environmental and social, that contribute to securing safe water and food, countering threats to food security in the world.

About 15 years ago the University of Arizona commenced field experimental for the planting of halophyte in many desert areas of the world, such as Mexico, Gulf of California, United Arab Emirates, the Gulf of Oman, and Egypt, and different areas in the Persian Gulf (Nasar, 2014). Israel has focused most seriously on desert agriculture and has been quite successful. Considering their long-term record in the field of halophyte and desert agriculture, they have invested extensively in both types of research and on the production for several years to date (Panta *et al.*, 2014).

The Integrated Seawater Agriculture System™ project (ISAS™) considers aquaponics as a viable and sustainable strategy that includes novel concepts as long-term sustainability, mineral recycling, re-use of water, and combined production of aquatic and agricultural food with an added value that allows not only self-consumption but the generation of profits (Murray *et al.*, 2014).

Critical points

It is this review, we have analyzed the numerous advantages of bio-saline agriculture as a viable option to produce food. However, there are still aspects that need to be investigated as the requirements of inputs for the production of protein. These, including the use of fossil energy, the amount of water needed to produce a kilo of protein, and energy in terms of labor. For example, the cost of producing one hectare of *Salicornia* spp. is around 1 300 US dollars. Although the investment of the aforementioned values is unknown, we should consider the positive effects in terms of sustainability, benefit to the environment and social benefit. In the same sense, we should consider the energy required to desalinate seawater or saline water. The elimination of salts through reversible electrodialysis or reverse osmosis methods implies a high energy cost and a high CO_2 footprint. At the global level, the economic and environmental costs of desalination are still prohibitive for extensive use in irrigated agriculture and are only recommended for high-value agricultural products. Ultimately, market prices, profit margins in producer but non-consumer regions and the cost of moving the products to distribution points or collection centers can greatly vary from one country to another due to reasons not covered in this revision, as culture, resources availability, land tenure, local food supply, profit-oriented approaches, and water quality policies (Tirado *et al.*, 2010). Finally, the political and social environment that favors all these conditions will always be important for the final benefit of the population.

CONCLUSSION

Rapid growing human population is heightening pressure on current food resources and so we should manage this critical situation. The fact is that problems related to aridity, desertification, freshwater disponibility, and climate change are increasing more and more. Bio-saline agriculture is one of the best alternatives, with halophytes and other plants with the highest potential for salt tolerance being an important option, without omitting the continuity of bioprospecting to enlarge the number of halophytes with agroindustrial importance. These systems, together with the aquaponics techniques for the combined production of aquaculture systems and agriculture species, seem to be the best option to simultaneously address their environmental, social and economic issues concurrent with their growth. However, we must take into account that there is still a lack of quantitative research to support the development of economically feasible aquaponics systems. Undeniably, the problems that must be overcome for an environmentally safe and economically convenient use of saline lands and waters are still formidable, and their solution requires a coordinated effort by a vast number of experts in various domains.

ACKNOWLEDGMENTS

We thank to Universidad de Sonora and Conacyt and CIBNOR by Project of halophytes and Plant Growth promoting bacteria.

REFERENCES

Abideen Z, Hameed A, Koyro H, Gul B, Ansari R, Ajmal K. Sustainable biofuel production from non-food sources – An overview. Emir J Food Agri. 2014; 26(12):1057–1066. Doi: https://doi.org/10.9755/ejfa.v26i12.19107

Alam H, Khattak J, Ppoyil S, Kurup S, Ksiksi T. Landscaping with Native Plants in the UAE: A Review. Emir J Food Agric. 2017;29(10):729-41. Doi: https://doi.org/10.9755/ejfa.2017.v29.i10.319

Anwar F, Bhanger M, Khalil M, Nasir A, Ismail S. Analytical characterization of *Salicornia bigelovii* seed oil cultivated in Pakistan. J of Agric Food Chem. 2002; 50(15):4210-4214. Doi: https://doi.org/10.1021/jf0114132

Attia FM, Alsobayel AA, Kriadees MS, Al-Saiady MY, Bayoumi MS. Nutrient composition and feeding value of *Salicornia bigelovii* Torr meal in broiler diets. An Feed Sc Tech. 1997; 65(1):257-263. Doi: https://doi.org/10.1016/S0377-8401(96)01074-7

Bareño Rojas P. Hierbas aromáticas culinarias para exportacion en fresco, manejo agronómico, producción y costos. Bogota: Universidad Nacional de Colombia; 2006. p. 86–87.

