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Isabel Márquez-Rangel , Mario Cruz * , Alberto A. Neira-Vielma , Sonia Noemi Ramírez-Barrón , Pedro Aguilar-Zarate , Ruth Belmares *

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Importance of Crops in Arid Zones of Mexico with Food Development Potential: An Alternative in Low-Water Requirement Crops and Food Production

Isabel Márquez-Rangel [1], Mario Cruz [2,*], Alberto A. Neira-Vielma [1], Sonia N. Ramírez-Barrón [2], Pedro Aguilar-Zarate [3] and Ruth Belmares [1,*].

[1] School of Chemical Sciences, Autonomous University of Coahuila, Saltillo Coahuila. Boulevard Venustiano Carranza e Ing. José Cárdenas, Col. República C.P. 25280, Saltillo, Coahuila, México
[2] Department of Food Science and Technology, Antonio Narro Autonomous Agricultural University, Calzada Antonio Narro no. 1923, Col. Buenavista C.P. 25315, Saltillo, Coahuila, Mexico
[3] Engineering Department, Technological Institute of Ciudad Valles. Ciudad Valles, San Luis Potosi, Mexico
* Correspondence: myke13_80@hotmail.com (M.C.); ruthbelmares@uadec.edu.mx (R.B.)

Abstract: (1) Background: Climate change has several consequences; one of them is increasing the severity of droughts. This leads to an opportunity to study arid zone plants as food sources that have potential biological activities and improve consumer's health; (2) Methods: In this work we review recent research focused on the traditional use and importance of arid zone plants, their nutritional contribution, and the beneficial effects on health when consumed; these effects are primarily because of the antioxidant activity that inhibits free radicals and contributes to improved nutrition that benefits consumer's health; (3) Results: Several plant-based functional foods studies have shown that the consumption of bioactive compounds is a complement to drugs for preventing some chronic-degenerative diseases such as gastrointestinal diseases, diabetes, and obesity; (4) Conclusions: With all the previously mentioned, plants from arid and semi-arid zone are potential sources for developing foodstuffs in the current climate change situation.

Keywords: bioactive compounds; dryland plants; functional food; traditional foods

1. Introduction

Global warming and desertification have been the most important reasons for exploiting crops with low water requirements [1]. Arid areas occupy 46% of the planet's surface [2], receives less than 400 mm of annual precipitation, and is supported by more than 20% of the world's population [3]. Arid zone is expected to expand further, leading to an increase in the severity of droughts and food security [4,5]. Consequently, it is proposed to select crops from semi-arid and arid regions, which are undervalued by the general public, as a viable solution [6]. The use of Arid Zone Plants (AZP) has the potential to improve the sustainability of the agricultural sector in a context of climate change, thus contributing to ensure food security [7].

AZP have evolved distinct genotypic, biochemical, and physiological traits to adapt to harsh environmental conditions. The predominant physiological attributes exhibited by these plants include the existence of an extensive root system, stomatal pits, smaller leaves, leaf hairs, and waxy cuticles, which allow them greater adaptability to extreme ecosystems. In addition, they employ efficient photosynthetic pathways that allow them to optimize carbon assimilation while minimizing water transpiration [8–10]. Because of this, AZP could play a vital role in feeding in the coming years with low maintenance and low investment [11].

AZP are of great interest for their nutritional contribution, mainly fiber and amino acids [12]. Some of these plants or fruits are considered a nutritionally complete food due to their varied contribution of vitamins and minerals, besides being a potential source of bioactive compounds, mainly phenolic compounds with an important antioxidant activity useful for the prevention of

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diseases such as diabetes, hypercholesterolemia, obesity and hypertension, offering a better quality of life since they eliminate free radicals generated in our organism by environmental and other factors [13,14].

The objective of this review is to highlight the importance of Mexican AZP with low water requirements and food potential, their traditional consumption and their nutritional or beneficial effect on health.

2. Arid Zone Plants in Mexico

Mexico has a substantial variety of AZP that have functional food potential, primarily in the northern states (Figure 1). Whereas arid zones represent about 56.92 million hectares out of the 138 million hectares of forest in the country, the largest population of flora is found in semi-arid areas. Other plants have adapted to dry sub-humid areas, because of their adaptability and water availability, which have led to higher economic development [15]. Within the Mexican national territory there is a substantial biodiversity of species from arid zones that have nutritional and medicinal properties; some of these species have the potential to be exploited by the food, pharmaceutical, and chemical, allowing the development of new products that allow their use and provide health benefits.

