Biology, Chemical Composition, Cultivation and Applications of Cacti from the Opuntia Genus

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ABSTRACT

In this review, we approached various aspects of Opuntia sp. that are a type of forage cacti. These plants stand out for its energy potential and have peculiar morphological and physiological features that allow tolerance for long periods of drought. In addition, Opuntia species has a cosmopolitan distribution, found mainly in arid and semi-arid regions. Opuntia sp. presents phenotypic variations related to weather conditions, like polyploidy occurring in a large number of populations and high hybridization capacity. These plants have a shrub morphological characteristic with ramifications, variable size, from creeping until arboreal; it can reach up to 4 m high and a series of fleshy stems with, depending on time of year, flowers and fruits. Opuntia sp. have a typical physiology with the photosynthetic process called crassulacean acid metabolism (CAM); stomata close during the day in order to maintain hydration of tissues. The chemical composition of Opuntia sp. varies according to species, age of reticule, and season. These cacti have excellent nutritional value with high water content (about 90%), digestibility in vitro (about 75%) and vitamin A; in addition, they have organic matter (67%), energy (2,61 Mcal.kg-1), crude fiber (4.3%), phosphorus (0.08 to 0.18%), calcium (4.2%), potassium (2.3%) and magnesium (1.4%), but shows low protein content (about 5%). The proper yield of the crop needs a climate with 400-800 mm annual rainfall, relative humidity above 40% and day/night temperature from 25 to 15°C. The wide variety of applications demonstrates the versatility of this plant species, being used in food and feed, agriculture, medicine, pharmaceutical and cosmetic industries, in water and wastewater treatments, and even as insecticide agent. Opuntia genus comprises about 1500 species and *O. ficus indica* is the most important as forage and human uses.

Keywords: Opuntia sp.; forage cactus; biological characteristics; cultivation; applications.

ABBREVIATIONS

CAM	*: Crassulacean Acid Metabolism*
COD	*: Chemical Oxygen Demand*
FT4	*: Serum-free Thyroxin*
FTIR	*: Fourier Transform Infrared Spectroscopy*
HDL-cholesterol	*: High Density Lipoprotein*
OfiL	*: Opuntia ficus indica Lectin*

1. INTRODUCTION

The *Opuntia* genus, with about 1500 species of cactus, are native to Mexico and widespread throughout Central and South America, Australia, South Africa, including the Mediterranean area [1].

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They grow in dry desert area where hard environmental conditions prevail, and they have been used for centuries as food resources and in folk medicine for the treatment of chronic diseases (obesity, cardiovascular and inflammatory diseases, diabetes, and gastric ulcer) and many other illnesses [2]. The forage cactus, originally grown only in the American continent, precisely on the East Coast of Mexico, was broadcasted later through trade throughout Mesoamerica, the Caribbean and possibly to South America. The species is currently around the world, from Canada (Latitude 95°N), Argentina (Latitude 52°S), from sea level to 5100 m of altitude in Peru. In Europe, this cactus spread from the Mediterranean, to Africa, Asia and Oceania [3,4,5,6]. The easy of clonal Opuntia propagation probably explains why it is easily distributed worldwide. Evidence exists for the use of Opuntia as human food since at least 9000 years ago [7] or even as early as 12,000 years ago [8].

Opuntia ficus indica Mill is a forage cactus that belongs to the family Cactaceae including approximately 130 genera and 2,000 species [9,10]. *O. ficus indica* is possibly native from Mexico and has the particularity to grow in semi-arid regions. It is widely distributed in Europe, Southwestern United States, Northern Mexico, much of Latin America, Africa and the Mediterranean countries [10,11] (Fig. 1). *O. ficus indica* is the most agronomically important species for the production of edible fruits and cladodes. The *Opuntias* species is known as prickly pear, cactus pear, barbary fig, tuna etc. indifferent countries and the name is slowly evolving into cactus pear [12]. In addition, it is an alternative crop extremely tolerant to dry condition and water deficiency which can be used as a vegetable and valuable forage resource in arid and semiarid lands during periods of drought and shortage of herbaceous plants [9,10,13]. Accoding to del Socorro Santos Díaz [2], *O. ficus indica* is as important as corn and tequila agave in the agricultural economy of modern Mexico [14] and represents important food and feed resources. Its economic importance has gradually increased around the world as a health-promoting food [15].