Barrett C. Measuring food insecurity. Science. 2010; 327(5967):825-828.

Bates B, Kundzewicz S, Wu S, Palutikof J. Climate change and water. Technical Paper VI. Intergovernmental Panel on Climate Change. Geneva: IPCC; 2008. 214 p.

Bermúdez G. Planes rectores, sistemas productos estratégicos de Baja California Sur- sistema productos orgánicos: albahaca. La Paz: B.C. Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA); 2005. 210 p.

Bresdin C. Agronomy of halophytes as constructive use of saline systems (tesis de doctorado). Arizona: Soil, Water and Environmental Science Departament, University of Arizona; 2015. p. 24-34

Brown M, Funk C. Food security under climate change. Science. 2008; 319(5863): 580-581.

Buhmann A. Waller U, Wecker B, Papenbrock J. Optimization of culturing conditions and selection of species for the use of halophytes as biofilter for nutrient-rich saline water. Agric Wat Manag. 2015; 149:102-114. Doi: https://doi.org/10.1016/j.agwat.2014.11.001

Burchi F, de Muro P. From food availability to nutritional capabilities: Advancing food security analysis. Food Pol. 2016;60:10-19. Doi: https://doi.org/10.1016/j.foodpol.2015.03.008

Cardona A, Carrillo-Rivera J, Huizar-Álvarez R. Salinization in coastal aquifers of arid zones: an example from Santo Domingo, Baja California Sur, Mexico. Environ Geo. 2004; 45: 350. Doi: https://doi.org/10.1007/s00254-003-0874-2

Cardozo K, Guaratini T, Barros M, Falcão V, Tonon A, Lopes N, *et al*. Metabolites from algae with economic impact.Comparative Biochemistry and Physiology Part C: Tox Pharm. 2007; 146(1-2) 60-78. Doi: https://doi.org/10.1016/j.cbpc.2006.05.007

Castellanos J, Ortega-Guerrero A, Grajeda O, Vázquez-Alarcón A, Villalobos S, Muñoz-Ramos J, Zamudio B, Martínez J, Hurtado B, Vargas P, Enríquez S. Changes in the quality of groundwater for agricultural use in Guanajuato. Terra. 2002; 20(2):161-170.

Davy AJ, Bishop GF, Costa CSB. *Salicornia L.* (*Salicornia pusilla* J. Woods, *S. ramosissima* J. Woods, *S. europaea* L., *S. obscura* P.W. Ball & Tutin, *S. nitens* P.W. Ball & Tutin, *S. fragilis* P.W. Ball & Tutin and *S. dolichostachya* Moss). J Ecol. 2001; 89(4): 681–707. Doi: https://doi.org/10.1046/j.0022-0477.2001.00607.x

D'Odorico P, Bhattachan A, Davis K, Ravi S, Runyan C. Global desertification: Drivers and feedbacks. Adv Wat Res. 2013; 51:326–344.

Enduta A, Jusoh A, Ali N, Wan Nik W. Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system. Des Wat Treat. 2011;32(1-3):422-430. Doi: https://doi.org/10.5004/dwt.2011.2761

FAO. World agriculture: towards 2015/2030. Summary report. Rome, Food and Agriculture Organization of the United Nations, 2002. Available in: http://www.fao.org/docrep/005/ac911e/ac911e05.htm Cited: 29 Sep 2019.