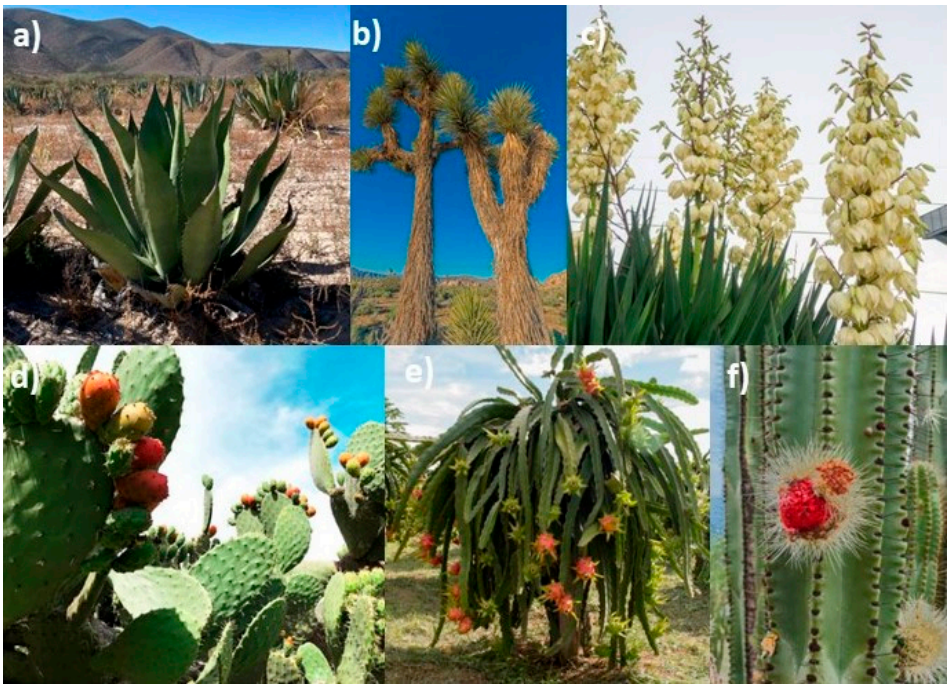

Figure 1. Arid zone plants a) Agave spp. b) Yucca spp. c) Yucca flowers d) Opuntia cladodes and fruit, e) Pitahaya, and f) Pitaya.

Agave spp. is a plant endemic to the American continent that has been used as a food source for more than 10,000 years, it is commonly known as maguey (Mexcalli from the Nahuatl language) [16]. There are more than 310 reported species, of which 272 are endemic to Mexico [17]. Agaves have great economic importance, they grow in arid and semi-arid areas and are characterized by three main parts: the leaves, which can be wide or narrow with or without thorns; a stem (heart or "pineapple"), this is found in the center of the plant surrounded by the leaves and is rich in fermentable sugars to obtain alcohols; and at the end of the plant's life (8-10 years and some species, such as *A. salmiana*, present a ramified inflorescence with flowers ("quiote") [18].

Yucca spp. belongs to the Agavoideae family of the genus *Asparagaceae*. *Yucca* spp. is endemic to North America, and it is one of the most representative succulents in Mexico, with nearly 50 species used in traditional medicine by Native Americans [19,20]. It is one of the plants with the lowest water

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requirements, consuming about 0.015 m3/day. It does not need much work to be cultivated and tolerates drought conditions in the arid and semi-arid zones, where it thrives [21].

Opuntia spp it is a cactus native to Mexico with exploitation in a substantial number of industries. It has been used as human and livestock food, in pharmaceutical development, wastewater treatment, pigment production, and soil erosion control [22]. *Opuntia Opuntia* is a perennial shrub or tree species with a trunk and crown of 3-5 m in height, characterized by segments called "cladodes" similar in appearance to a flat, fleshy, oval-shaped leaf; most species are found in Mexico, although cultivars have spread to some areas of Europe, Africa and Asia [23–25].

Opuntia spp. fruits, commonly called "tuna", have a spherical shape with cylindrical tendencies with different yellow, green, red and purple colorations due to their bioactive compounds. The fruits are small, between 7-9 cm long by 5-6 cm wide, while their weight varies between 86 to 146 g. Inside, the pulp contains seeds rich in linoleic acid, which has potential to be exploited in nutritional supplements, cosmetics and pharmaceuticals. While its peel whose main function is to protect the fruit, has a thickness of 0.65 mm and a coloration similar to that of its pulp, with small thorns of 3 to 10 mm and an umbilical zone. The peel comprises 40% of the fresh fruit weight and has potential for the extraction of starches, pectin, and fiber [26,27].

Hylocereus spp., also known as "pitayaha" or dragon fruit, are optional epiphytes that initially grow in the soil and then become epiphytes. The pitahaya is endemic to Mexico, Martinique, Guatemala, Costa Rica, Salvador, and Colombia. Although it is cultivated in many countries it is most cultivated countries with in arid, semi-arid or water-scarce regions. They grow in warm climates (38 to 40 °C) and thrive in rainy regions, but can adapt to different types of well-drained soils [28]. Depending on the variety, the flesh of the fruit is juicy and white, dark red or yellow, depending on the variety, and the pulp contains small black seeds. Its skin is bright red with green scales and represents 33% of the weight of the fruit, due to the appearance the fruit is decorative [29,30].