(A) **(B)**

Fig. 1. *O. ficus indica* (palm) used for livestock subsistence in the Brazilian Northeast (A) and from city of Marrakech, Africa (B)

2. TAXONOMY, MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS

The taxonomical classification of the genus *Opuntia* is intriguing due to its phenotypic variations in term of ecology, reproduction, climatic conditions, polyploidy occurring in a large number of populations and also with high capacity of hybridization [13]. *Opuntia* sp. can be classified in the kingdom Plantae, division Magnoliophyta, class Magnoliopsida, order Caryophyllales, family Cactaceae, subfamily Opuntioideae and genus *Opuntia*.

The *Opuntia* genus is usefulness to man; it has a great success in distribution processes, dispersion and multiplication. The plant species can be divided into two cultivar types: Giant and round forage cactus. Giant forage cactus belonging to the species *O. ficus indica*, are plants with a sized well developed and stem with fewer branches, with more upright appearance and a less leafy vertical growth. The cladodes weight is about 1 kg, and may be up to 50 cm long, oval, elliptical or sub-oval with a green matte color (Fig. 2A). The flowers are hermaphrodites with medium size and bright yellow color (Fig. 2B). The fruit is an ovoid berry, big, with yellow color going to purple when ripe. The plant is considered one of the most resistant palms to dry regions, however, is less palatable and with less nutritional value for cattle. Round forage cactus [16] coming from the giant forage cactus, has an average size and the stem has many branches, damaging the vertical growth. The cladode weighs an average of 1.8 kg having about 40 cm in length, with rounded and ovoid shapes. It results in large income of a more tender and flavorful material than the giant forage cactus. These two types of forage cactus have a cuticle that covers its cladodes and controls the evaporation process, allowing and favoring water storage. Both cultivars do not have thorns; they were developed from species with thorns [17].

Most of the species from the genus *Opuntia* have thorns involving the cladodes. The presence or absence of thorns is a characteristic often used for the identification of plant ecotypes [18]. In addition, this plant has a great variability, not only on phenotypic and organoleptic characteristics of the fruit, but also for the morphology of cladodes. Scanning microscopy studies of cladode surface revealed several differences among cultivars of *O. ficus indica*, mainly related to the epicuticular wax morphology and ultrastructure of thorns [19].

Labra et al. [20] detected a common genetic constitution of *O. ficus indica* and *O. megacantha* based on molecular data, morphological traits and biogeographical distribution; then they suggested that *O. ficus indica* should be considered as a domesticated form of *O. megacantha*.

(A) **(B)**

Fig. 2. *Opuntia* cladode sprout (A) from Ear African Elephant variety at Arcoverde city, State of Pernambuco (PE), Brazil, and Palm flower, variety Ear Mexican Elephant at Caruaru city, PE (B)

O. ficus indica fruit is a berry, varying in shape, size and colour and has a consistent number of hard seeds [21]. This fruit is sweet, fleshy, juicy, has ovoid shape, globular, cylindrical and umbilicated at the upper end; it has a hard pericarp, where small cellulose thorns are found. Fruits vary from 4.8 to 10 cm long, with a width of 4 to 8 cm and weighing between 100 and 200 g. They have a thick rind that in the early stages of development is green, but this color will be changing to white-green, yellow, orange, red, purple, yellow-purple, violet or to brownish, depending on culture conditions. The pulp is juicy and gelatinous and is the edible part; seeds are found inside [22].