Fedoroff NV, Battisti DS, Beachy RN, Cooper PJM, Fischhoff, DA, Hodges CN, *et al*. Radically Rethinking Agriculture for the 21st Century. Science. 2010; 327:833–834. Doi: https://doi.org/10.1126/science.1186834

Wade O, WatanabeT, Losordo M, Fitzsimmons K, Hanley F. Tilapia Production Systems in the Americas: Tech Adv T Chal. 2010;465-498. Doi: https://doi.org/10.1080/20026491051758

Flowers T, Galal H, Bromham L. Evolution of halophytes : multiple origins of salt tolerance in land plants. Func Plant Biol. 2010; 37:604–612.

Flores-Márquez EL, Campos-Enríquez JO, Chávez-Segura RE, Castro-García JA. Intrusión de agua salada del acuífero de la Costa de Hermosillo, Sonora, México: una simulación numérica. Geo Int. 1998; 37(3):133-151.

Jafari B, Hanifezadeh M, Jalali Parvin M. Molecular study of bacteria associated with *Salicornia* symbiotic bacteria as a candidate for Hormozgan salty zone culturing by Persian Gulf water irrigation. Af J Microbiol Res. 2012; 6(22):4687–4695.

Geissler N, Lieth H, Koyro H. Cash crop halophytes: the ecologically and economically sustainable use of naturally salt-resistant plants in the context of global changes. In: Ahmad P, Wani M, editors. Physiological Mechanisms and Adaptation Strategies in Plants Under Changing Environment. New York: Springer; 2014. 450 p.

Gerber N. Bioenergy and rural development in developing countries: a review of existing studies. Zentrum für Entwicklungsforschung (ZEF)-Discussion Papers on Development Policy; 2008. 76 p.

Glenn EP, O'Leary JW, Watson MC. Thompson TL, Kuehl RO. *Salicornia bigelovii* Torr.: an oilseed halophyte for seawater irrigation. Science. 1991; 251(4997): 1065-1067.

Graber A, Junge R. Aquaponic Systems: nutrient recycling from fish wastewater by vegetable production. Desalination. 2009; 246(1–3):147-156. Doi: https://doi.org/10.1016/j.desal.2008.03.048.

Greenlee FL, Lawler DF, Freeman BD, Marrot B, Moulin P. Reverse osmosis desalination: water sources, technology, and today's challenges. Wat Res. 2009; 43(9):2317-2348. Doi: https://doi.org/10.1016/j.watres.2009.03.010

Grigore M, Toma C, editors. Anatomical Adaptations of Halophytes. Iasi, Romania: Springer International Publishing AG; 2017. 322 p.

Gunning D, Maguire J, Burnell G. The Development of Sustainable Saltwater-Based Food Production Systems: A Review of Established and Novel Concepts. Water. 2016; 8(12):598. Doi: https://doi.org/10.3390/w8120598

Hari TK, Yaakob Z, Binitha NN. Aviation biofuel from renewable resources: Routes, opportunities and challenges. Ren Sust Ener Rev. 2015; 42, 1234-1244. Doi: https://doi.org/10.1016/j.rser.2014.10.095

Hillebard E. The Global Distribution of Income in 2050. W Dev. 2008; 36(5):727-740

Himabindu Y, Chakradhar T, Reddy MC, Kanygin A, Redding KE, Chandrasekhar T. Salt-tolerant genes from halophytes are potential key players of salt tolerance in glycophytes. Env Exp Bot. 2016; 124:39-63. Doi: https://doi.org/10.1016/j.envexpbot.2015.11.010

Kearney J. Food cons tr dri. Phil Tran Roy Soc B: Biol Sc. 2010; 365(1554):2793-2807. Doi: http://doi.org/10.1098/rstb.2010.0149

Klim B. Optimization model for the management of a horizontal sub-surface flow constructed wetland planted with the halophyte *Salicornia bigelovii* in the treatment of shrimp mariculture effluent (Order No. 1531818). Available in: https://search.proquest.com/docview/283126800?accountid=27958 Cited: 29 Sep 2019.