Stenocereus spp. Belongs to the Cactaceae family, which is composed of 24 species, some of which are mainly cultivated for their economic value such as *S. pruinosus*, *S. stellatus*, and *S. queretaroensis*, *S. thurberi*, *S. griseus*, *S. laevigatus*, *S. longispinus*, and *S. huastecorum*; they have been categorized as endemic to Mexico. The genus *Stenocereus* grows as a columnar cactus in arid and semi-arid areas, and it has low water and nutrient requirements; their reproductive season takes place between April and September. They bloom pink flowers, which can lead to a small, slightly oval, or spherical fruit with deciduous thorns in its skin. The fruit's pulp can be of different intense colors due to the presence of betalains (white, yellow, pink, orange, red or purple), it has small edible seeds, low acidity, and a sweet flavour [31,32].

Being plants with low water requirements and that thrive in drought conditions, they can be considered an alternative for developing food additives or used directly as foodstuff. The nutritional value of some of these species has not been studied enough to be considered as food ingredients with some beneficial functionality to health, so it is important to raise awareness among the population of their use for greater utilization and in encourage the population to use them for better utilization and in response to the availability of low-maintenance food.

As these plants have low water requirements and thrive in drought conditions, they can be considered as an alternative to develop food additives or be used directly as food. The nutritional value of some of these species has not been studied enough to be considered as food ingredients with some beneficial functionality to health, however, it is important to encourage the population to use them for better utilization and in response to the availability of low-maintenance food.

3. Nutritional Benefits and Importance of Arid Zone Plants

Several studies have evaluated the nutritional composition of plants from arid and semi-arid areas. These studies have determined the content of moisture, proteins, carbohydrates, fiber and lipids, most of these plants are characterized by their high moisture and carbohydrate content (Table 1), however, in some cases the amount of lipids and proteins is important.

Table 1. Macronutrient composition of Arid zone plants.

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Component (%)	*Agave* spp	*Yucca* flowers	*Opuntia* spp	*Opuntia* fruit	*Hylocereus*	*Stenocereus*
Moisture	6.44-8.5	50-70	90.1	89.96	87-88.01	85.8
Carbohydrate	60-74	9.77	8.17	1.35	9.34-11	12.33
Proteins	2.5-8.35	0.31	0.36	1.18	0.18-1.1	1.29
Lipids	0.3	17.55	0.14	0.76	0.4-0.45	0.12
Fiber	5-8	19.23	2.75	2.84	0.45-3	3.23
Ashes	6-8	1.60	1.32	6.75	0.96	0.46
Authors	[16,33]	[34]	[35]	[36]	[37]	[38]

Agave spp. Its main use has been for the production of distilled and non-distilled alcoholic beverages thanks to its high reserve sugar content [39]. Agaves contain mostly carbohydrates such as sucrose, fructose, glucose and fructans [40]. Fructans are fructose polymers derived from sucrose with β (2→1) and/or β (2→6) bonds that can have terminal or intermediate glucose, nutritionally they have been of interest due to their prebiotic benefits such as soluble dietary fiber helping improve intestinal health, as well as the improvement of technological functions in foods such as stabilizers and sweeteners [41–43].

Yucca spp.'s flowers have been the primary interest of Yucca spp. because of their antioxidant compound content and their effect on chronic-degenerative diseases [44].

Opuntia spp.'s nutritional profiles vary according to the species, the post-harvest treatment, the environmental conditions, and the age of the plant. One of the greatest nutritional compounds of interest is its natural fiber, in which the soluble fiber is in the form of a mucilage [24,45,46]. Opuntia fruits are 57 % of the edible fraction; most of the edible fraction is composed of water, whereas the rest are different nutrients: primarily carbohydrates, fiber, and proteins. In addition, it has a high content of minerals including potassium, magnesium, and calcium and a high content of vitamins, namely, vitamin C and niacin [23].

Hylocereus pulp represent 45 % of the fruit; water content in the pulp ranges from 87 to 88 %. It is a fruit with acceptable nutritional value because of its high content of carbohydrate, fiber, protein, and vitamins (B1, B2, B3, and C), providing some minerals such as a potassium, sodium, phosphorus, iron, and calcium [37,47].

Stenocereus or pitaya fruits contain nutrients very similar to the fruit of Hylocereus, but with different concentrations. They have an acidic pH of 3.7 to 4.46 and presence of carbohydrates, proteins, fiber, and fats [38,48].

4. Importance and Traditional Use of Arid Zone Plants

The use of most of the Mexican endemic plants is focused on medicine in accordance to the belief of the native indigenous people that some plants were able to alleviate the discomforts of the body through their consumption. Recent research has helped to understand these beliefs. However, a substantial number of the AZP have been consumed as part of the diet or for specific purposes. Many of these plants have strong culinary importance within traditional gastronomy as well as new food applications. Some of these uses can be seen in Figure 2.