O. ficus indica seeds have low germination capacity mainly due to their hard lignified integuments, the most inward of which is the funiculus that envelops the embryo and obstructs radicle protrusion [10]. This cactus is a xerophytic plant with adaptation to the harsh conditions of the semi-arid region because of their physiology characteristic with a photosynthetic process called Acid Metabolism of Crassulacean (CAM). Restrictions on water availability and high ambient pressure results in high transpiration; plants assimilate CO_2 through the CAM system, closing their stomata during the day in order to maintain hydration of the tissues [23]. The efficiency of water use by plants that obey the CAM is higher than the plants of C3 metabolism (grasses and temperate climate legumes) [23,24,25].

Mizrahi et al. [26] studied real data taken from fruit growers in semi-arid zones in Israel. Their analyses showed the high water-use-efficiency of the *Opuntia*. Also, they refered that CAM plants have several times higher horticultural water use efficiency than other fruit crops grown in the same eco-zone.

3. CHEMICAL COMPOSITION

The chemical composition of *O. ficus indica* varies according to species, ambient conditions and seasons. This plant revealed as regards to its nutritional value, high moisture content (about 90%), high *in vitro* digestibility (about 75%) and a high content of vitamin A. Also, showed 29 µg of carotenoids and 13 mg of ascorbic acid per 100 g of cladodes, organic matter (67%), energy (2.61 $Mcal.kg^{-1}$), crude fiber (4.3%), phosphorus (0.08 -0.18%), calcium (4.2%), potassium (2.3%) and magnesium (1.4%); a lower protein content was detected (about 5%) [16,27-30]. The values of organic compounds were expressed in a fresh weight basis and the values of mineral composition were expressed in a dried weight basis.

The prickly pear fruit, divided into three components may be commercially exploited seeds, peel, and pulp. This fruit contains approximately 85% water, 15% sugar, 0.3% ash, and less than 1% protein. The flesh is a good source of minerals and several types of amino acids (alanine, arginine, and asparagine). Important vitamins include vitamin C (ascorbic acid), E, K, and beta-carotenes. Flavonoids, effective antioxidants, are other important constituents. The betalain pigments are responsible for the colors of the fruit and have antioxidant properties [31]. Chougui et al. [32] referred that seeds from various forage cactus showed an appreciable amount of oil, with high level of unsaturated fatty acids that are beneficial and healthy. The rate and the oil composition varied between total phenols, flavonoids and tannin levels. The *Opuntia* seeds do not contain any trace of sugars [21].

The *Opuntia* cladodes have high content of fiber and beneficial effects in the metabolism of glucose [33,34]. In addition, minerals, especially potassium and calcium, as well as phenol contents were present in the cladodes [33]. The heat treatment affected the chemical and nutritional composition of cladodes on soluble compounds such as sugars, minerals, ascorbic acid and certain phenolic compounds; in addition reduced the viscosity and gel strength produced from them. These changes affected the physiological properties related to antioxidant activity and ability of cladodes to maintain glucose and control of the glycemic response [6,34]. The by-products from cladodes and fruits of *Opuntia* could be attractive for use as functional food ingredients since are rich in dietary fiber and antioxidants. The combination of high dietary fiber and phytochemicals in a single matrix results in samples with specific properties suitable as dietary supplements and food ingredients with legitimate health claims [35].

Ammar et al. [1] studied the chemical composition of the flowers and showed that during the maturation stage, there is a decrease in protein contents whereas fat contents increase. *Opuntia* is an excellent source of minerals; in this study, the fatty acid profiles were mainly palmitic acid (38-59%). The techno-functional properties (swelling capacity, water solubility index, water holding and oil holding capacity) were important and modulated according to temperatures. *Opuntia* flowers constitute ingredients to improve different physical and nutritional properties of foods, owing to its chemical profile and functional properties.