Knaus U, Palm H. Effects of the fish species choice on vegetables in aquaponics under spring-summer conditions in northern Germany (Mecklenburg Western Pomerania). Aquaculture. 2017; 473:62-73. Doi: https://doi.org/10.1016/j.aquaculture.2017.01.020

Klinger D, Naylor D. Searching for solutions in aquaculture: charting a sustainable course. An Rev Env Res. 2012; 37(1):247-276

Koehler A. Water use in LCA: managing the planet's freshwater resources. Int J Life. 2008; 13:451-455. Doi: https://doi.org/10.1007/s11367-008-0028-6

Körner C. Plant–environment interactions. Strasburger's Plant Sciences, Berlin, Heidelberg: Springer; 2013. p. 1065-1166. Doi: https://doi.org/10.1007/978-3-642-15518-5_12

Koyro H, Lieth H. Global water crisis: the potential of cash crop halophytes to reduce the dilemma. In: Lieth H, Sucre MG, Herzog B, editors. Mangroves and halophytes: restoration and utilisation. Tasks for Veg Sc, Springer; 2008. p. 43.

Koyro H, Khan M, Lieth H. Halophytic crops: A resource for the future to reduce the water crisis?. Em J Food Agric. 2011; 23(1):1–16. Doi: https://doi.org/10.9755/ejfa.v23i1.5308

Ksouri R, Ksouri W, Jallali I, Debez A, Magné C, Hiroko I, *et al*. Medicinal halophytes: potent source of health promoting biomolecules with medical, nutraceutical and food applications. Crit Rev Biot. 2012; 32(4):289-326. Doi: https://doi.org/10.3109/07388551.2011.630647

Ladeiro B. Saline agriculture in the 21st Century: Using salt contaminated resources to cope food requirements. J Bot. 2012; 7p. Doi: https://doi.org/10.1155/2012/310705

Lambin EF, Geist HJ, Lepers E. Dynamics of Land-Use and Land-Cover Change in Tropical Regions. An Rev Env Res. 2003; 28(1):205-241. Doi: https://doi.org/10.1146/annurev.energy.28.050302.105459

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor Rl, *et al*. Priorizing climate change adaptation needs for food security in 2030. Science. 2008; 319(5863):607-610. Doi: https://doi.org/10.1126/science.1152339

Mariscal-Lagarda M, Páez-Osuna F, Esquer-Méndez J, Guerrero-Monroy I, Romo del Vivar A, Félix-Gastelum R. Integrated culture of white shrimp (*Litopenaeus vannamei*) and tomato (*Lycopersicon esculentum* Mill) with low salinity groundwater: Management and production. Aquaculture. 2012; 366–367:76-84. Doi: https://doi.org/10.1016/j.aquaculture.2012.09.003

Masters DG, Benes SE, Norman HC. Biosaline agriculture for forage and livestock production. Agric Ecos Env. 2007; 119(3–4):234-248. Doi: https://doi.org/10.1016/j.agee.2006.08.003

Nasar M. Exploitation survey of sea water in agriculture of coastal deserts. Int Acad Ecol Env Sc. 2014; 4(2):72–80.

Marques B, Calado R, Lillebo AI. New species for the biomitigation of a super-intensive marine fish farm effluent: combined use of polychaete-assisted sand filters and halophyte aquaponics. Sci Total Environ. 2017; 599-600:1922-1928. Doi: https://doi.org/10.1016/j.scitotenv.2017.05.121

Martínez-Porchas M, Martínez-Córdova LR, Porchas-Cornejo MA, López-Elías JA. Shrimp polyculture: a potentially profitable, sustainable, but uncommon aquacultural practice. Rev Aq. 2010; 2(2):73–85. Doi: https://doi.org/10.1111/j.1753-5131.2010.01023.x

Mbaga M. The Prospects of sustainable desert agriculture to improve food security in Oman. Cons: J Sust Dev. 2014; 13(1):114-129.

Murray F, Bostock J, Fletcher D. Review of recirculation aquaculture system technologies and their commercial application. Stirling, Scotland: Highlands and Islands Enterprise, University of Stirling Aquaculture. 2014; 84 p.