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Figure 2. Traditional food uses of arid zone plants a) Pulque, b) Pulque bread, c) Yucca flower dish, d) Nopales dish, e) Artisanal fermented prickly pear juice (Colonche), f) Pitaya wine, g) Dragon fruit (Pitahaya), and h) Pitaya fruit ("tuna de pitaya").

Agaves, in Mexican culture, have been used as a source of food for man and livestock, medicine, drinks, preparation of some dishes, honey, syrups, construction material, fibers, vinegar and ornaments. Currently, greater importance has been given to the production of alcoholic beverages [39,49]. Alcoholic beverages obtained from agaves have different names depending on their process and their designation of origin [50]. Some of the distillates are Tequila, Mezcal, Bacanora, and Raicilla, obtained from different species of agaves and their name is given by the state where the species are grown [18,51]. While in fermented drinks, pulque is found with probiotic properties and is obtained through the fermentation of aguamiel, a sweet liquid obtained from the center of species such as A. salmiana. A bread called "Pan de Pulque" is also produced from pulque [18,52].

Yucca spp. is mostly used for its flowers, which receive different names depending on the geographical area ("flor de izote", "chochas" or "flor de palma"). It is common to see them freshly cut in local markets. The flowers are incorporated into various dishes of Mexican cuisine: salads, side dishes, and stews with various vegetables, meats, and peppers. To prepare them, the stem and pistil are removed, then they are cooked with water and salt. One of its principal characteristics is its bitter taste, and its consumption is limited to the traditional use of indigenous cultures [44].

Traditional dishes with the cladodes of Opuntia spp. have been used in traditional folk medicine for its beneficial effects to treat chronic diseases, but also as a food source because of its nutritional properties and biological activities. Its consumption is distributed worldwide due to its low cost, and in gastronomy there is a great diversity of dishes made with this plant [53]. In some places the plant is used as livestock food, to build fences, and for ornamental purposes [54].

Opuntia spp.´s fruit or "tuna" is used in traditional folk medicine for treating stomach-related diseases, diabetes, and obesity [55]. In ancient times it was used to make wine, however, recently it is used to produce cheese, jam, and juices, in addition to various compounds of interest to the food industry. Fruit residues are also used as fodder for animal in dry seasons [56].

In the pre-Hispanic Mexican population, pitaya and pitahaya fruits have been an important source of food because of their water and nutrient content, but also parts of the plant such as the stem have been used for gastritis problems. Because of their flavor, the fruits have been consumed as fresh fruit or in processed products such as dried fruits and licors [48]. The pulp of Hylocereus has nutritional and healing properties, its consumption can help reduce blood sugar levels, improve nutrient absorption, reduce blood cholesterol, while the leaves have antibacterial properties that have been used in the treatment of infectious diseases and the stems have helped to improve the health of some people, due to its traditional consumption there are some theories that indicate that the fruit of Hylocereus prevents colon cancer and improves the functioning of the brain, kidneys and visual acuity [37].

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5. Arid Zone Plants' Bioactive Compounds and Their Foodstuff Usage

Bioactive compounds are relevant in foodstuffs because they can improve health through the different functional activities involved in their metabolism. AZP contain several bioactive compounds that have been evaluated for human consumption, and several have been found to improve health. Table 2 lists the bioactive compounds found in AZP and briefly describes their functional activities.

Table 2. Bioactive compounds found in arid zone plants and their functionality.

Plants	Bioactive compounds	Functional activity	Author
Agave spp.	Polyphenols (flavonoids), Terpenoids, Steroids, Glycosides, Fructans, Inulin, Oligosaccharides (fructooligosaccharides).	Prebiotic activity Antioxidant activity Anti-inflammatory activity Antimicrobial activity Antifungal activity Improvement of nutritional, rheological, thermal, and sensory properties	[51,57–64]
***Yucca* spp.**	Polyphenols (Gallic acid, 4-hydroxybenzoic acid, Vanillic acid, Chlorogenic acid, Caffeic acid, 4-Coumaric acid, Ferulic acid, Rutin, Quercetin 3-D-galactoside, Quercetin 3-glucoside, *Trans*-cinnamic acid, Quercetin, Kaempferol), saponins.	Antioxidant activity Ant—inflammatory activity Antimicrobial activity	[34,65,66]
***Opuntia spp* (Cladodes)**	Phenols (gallic acid, epicatechin gallate, vanillic acid, chlorogenic acid, procyanidin B2, epicatechin, vanillin, p-coumaric acid, epigallocatechin, ferulic acid, synapic acid, benzoic acid, ellagic acid, hyperoside, isoquercetin, rutin, chloridzine, quercetin, vitamin C & E, and flavonoids; Caempferol, Hyperoside, Prociadin), Terpenoids (β-carotene, α-carotene, lutein, zeaxanthin).	Antioxidant activity Hypoglycemic activity Antibacterial activity	[23,53,67–70]
***Opuntia spp* (fruit)**	Phenols (vitamin A, C & E, flavonoids; rutin, quercetin glucoside, isorhamnetin glucosyl-dirhamnoside, isorhamnetin	Antioxidant activity Antimicrobial activity	[71–75]