Matsuhiro et al. [36] showed that the mucilage fruits from *O. ficus indica* has a complex mixture of polysaccharides, less than 50% corresponding to a pectin-like polysaccharide. Sepúlveda et al. [37] studied the conditions for the extraction (pad/water ratios, extraction temperature and time) and precipitation of plant mucilage; results showed no differences in any of the measured variables among the different extraction or precipitation methods. The dried mucilage had in average 5.6% moisture; 7.3% protein; 37.3% ash; 1.14% nitrogen; 9.86% calcium and 1.55% of potassium. The color analysis showed a high lightness value and the chromatic coordinates were in the yellow-greenish spectrum. The use of isopropyl alcohol was recommended in ratio 1:3.

Chemical composition of pulp and skin of *O. ficus indica* revealed high amount of water in the pulp (84.14%) and skin (90.33%). Glucose and fructose (29 and 24%, respectively) in the pulp were greater than in the skin (14 and 2.29%, respectively) whereas saccharose was much lower in the pulp (0.19%) than in the skin (2.25%). Potassium was very high in this fractions of the fruit compared to other minerals [21].

4. CULTIVATION AND HARVEST

The forage cactus cultivation in native areas in Mexico dates back to pre-Hispanic period; however, it was only in the 1950s that modern commercial plantations developed, with an increase of 10 000 to more than 50 000 ha, in the 1980s. The *Opuntia* grown in arid and semi-arid regions around the world developed a sustainable system with high incomes and energy efficiency [38]. In countries such as Mexico, Italy and Africa, *O. ficus indica* is cultivated on considerable surfaces for industrial purposes. Except in the Sahara and mountainous regions, the Prickly pear is broadly present in the Moroccan country [11].

This plant represents the best choice to cultivation since it shows great adaptability to various soil conditions, as well as, prevent environmental destruction caused by erosion (Figs. 3 A and B). Moreover, farmers in many arid areas of the world use *O. ficus indica* extensively as emergency forage harvested from both wild and cultivated populations to prevent disastrous consequences of frequent and severe droughts. Protocols developed provided a basis to achieve massive propagation of *O. ficus indica* by *in vitro* culture of areoles as strategic tool to combat desertification in arid and semi-arid regions [10].

The good income of forage cactus culture relates to climate areas having 400 to 800 mm annual rainfall, relative humidity above 40% and daytime/night temperature of 25 to 15°C [38]. Some semi-arid regions with low relative humidity and high night temperatures may result in lower productivity or even death of the plant [39]. The cactus comes also as a relatively demanding culture depending upon the physical and chemical characteristics of the soil.

Dubeux Jr. et al. [40] studied that increasing plant population and fertilizing with phosphorus and nitrogen resulted in greater productivity of *O. ficus indica* in northeast Brazil. Plants are present in different types of soils, such as vertisols and luvisols in Mexico; also regosols, lithosols, cambisols and fluvisols in Italy. The pH of soil ranges from sub-acid (luvisols) and sub-alkaline (lithosols), which shows good adaptability of the species. Soils with low drainage capacity, shallow groundwater and/or impermeable surface layer are not be regarded as adequate. Clay content should not exceed 15-20%, in order to avoid reduced canopy and putrefaction of roots [38].

The propagation of forage cactus uses healthy cladodes of adult plant; seedlings obtained from the central part of the plant are of choice, since cladodes at the cellulosic base are very difficult to sprouting. The palm is of slow growth, so the availability of seedlings only is possible after two years of planting, making difficult to purchase vegetative propagules [41].

The genus *Dactylopius* includes a homologous group of phytophagous hemipterous insects of 1–6 mm in length with the adult males being smaller than the adult females [42]. These insects live in cladodes in colonies protected by a white wax wireless coverage and are used for the production of a natural dye known as carmine. It is the most important pest of palm in the State of Pernambuco, Brazil (Fig. 3C).