Naylor RL, Hardy RW, Bureau DP, Chiu A, Elliott M, Farrell A, *et al*. Feeding aquaculture in an era of finite resources. PNAS. 2009; 106 (36):15103-15110. Doi: https://doi.org/10.1073/pnas.0905235106

Neori A, Shpigel M, Guttman L. The Development of Polyculture and Integrated Multi -Trophic Aquaculture (IMTA) in Israel: A Review. Isr J Aq. Bamidgeh, IJA_69.2017.1385. 2017; 19

Okemwa E. Challenges and opportunities to sustainability in aquaponics and hydroponics systems. Int J Sc Res Inn Tech. 2015; 2(11):23 p. 54

Padmavathiamma PK, Ahmed Mushtaque, Rahman HA. Phytoremediation - A sustainable approach for contaminant remediation in arid and semi-arid regions -a review. Em J Food Agric. 2014; 26(9):757-772. Doi: https://doi.org/10.9755/ejfa.v26i9.18202

Panta S, Flowers T, Lane P, Doylr R, Haros G, Shabala S. Halophyte agriculture : Success stories. Env Exp Bot. 2014; 107:71–83. Doi: https://doi.org/10.1016/j.envexpbot.2014.05.006

Pérez-Fuentes JA, Hernández-Vergara MP, Pérez-Rostro CI, Fogel I. C:N ratios affect nitrogen removal and production of Nile tilapia *Oreochromis niloticus* raised in a biofloc system under high density cultivation. Aquaculture. 2016; 452:247-251. ISSN 0044-8486. Doi: https://doi.org/10.1016/j.aquaculture.2015.11.010

Pimentel D, Berger B, Filiberto D, Newton M, Wolfe B, Karabinakis E, *et al*. Water resources: agricultural and environmental issues. BioSc. 2004; 54 (10):909-918

PRB. Population Reference Bureau. World Population Data Sheet. 2017; 20 p. Available in: http://www.prb.org. Cited: 25 Sep 2019.

Qadir M, Tubeileh A, Akhtar J, Larbi A, Minhas PS, Khan MA. Productivity enhancement of salt-affected environments through crop diversification. Land Deg Devel. 2008; 19(4), p.429–453.

Quezada F. Status and potential of commercial bioprospecting activities in Latin America and Caribe. Serie medio ambiente y desarrollo no. 132. Chile: Onu, Cepal; 2007. 24 p.

Ravallion M. How long will it take to lift one billion people out of poverty? The World Bank Research Observer. 2013; 28(2):139-158

Rees W, Wackernagel M. Urban ecological footprints: why cities cannot be sustainable—and why they are a key to sustainability. Env Imp As Rev. 1996; 16(4–6):223-248. Doi: https://doi.org/10.1016/S0195-9255(96)00022-4

Rakocy J, Shultz RC, Bailey DS, Thoman ES. Aquaponic production of tilapia and basil: Comparinga batch and staggered cropping system. Acta Hortic. 2004; 648:63–69. Doi: https://doi.org/10.17660/ActaHortic.2004.648.8

Raskin I, Ribnicky DM, Komarnytsk S, Ilic N, Poulev A, Borisjuk N, *et al*. Plants and human health in the twenty-first century. Tr Biot. 2002; 20(12):522-531. Doi: https://doi.org/10.1016/S0167-7799(02)02080-2

Riley JJ, Glenn EP, Mota CU. Small ruminant feeding trials on the Arabian Peninsula with Salicornia bigelovii Torr. In: Squires VR, Ayoub AT, editors. Halophytes as a resource for livestock and for rehabilitation of degraded lands. Netherlands: Springer Netherlands; 1994. p. 273-276.

Ríos-Durán MG, Valencia IR, Ross LG, Martínez-Palacios CA. Nutritional evaluation of autoclaved *Salicornia bigelovii* Torr. seed meal supplemented with varying levels of cholesterol on growth, nutrient utilization and survival of the Nile tilapia (*Oreochromis niloticus*). Aq int. 2013;21(6): 1355-1371. Doi: https://doi.org/10.1007/s10499-013-9638-5

Rodríguez-González H, Rubio-Cabrera S, García-Ulloa M, Montoya-Mejía M, Magallón-Barajas F. Análisis técnico de la producción de tilapia (*Oreochromis niloticus*) y lechuga (*Lactuca sativa*) en dos sistemas de acuaponía. Agro produc. 2015; 8(3):15-19.