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	pentosyl-rutinoside, isorhamnetin pentosyl-glucoside, isorhamnetin pentosyl-rhamnoside, isorhamnetin rutinoside, isorhamnetin glucoside, quercetin), Betalains (betaxanthins, muscaaurin, indicaxanthin isomer I, indicaxanthin isomer II, betacyanins, betanin, betanidin-5-O-β-glucoside, gomphrenin, betanidin isobetanin, indicaxanthin isomer, indicaxanthin, betanin isomer), Terpenoids (carotenoids), and Organic acids (malic acid, quinic acid, citric acid, succinic acid, piscidic acid derivative I, piscidic acid derivative II, piscidic acid, 2-Feruloyl piscidic acid, hydroxybenzoic acid, eucomic acid, ferulic acid glucoside, caffeic acid, and fumaric acid)	Anti-inflammatory activity Hypoglycemic activity Antiulcerogenic activity	
Hylocereus spp.	Phenols (vitamins, flavonoids, phenolic acids, and betalains; betacyanins, betanin, isobetanin, betanidin, phyllocactin and hylocerenin), Terpenoids, Fatty acids and sterols	Antioxidant activity Antimicrobial activity Prebiotic activity	[47,76–82]
Stenocereus spp.	Phenols and betalains (isobetanin, betanidin, 17-Decarboxy-neobetanin, isobetanidin, neobetanin, 2-Decarboxy-neobetanin, betacyanins and betaxanthines).	Antioxidant potential	[31,83,84]

5.1. Agave Leaves

Agave leaves, which are considered an agro-industrial waste, are of interest because they contain bioactive compounds with substantial biological activities (López-Romero et al. 2017; Puente-Garza, García-Lara, et al. 2017). Saponins, flavonoids, homoisoflavonoids, phenolic acids, and fatty acids have been identified in different cultivars of Agaves. Saponins and homoisoflavonoids have shown anti-inflammatory and ulceroprotective activities in rats treated with extracts from *A. pygmaea* (81 and 85 % protection) and *A. angustifolia* var. *Marginata* (84 % and 91 % protection). These results compared to the 96.875 % protection offered by ranitidine suggests that these extracts could be an alternative to a drug treatment for ulcers (El-Hawary et al. 2020). The crude extracts of *A. americana* have shown the presence of alkaloids, saponins, tannins, polyphenols, and flavonoids. The

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antibacterial activity of these extracts has been evaluated in the crude and the solvent fractions; the results showed an efficient bactericidal effect with an inhibition of 17 to 40 mm, comparable to gentamicin, in pathogenic bacteria commonly present in food as S. typhi, *S. aureus* and *E. coli*. The bactericidal effect obtained is mostly due to the saponins, however, other compounds could also interfere with the antimicrobial activity as alkaloids, flavonoids, tannins, and phenolic compounds (Shegute and Wasihun 2020). Although agave leaves have been mostly used for developing biopolymers, recent research suggests the use of bioactive compounds in the pharmaceutical industry. Nevertheless, the application of agave leaves in the food industry is of primary relevance.

5.2. Pulque and Agave Syrup

Pulque, a beverage of traditional relevance, has been used for prevention and treatment of gastrointestinal diseases; the *Lactobacillus* it contains exert and anti-inflammatory effect whereas its exopolysaccharides reduce cholesterol [85]. Fructooligosaccharides in agave syrup help activating the immune system; consequently, increasing resistance to infections [86]. Recent research suggests that consumption of agave fructans can help treat obesity, metabolic syndrome, type II diabetes, and gastrointestinal diseases such as Crohn's disease, ulcerative colitis, and irritable bowel syndrome [60,87]. The most important component of mead and pulque is the substantial diversity of microorganisms that confer a probiotic effect. Researchers have identified yeasts of the *Candida*, *Kluyveromyces*, *Saccharomyces*, and *Clavispora* genus and bacteria of *Lactobacillus*, *Leuconostoc,* and *Acetobacter* genus in mead and pulque [88]. In addition, the fructan content can lead to a prebiotic effect, which means that these beverages can have a symbiotic effect in the gastrointestinal microbiota. The symbiotic effect improves health by producing short-chain fatty acids such as acetate, propionate, and butyrate [89]. Kammogenins, manogenin, gentrogenin, and hecogenin derived saponins have been identified in mead; the saponin content heavily relies on the maturity of the agave used to produce the mead. These saponins have several biological properties such as anticancer, antibacterial, and antifungal activities. In addition, their antioxidant effect has been reported equivalent to 904.8 μM of gallic acid, which means they can also provide antioxidant-associated health benefits [90].