According to Inglese et al. [43] the cladodes can be placed in three different ways in the holes: up, at an angle of 30° and lying. The first method is the most frequently used. In this method, the cladodes are positioned to up with baseline cut on the ground. Planting done superficially can be easily knocked over by the wind, developing a very shallow root system. However, if more than 70% of the cladodes are within the soil, the part that is exposed may not feed properly through photosynthesis, therefore, it is a recommended practice to bury half cladodes. The second option is to plant the cladodes with an angle of 30°; this method is viable when only one cladode is planted and when the aim is not the production of fruit. It is observed that there is the development of a strong basal stem, but easily occurs rooting. Finally, in the method lying or "plan", the cladodes are placed with the most flat area on the ground, this method puts up a small stone on the cladode to improve contact with the ground and prevent it from being lifted by the wind. The advantage of this approach is only the lowest cost to plant and no need to make holes. If the soil is too dry, the cladodes will benefit with a watering after planting.

Some factors can influence the choice of the crop design, including the size of the agricultural area, the environmental conditions (especially the light intensity, slope and sun exposure), the growth conditions of the species to be cultivated as well as presence of pests. Wit et al. [44] studied the effects of locality on internal quality parameters of available cactus pear varieties. Highly significant differences between the mean values for the measured characteristics were observed, not only among the locations (except for the pulp glucose values), but also for the influences of genotype and interaction between locality and genotype. Authors concluded that Meyers, Roedtan, Gymno Carpo and Robusta × Castillo would be the recommended cultivars for fruit production at any location in South Africa, with Meyers being the most appropriate cultivar for economical purposes.

(A) **(B)**

(C)

Fig. 3. A: Giant cactus variety of drought conditions, Caruaru city, State of Pernambuco (PE), Brazil; B: Palm plantation, variety Mexican Elephant Ear, Ibimirim city, PE; C: *Opuntia* sp., Mexican Giant variety, with cochineal carmine. We can observe the larva/insect from *Dactylopius* sp. in intact and crushed form, transpiring the carmine dye, Arcoverde city, PE

The dense spacing of the palm is the most recently technique used. In these gaps, the cultivation and harvesting are hampered increasing labor costs. Moreover, in addition to these aspects, there is an increased amount of nutrients from soil, whereas the 2.0x1.0 m spacing can have 5,000 plants / ha; with 1.0x0.25 m spacing amount plants are eight times greater, ie, 40,000 plants / ha, requiring care with fertilization.

To maintain the productivity of an area with palm for long-term it is important to consider the proper spacing of planting, management of harvest and fertilization [45,43].

Despite the palm is a species that tolerates drought and has a high efficiency in water use, remains a source of by-products and antioxidants, and are therefore useful, as previously reported, its cultivation in arid and semi-arid Regions. However, it is common to make irrigation in areas with a dry season in summer; and where the palm is intensively cultivated for fruit production, especially in Israel, Italy and Chile [46].

5. APPLICATIONS AND POTENTIAL USES

The great diversity of applications of forage cactus, *O. ficus indica*, demonstrates the versatility of this plant species, often used for animal feed, has not fully exploited its potential, as shown (Table 1).

5.1 Human Food

Several food products have cactus as a main ingredient [10]. *O. ficus indica* is included in the Mexican human diet [34]. The palm shoots or young cladodes, so called vegetables, are used as culinary preparations for human consumption, as well as the palm fruit, fresh or processed. Cladodes and fruits are consumed fresh or processed in Latin America; fresh fruits are more widespread in European and North American market, being considered a "specialty" [47,34]. In Mexico and in the United States the palm is prepared with several different cooking methods. It is consumed as salads, but the older stage varieties are also used as cooked consumption items.

The palm can also be applied for the preparation of juices, alcoholic beverages, jams [48], production of liquid natural sweetener, salads, and stews, baked and sweet dishes. The prejudice to the use of palm as human food is a major obstacle in the hinterland, since traditionally the palm is utilized only as animal feed. The plant is considered a noble food served in restaurants and luxury hotels in countries like Mexico, United States and Japan [49].