Ronzon-Ortega M, Hernández-Vergara M, Pérez-Rostro C. Hydroponic and aquaponic production of sweet basil (*Ocimum basilicum*) and Giant River prawn (Macrobrachium rosenbergii). Trop Subt Agroecos. 2012; 15:(2): S63-S71.

Rougoor W, van Marrewijk C. Demography, growth, and global income inequality. World Development. 2015; 74:220-232. Doi: https://doi.org/10.1016/j.worlddev.2015.05.013

Rueda-Puente E, Castellanos T, Troyo-Diéguez E, Díaz de León-Alvarez JL, Murillo-Amador B. Effects of a nitrogen-fixing indigenous bacterium (*Klebsiella pneumoniae*) on the growth and development of the halophyte *Salicornia bigelovii* as a new crop for saline environments. J Agr Crop Sc. 2003; 189(5): 323–332. Doi: https://doi.org/10.1046/j.1439-037X.2003.00051.x

Rueda-Puente E, Murillo-Amador B, Ortega-García J, Rangel-Preciado P, Nieto- Garibay A, Holguín Peña R, *et al*. Desarrollo natural de la halófita *Salicornia bigelovii* (Tor.) en zona costera del estado de Sonora. Trop Subt Agroecos. 2017; 20(1):1-9.

Satreps. Development of Aquaponics Combined with Open Culture Adapting to Arid Regions for Sustainable Food Production. Avert food crises by making effective use of limited water resources. Science and technology Research Development Program. SATREPS. 2016. Available in: https://www.jst.go.jp/global/english/kadai/h2605_mexico.html Cited: 25 Sep 2020.

Saoud IP. Ensuring Food Security by Improving "Freshwater Use Efficiency" or by Farming the Seas. In: Murad S, Baydoun E, Daghir N, editors. Wat Ener Food Sus Mid East. Cham: Springer; 2017. 320 p.

Savidov NA, Hutchings E, Rakocy JE. Fish and plant production in a recirculating aquaponics system: a new approach to sustainable agriculture in Canada. Acta Hortic. 2007; 742:209-221. Doi: https://doi.org/10.17660/ActaHortic.2007.742.28

Shahid M, Jaradat AA, Rao NK. Use of Marginal Water for *Salicornia bigelovii* Torr. Planting in the United Arab Emirates. In: Shahid SA, Abdelfattah MA, Taha FK, editors. Developments in Soil Salinity Assessment and Reclamation; Netherlands: Springer Netherlands. 2013; p. 451-462.

Segovia-Quintero M. An overview on desert aquaculture in Mexico. In: Crespi V, Lovatelli A, editors. Aquaculture in desert and arid lands: development constraints and opportunities. FAO Technical Workshop. 6–9 July 2010, Hermosillo, Mexico. Rome: FAO Fisheries and Aquaculture Proceedings No. 20; 2011. p. 187–202.

Schmidhuber J, Tubiello NT. Global food security under climate change. Proc Nat Ac Sc USA. 2007; 104(50):19703-19708. Doi: http://doi.org/10.1073/pnas.0701976104

Shabala S, Mackay A. Ion Transport in Halophytes. Adv Bot Res. 2011; 57:152–187. Doi: https://doi.org/10.1016/B978-0-12-387692-8.00005-9

Zhanga S-Y, Li G, Wu H-B, Liu X-G, Yao Y-H, Tao L, *et al*. An integrated recirculating aquaculture system (RAS) for land-based fish farming: The effects on water quality and fish production. Aq Eng. 2011; 45(3):93-102. Doi: https://doi.org/10.1016/j.aquaeng.2011.08.001

Siap. Estadísticas de producción nacional. Available in: http://www.siap. gob.mx/cierre-de-laproduccion-agricola-por-estado. Cited: 18 Nov 2015.