5.3. Yucca Leaves and Fruits

Yucca spp. have a high saponin content that have surfactant and detergent properties. The plant is rich in polyphenols with antioxidant, antimicrobial, and anti-inflammatory properties and they are used to improve intestinal health [65,66]. Additionally, there are several other compounds that have shown antimicrobial activity towards relevant bacteria in food safety, namely, *Escherichia coli, Salmonella typhimurium*, and *Staphylococcus aureus*. These compounds are saponins (Spirostan-3-ol, spirostanol-3-ol-dihexose, di-glucoside, and hecogenin), organic and phenolic acids (maleic acid, citraconic acid, muconic acid, and caffeic acid) and other compounds such as flavones, flavonoids, and some glycosides.

One of the negative effects of food infections by bacteria is intestinal inflammation, it has been shown that the compounds present in yucca reduce inflammation by the effect of antioxidant activity capable of eliminating free radicals, a study demonstrated through a model of acute inflammation in mice the reduction of edema in paw using 200 mg / kg of *Yucca gigantea* extract in which a reduction was obtained from 0. 3703 mm to 0.01 mm after four hours of study, so the antimicrobial effect of this plant promises the ability to help reduce or prevent intestinal inflammation caused by pathogens and in turn could prevent cancer when incorporated into functional foods, nutraceuticals, or natural drugs [91]. Morales-Figueroa and colleagues determined the antimicrobial activity of the phenolic compounds and saponins found in *Y. baccata* against gram-negative bacteria with relevance in the pharmaceutical and food industry as an *Escherichia coli, Pseudomonas aeruginosa*, and *Salmonella typhi*. Values of 100 mg mL-1 and 120 mg mL-1 of minimum inhibitory concentration were estimated for pathogenic bacteria; the inhibitory effect was higher for large negative bacteria due to the presence of phenolic compounds and saponins [92]. Similarly, the oil of *Y. aloifolia* Linn fruits were characterized, and the results showed the presence of fatty acids, namely, linoleic acid (73.38 %), oleic

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acid (13.52 %), and palmitic acid (8. 18 %), and a total of 204 mg/100 g of vitamin E. All these compounds provide potential for antioxidant, anticarcinogenic, neuro and cardio protective effects, in addition to cholesterol-lowering properties. In vivo and clinical studies should be conducted to determine it, but this could lead to consider *Y. aloifolia* fruit oil a functional oil with beneficial effects to human health that could be used for disease prevention [93].

5.4. Opuntia Cladodes and Fruits

Several studies working with Opuntia plants have shown in vitro and in vivo that their biological activities are beneficial to health [23,53]. Cladodes and fruits are rich in phenolic compounds and terpenoids [67–70]. Consuming Opuntia cladodes and fruits regulates weight, control diabetes, and reduce cholesterol levels; also, they are a good source of potassium [24,45,46]. When Opuntia fruits are consumed raw, their bioactive compounds show antimicrobial, antiproliferative, hypolipidemic, glycemic control and positive effects on colonic health [27].

Fermenting the juice from O. humifusa cladodes with lactic acid bacteria (LAB) and the own plant's enzymes has shown to improve its functional properties. The fermentation increases polyphenol content during the first 24 hours; after fermenting the juice with LAB for 60 h, the final amount of polyphenols was in the range of 723 to 785 μg GAE mL-1. Testing Lactobacillus plantarum, Streptococcus salivarius, and Weissella confuse, and a mixture of the three bacteria by adding an enzyme to all treatments, a treatment with the enzyme alone was used, which showed a lower antioxidant activity. Therefore, this helped to determine that the interaction of LAB in the presence of an enzyme works to increase the phenolic content of the treatments. Two of the identified compounds responsible for the antioxidant activity were quercetin and isorhamnetin, which are flavonoid aglycones with strong antioxidant power. However, the isorhamnetin-3-O-glucoside content decreased to undetectable levels after fermentation, which might lead to believe the highest antioxidant activity relies on quercetin. This study demonstrates that fermentation with certain bacteria may be suitable to enhance the beneficial effects of the compounds found in these plants and have a greater effect on consumer's health [94].