In the semi-arid northeastern of Brazil, palm is used in the combat to human hunger and malnutrition, and is a powerful alternative food rich in vitamins A, B complex C and minerals like calcium, magnesium, sodium, potassium, as well as seventeen amino acids. It is a more nutritious food than cabbage, beets and bananas, in addition to the fact of being a cheap product [49].

O. ficus indica mucilage is an interesting ingredient for the food industry due to its viscosity properties [37]. Studies using mucilage of palm powder for the encapsulation of bioactive functional foods was efficient, providing adequate additional structure. The microcapsules of mucilage described represent a promising food additive for incorporation of functional ingredients into foods [35,50].

The great number of potentially active nutrients and their multifunctional properties make cactus fruits and cladodes perfect candidates for the production of health-promoting food and food supplements [47]. Ennouri et al. [51] described that rats fed with a diet supplemented with seed powder of *O. ficus indica* showed significant decrease in body weight, probably due to a significant decrease in serum-free thyroxin (FT4) compared to control group. Then, seed powder from *O. ficus indica* also can be used as a healthy food. According to Contreras-Padilla et al. [52]. *O. ficus indica* powder showed high content of calcium oxalate and calcium and might be included in human diets as a natural source of calcium. Also, Saénz et al. [53] studied the microencapsulation by spray drying of bioactive compounds from *O. ficus indica* and this process represents an interesting food additive for incorporation into functional foods, due to both the presence of antioxidants and a red colourant. Otálora et al. [54] incorporated betalain-rich capsules in gummy candies using a betalain-rich extract of *O. ficus indica* fruit as source of the pigment. The stability of the betalain colour in the gummy was demonstrated resulting in a vivid red-purple colour and highlighting the potential for use this natural pigment in foods.

An *O. ficus indica* gum containing glucose (78.0%), arabinose (12.9%), xylose (4.8%), galactose (2.4%), and mannose (2.4%), suggesting an arabinoglucan structure showed antioxidant activity on DPPH radicals similar to that of butylated hydroxytoluene (BHT), having potential to be used as thickener, stabilizer and antioxidant agent in food and pharmaceutical systems [55].

5.2 Animal Feed

It is necessary, in relation to animal feed, the knowledge of nutritional requirements to each animal in function of energy, protein, minerals, vitamins and water; these aspects can be affected by animal race, productive ability, age, body size, physiological age and environmental factors. *O. ficus indica* in mature stage is used as forage when fresh food is insufficient due to scarcity of rain [56]. Due to the low dry matter content of this plant, diets containing large percentages of palm usually possess high moisture content. That is, the use of palm in animal feed should be for its richness in water and mucilage and the high coefficient of dry matter digestibility and high productivity. However, the palm has some limiting aspects, such as crude protein deficiency, which is the lower limit needs for growth and development of bovine rumen microorganisms responsible for degradation of nutrients through of the fiber forage. The diets of animals should contain crude protein levels between 6 and 7%, despite the low level of dry matter intake and also reduced amount of fiber [57].

Pears of *O. ficus indica*, due to its energy, high coefficient of digestibility of dry matter and adaptability to soil conditions and climate, has become the basis for the feeding of ruminants in the Brazilian semi-arid region. Cactus pear is a very important food in prolonged periods of drought; in addition to feature nutrients; it provides a large proportion of water requirements for animals during this time of year [58].

Table 1. Application areas of *O. ficus indica*

***O. ficus indica* tissues and compounds**	**Aplications**	**References**
Fruits	Human diet, animal feed, medical applications, cosmetic industry	[10,47,34,58,59,60,61, 62,63,64,65]
Cladodes	Human diet, medical applications, cosmetic industry, insecticidal activity; wastewater treatment; biogas production	[47,34,66,67,68,69,70, 71]
Mucilage	Vitamin supplement, food industries, medical applications	[49,37,35,50,28,72]
Seeds	Healthy food preparation	[51]
Seed oil	Medical applications	[73]

Costa et al. [58] evaluated the replacement of corn by cactus pear in the performance and nutrient digestibility of sheep nutrients; the substitution did not affect the conversion of the feed. In general, increasing the cactus levels in sheep diet favors a high nutrient digestibility, improved forage quality, reduced the voluntary intake of water, and therefore is an important source of forage and water supplies for use in semi-arid regions.