Stanley O. Bio prospecting marine halophyte *Salicornia brachiata* for medical importance and salt encrusted land development. J Coa Dev. 2008; 11(2): 62-69.

Stankus A. Integrating Biosystems to foster Sustainable Aquaculture: Using Black Soldier Fly Larvae as Feed in Aquaponic Systems. (Master of Science Candidate). Zoology Department, University of Hawai'i Mānoa; 2013. 167 p.

Sternberg T, Rueff H, Middleton N. Contraction of the Gobi Desert, 2000 – 2012. Rem Sen. 2015; 7(2):1346–1358. Doi: https://doi.org/10.3390/rs70201346

Sullivan C. Calculating a water poverty index. World Dev. 2002; 30(7):1195-1210. Doi: https://doi.org/10.1016/S0305-750X(02)00035-9.

Tirado MC, Clarke R, Jaykus LA, McQuatters-Gollop A, Frank JM. Climate change and food safety: a review. Food Res Int. 2010; 43(7):1745-1765. Doi: https://doi.org/10.1016/j.foodres.2010.07.003

Thornton PK. Livestock production: Recent trends, future prospects. Phil Trans: Biol Sc. 2010; 365(1554), 2853-2867. Doi: https://doi.org/10.1098/rstb.2010.0134

Van Wesenbeeck CFA, Keyzer MA, Nubé M. Estimation of undernutrition and mean calorie intake in Africa: methodology, findings and implications. Int J Health Geo. 2009; 8: 37. Doi: http://doi.org/10.1186/1476-072X-8-37

Ventura Y, Wuddineh WA, Myrzabayeva M, Alikulov Z, Khozin-Goldberg I, Shpigel M, *et al*. Effect of seawater concentration on the productivity and nutritional value of annual *Salicornia* and perennial *Sarcocornia* halophytes as leafy vegetable crops. Sc Hort. 2011; 128(3): 189-196. Doi: https://doi.org/10.1016/j.scienta.2011.02.001

Von Grebmer K, Von Grebmer C, Rosegrant M, Olofinbiyi T, Wiesmann D, Fritschel H, *et al*. Global Hunger Index: The Challenge of Hunger: Ensuring Sustainable Food; 2012. 67 pp

Webb P, Coates J, Frongillo EA, Rogers BL, Swindale A, Bilisky P. Measurement measuring household food insecurity: why it's so important and yet so difficult to do. Advances in developing country food insecurity. J Nut. 2006; 136:1404S-1408S. Doi: https://doi.org/10.1093/jn/136.5.1404S

Wheeler T, Von Braun J. Climate change impacts on global food security. J Sc. 2013; 341(6145):508-513. Doi: https://doi.org/10.1126/science.1239402

Yamaguchi T, Blumwald E. Developing salt-tolerant crop plants: challenges and opportunities. Tr Plant Sc. 2005; 10(12):615-620. Doi: https://doi.org/10.1016/j.tplants.2005.10.002

Zanella D. Seawater forestry farming: An adaptive management strategy for productive opportunities in "barren" coastal lands (Order No. 1470817). Available from ProQuest Dissertations & Theses Global. 2009; (305183800). Available in: https://search.proquest.com/docview/305183800?accountid=27958. Cited: 25 Sep 2019.

Zerai DB, Glenn EP, Chaterved R, Lu Z, Mamood AN, Nelson SG, *et al*. Potential for improvement of *Salicornia bigelovii* through selective breeding. Ecol Engin. 2010; 36:730–9. Doi: https://doi.org/10.1016/j.ecoleng.2010.01.002

Zetina-Córdoba P, Reta-Mendiola J, Olguín-Palacios C, Acosta-Barradas R, Espinosa-Sánchez G. El cultivo de tilapia (*Oreochromis* spp) en la rentabilidad de seis agroecosistemas en el estado de Veracruz. Tec Pecu Mex. 2006; 44(2):169-179.