O. littoralis cladodes and fruits have already been characterized. Kaempferol was quantitated at 503.96 mg g-1 in cladodes and 428.96 mg g-1 in fruits. Terpenes were quantitated at 16.75 mg g-1 in cladodes and 15.69 mg g-1 in fruits. Additionally, the total content of betalains in fruits were determined to 59.5 mg g-1, of which, 23 mg g-1 are betaxanthins and 36.7 mg g-1 to betacyanins. Similarly, Opuntia fruits have a significant antidiabetic activity due to the α-glucosidase inhibitor. A microplate study showed an anti-diabetic activity due to the α-glucosidase inhibitor of IC50 57.7 % compared to the control drug (Acarbose) with an inhibition of IC50 30.57 %. This effect is given by the compounds present in the fruit such as Kaempferol and ferulic acid which help in blood glucose lowering. This could lead to Opuntia fruits being able to be considered for the prevention, treatment or both of glycemia and type 2 diabetes mellitus [95].

Opuntia fruits are rich in organic acids including, phenolic compounds, betalains, and carotenoids [72–75]. Its fiber content causes significant reductions in total cholesterol in hyperlipidemic populations; however, the effects are lower in patients that consumed the fruits and cladodes [46]. The fruit's antioxidant, hypoglycemic, anti-ulcerogenic, and anti-inflammatory activity has also been documented [26].

The antioxidant and antimicrobial compounds of O. microdasys' and O. macrorhiza's fruits were quantitated. The fruits' peels have phenolic compounds, with a content of 0.58 mg g-1 for O. microdasys' peel and 1.55 mg g-1 for O. macrorhiza's peel, and betacyanins with a content of 3.6 for O. microdasys' skin and 131 mg g-1 O. macrorhiza's skin. The same study demonstrated the antifungal and antimicrobial potential that the fruit peel has; the fruit's peel showed inhibition of microorganisms and leads to think that the fruit's peel has an important food application [96].

A comparative study of the betalain content between of O. ficus-indica's fruits from Mexican and Spanish cultivars showed that both cultivars have potential to be used as functional ingredients. Betalain content was quantitated to 2422.5 μg g-1 for the Mexican cultivar and 1650.6 μg g-1 for the Spanish cultivar in purple dry whole fruit. In dry red whole fruit, it was determined to 582.6 μg g-1

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for the Mexican cultivar and to 819.8 μg g-1 for the Spanish cultivar. Finally, for yellow dry whole fruit the betalain content was quantitated to 587.9 μg g-1 for the Mexican cultivar and 156.2 μg g-1 for the Spanish cultivar. Additionally, the psidic acid content was determined to be 43882.7 μg g-1 in dry peel of the purple Spanish cultivar. A betalain content of 2422.5 and 1650.6 μg g-1 dry base of the whole fruit (purple), 582.6 and 819.8 μg g-1 dry base of the whole fruit (red) 587.9 and 156.2 μg g-1 respectively in dry base of the whole fruit (yellow) and an important content of phenolic compounds such as piscidic acid with a value of 43882.7 μg g-1 dry base in the peel of the purple Spanish cultivar were identified. These results indicate that the content of betalains and phenols in these cultivars is important for their use in the development of foods and nutraceuticals, as well as in the investigation of their biological activities [97].

5.5. Pitahaya and Pitaya Fruits

Hylocereus' (pitahaya) fruits, also known as dragon fruits, contain several phenolic compounds that exert antioxidant and antimicrobial activities [47,80,81]. Its main component is betalains [31]. Dragon fruits' pulp also contain oligosaccharides of different molecular weights that can provide prebiotic effects against beneficial strains, including Lactobacillus and Bifidobacterium. Its consistent consumption regulates cholesterol metabolism and ameliorates weight control and diabetes [47].

The seeds are a source of antioxidants and essential fatty acids such as linoleic acid, and they may be a new source of essential oils because they are in higher amounts than in canola, flaxseed, or sesame seeds [47]. Bioactive compounds in the fruit have shown to aid in obesity control, non-alcoholic fatty liver disease, type II diabetes, and they prevent colon and intestines inflammation [98].

Stenocereus (pitaya) fruits are distinctive by their betalains content [84], which is responsible for the color of the fruit, and by their water-soluble phenolic compounds that confer the fruits their antioxidant activity. The presence of both betalains and phenolic compounds makes the pitaya fruits a better alternative to other natural pigments [31,99].

6. Use of Traditional Crops for the Development of Functional Foods

Currently, the area of functional foods has focused on using raw foodstuffs, with bioactive activities, to can help improve consumer's health, many of these foods have been associated with a lower incidence related to health problems. The primary objective of functional food and nutrition research is to ameliorate health problems that society faces including bioactive compounds such as fiber, antioxidants, phytochemicals, and others, these have the capacity to improve health, generate well-being, and are useful to prevent the risk of suffering diseases nowadays like gastrointestinal diseases, diabetes, obesity, cancer, and diseases related with free radicals in the human body. Incorporating bioactive compounds into foodstuffs leads to several changes; these include modifying the physical characteristics of a product, decreasing the caloric intake of the food, and improving absorption the bioactive compounds and nutrients during digestion. Ultimately, these bioactive compounds are a healthier option than chemical additives have a better stability and bioavailability of their benefits, representing a better option for the use of food ingredients [100–102].