5.3 Health and Medicine

Different tissues from *O. ficus indica* can be used in health and medicine. Folk medicine, particularly at Mexican population, records the healing of a large number of diseases with the use of this plant. Scientific studies showed that *O. ficus indica* tissues revealed antiviral, anticancer, hypoglycemic [73], antioxidant and diuretic activity [64,66,74-76]. The fruits have anti-inflammatory and analgesic effects [59-61]. Also, the pigments betanin a betacyanin extracted from fruits of *O. ficus indica* showed antiproliferative effects inducing apoptosis in human chronic myeloid leukemia cell line-K562 [77]. Tesoriere et al. [75] studied the anti-inflammatory activity of indicaxanthin, another pigment from the edible fruit of *O. ficus indica* and showed that the pigment may have the potential to modulate inflammatory processes at the intestinal level. The cladodes showed anti-ulcer property [66,67]. Ennouri et al. [51,78] suggested that the seed oil might have hypocholesterolemic and hypolipidemic activities. Berraaouan et al. [73] showed that cactus pear seed oil prevent alloxan-induced-diabetes by quenching free radicals produced by alloxan and inhibiting tissue injuries in pancreatic β cells. *Opuntia* stem extract protects the liver and decreases the toxicity induced by the organophosphorous pesticide chlorpyrifos [79].

Searches using the mucilage obtained from *O. ficus indica* report the palm as a topical therapeutic agent against inflammation, gastritis and ulcers of the skin; also showed antiulcerogenic activity. Other benefits that have been attributed to ingestion of mucilage are interactions with drugs and intestinal homeostasis [28,72].

The powder of palm contains some essential nutrients that help the maintenance of human health. The benefits associated with these nutrients and with the fiber content are well known, especially for improving the symptoms of diabetes by reducing the blood glucose values, in addition to anti-hyperlipidemic and hypercholesterolemic actions [47,80].

Nanoparticles from *O. ficus indica* compounds were developed and showed antibacterial activity, which can be used effectively against bacteria resistant to multiple drugs. Thus, the synthesized nanoparticles are shown as an effective alternative to drug delivery systems because of its biocompatibility and biogenic nature [81].

The consumption of *O. ficus indica* cladode and fruit skin specific extract after exercise stimulated the secretion of insulin while reducing blood glucose in healthy young volunteers [82]. In addition, Godard et al. [83] showed the acute blood glucose lowering effects and the long-term safety of this extract supporting the traditional use of this plant for blood glucose management. Ennouri et al. [51] observed a decrease of glucose concentration in blood and an increase of glycogen in liver and skeletal muscle, as well as, a significant increase in high-density lipoprotein-cholesterol (HDL-cholesterol) in rats fed with a diet supplemented with seed powder of *O. ficus indica*.

Other important medicinal use of cactus was studied by Jonas et al. [84], which showed that flower extracts might be beneficial in benign prostatic hyperplasia due to inhibition of 5α reductase activity, aromatase activity and lipid peroxidation.

The cosmetic industry has manufactured and marketed in a large variety of products made of various components of *Opuntia* sp., such as shampoos, astringent lotions, body lotions, soaps, creams, and lip balm. *O. ficus indica* cladodes and the fruit showed antioxidant capacity; their composition revealed the presence of flavonoids and phenolic compounds, which have recognized photoprotective action [47,62-65]. Thus, studies of a cosmetic product made based in cactus extract of forage palm, on a cell culture model with sensory neuron and keratinocytes, showed protection against UVA radiation [85]. Ribeiro et al. [86] evaluated the prodution and characterization of an oil in water nanoemulsion containing *O. ficus indica* hydroglycolic extract; this emulsion was stable and had moisturizing efficacy, proving to be a product with potential in the cosmetic area. A summary of the *Opuntia sp*. applications in medicine can be observed in Table 2.