Every passing day consumers are more involved in their nutrition and the health benefits proper nutrition offers [103]. There is a direct relationship between food and health, however, factors such as urbanization, economic development and changes in lifestyle can negatively affect eating habits [104]. Therefore, improving nutrition with foods, plants, and fruits with a functional effect to reduce the health issues is of great importance.

Recent research shows us an alternative to new products that could be marketed within the functional food market. However, two of the greatest challenges are determining the effectiveness in human health of this type of food and achieving consumer acceptance. Therefore, it of great importance to continue working to obtain foods that guarantee health benefits and at the same time have the sensory characteristics that the customer demands.

The different foods developed with AZP are mainly characterized by their antioxidant content. Unfortunately, no study has been able to guarantee the effectiveness of the bioactive potential directly in humans in a clinical setting. However, tests carried out at laboratory level show a strong response

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to biological activities, namely, antioxidant, antimicrobial, hypoglycemic, anti-inflammatory, probiotic, and prebiotic activities. These could be able to contribute to prevent health problems in addition to proper nutrition and physical activity. Table 3 summarizes work done using AZP in different foodstuffs.

Table 3. Use of arid zone plants in foods with functional potential and/or improvement of physical properties.

Plants	Food or additive	Functional contribution	Bioactive compound	Author
Agave spp	Powdered extract of *Agave salmiana* fructans	Prebiotic activity and Anti-inflammatory activity	Fructans	[63]
	Cookies with *Agave angustifolia* fructans as a fat substitute	Improved rheological properties	Fructans	[59]
	Reduced fat cheeses	Improved nutritional qualities	Fructans	[61]
	Ice cream	Improved thermal properties	Fructans	[62]
	Dehydrated apple enriched with prebiotics	Prebiotic activity and sensory properties	Fructans	[64]
***Yucca* spp.**	Antimicrobial control in food Food packaging development	Antimicrobial activity	Saponins	[105]
***Opuntia spp* (Cladodes)**	Pasta with flour from *Opuntia* cladodes	Antioxidant activity Hypoglycemic activity	Fiber	[45]
	Prickly pear cladode juice	Antioxidant activity	Gallic acid, epicatechin gallate, vanillic acid, procyanidin B2, epicatechin, p-Coumaric acid, epigallocatechin, ferulic acid, sinapic acid, benzoic acid, hyperoside, isoquercetin, rutin, quercetin	[67]
	Cookies gluten-free with flour from cactus	Antioxidant activity	Fiber soluble and insoluble, flavonoids, phenolic acids, leutin. β-carotene, zeaxanthin, α-carotene	[70]
	Bread with *Opuntia ficus-indica* mucilage	Antioxidant activity	Mucilage	[69]
	Pigment	Antioxidant activity	Betacyanins, betaxanthins	[72]

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***Opuntia spp* (fruit)**	Gummy candy	Antioxidant activity	Betalains	[73]
	Cookies enriched with prickly pear peel flour	Antioxidant activity	Carotenoids, betalains, betacyanins, betaxantins	[74]
	Edible films	Antioxidant activity and antimicrobial activity	Betalains	[75]
	Yogurt	Antioxidant activity	Betacyanins; betanin, isobetanin, betanidin, phyllocactin,hyloccerenin	[76]
	Wine	Antioxidant activity	Succinic acid, citric acid, acetic acid,	[77]
Hylocereus spp.	Gummy candy	Antioxidant activity	Betalains	[78]
	Chinese steamed bread enriched with pitaya peel powder	Antioxidant activity	Batacyanin	[79]
	Reduced-fat ice cream	Antioxidant activity Technological and physicochemical properties	Betacyanins, fiber and minerals	[82]
	Natural colourant	Antioxidant activity	Betalains, isobetanin, betanidin, 17-Decarboxy-neobetanin, isobetanidin, neobetanin, 2-Decarbaxy-neobetanin	[84]
	Pitaya juice powders	Antioxidant activity	Betalains, fructose, glucose, sucrose, citric acid, malic acid and tartaric acid	[106]
Stenocereus spp.	Low-sugar food colorant	Antioxidant and antimicrobial activity	Betaxantinas	[99]

7. Conclusions

In recent years, growing concern has focused on food shortage and climate change; crops or plants that thrive with low water requirements have become an alternative in human diet due to their accessibility, low cost, and nutritional contributions.

AZP contain various bioactive compounds that possess different biological activities, primarily antioxidant activity. However, studies to verify their effectiveness in a clinical setting are limited; it would be ideal to study the effects directly on humans to evaluate the beneficial potential of a compound, plant, or food. It should be expected in the future that clinical research will be done to continue innovating with nutritious, safe, and functional products that help improve consumer's health, while also contributing to food security.

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