Slimen et al. [87] demonstrated that natural antioxidants extracted from *O. ficus indica* f. *inermis*, cladodes and mesocarps confer thermoprotection to heat-stressed lymphocytes. The effect was attributed to betaxanthin and betacyanin pigments.

5.4 Insecticide Activity

Lectins are proteins or glycoproteins that bind specifically and reversibly to mono- or oligosaccharides. This peculiar interaction of these proteins to glycoconjugates, either in solution or on the surface of cells, characterize these molecules with diverse biological activities including insecticidal and make them powerful tools in several biotechnological applications. A study by Paiva et al. [68] using a lectin from *Opuntia ficus indica* (OfiL) showed that this protein have biotechnological potential and can be used in pest control of *Nasutitermes corniger* since it was highly toxic to workers of termites in low concentrations.

OfiL was also evaluated for insecticidal activity against the maize weevil (*Sitophilus zeamais*). When incorporated into artificial diets at doses of 15, 60, and 95 mg/g, OfiL did not induce insect mortality and did not show deterrent effect. However, the lectin showed antinutritional effect since its ingestion led to weight loss, reflected in negative values of efficiency in conversion of the ingested food [88]. Saline extract from *O. ficus indica* cladodes, containing OfiL, was toxic to *Aedes aegypti* larvae by interfering with the permeability of the peritrophic matrix [89].

5.5 Wastewater Treatment

Barka et al. [69] studied the removal of metals (cadmium (II) and lead (II) ions) present in wastewater using dried cactus cladodes as an alternative effective natural biosorbent. Vishali and Karthikeyan [90] showed the potentiality of *O. ficus indica*, as a coagulant for the treatment of simulated industrial water-based paint wastewater in terms of color, chemical oxygen demand and turbidity. The removal efficiency increased as the pollution load swelled. The Fourier transform infrared spectroscopy (FTIR) study revealed the presence of various functional groups, which are responsible for the coagulation process. The obtained results were compared with conventional coagulant ferric chloride. Therefore, this plant is a natural, eco-friendly coagulant, and could be a strong alternative to the conventional coagulant in the treatment of water-based paint wastewater.

Depollution of a variety of contaminated wastewaters using *O. ficus indica* cladodes, fruit pulp and peels mucilage as well as electrolytes show very high and promising pollutant maximum sorption capacities. Also, removal percentages in the range 125.4–1000 mg/g and 0.31–2251.56 mg/g for biosorption of dyes and metallic species respectively and removal% ranges of 50–98.7%, 11–93.62% and 17–100% for turbidity, chemical oxygen demand and heavy metals through coagulation-flocculation process. These biomaterials proved to be efficient in pollutant removal that there is need to explore the scaling up of the study from the laboratory scale to community pilot plants and eventually to industrial levels [70].

The mucilage of *Opuntia ficus indica* was evaluated as a coagulant for treatment of tailing pond water from the oil sands process industry. This material was able to remove 98% of the turbidity and was more effective in removing arsenic than alum and ferric chloride, while alum and ferric chloride [91].

Table 2. Medicinal properties and benefits from *Opuntia* sp.

***Opuntia* sp.**	**Properties and benefits**	**References**
Cladodes	Treatment of gastric ulcer; hypoglycemic, antioxidant and antimicrobial activities.	[59,67,80,81,85]
Fruits and juice	Anti-inflammatory, analgesic, antioxidant, hypoglycemic and antiproliferative effects.	[59,60,61,75,56,80,81]
Seed oil	Hypocholesterolemic activity; triglycerides reduction effect.	[76,73]
Mucilage	Anti-nflammatory and antiulcerogenic activities; interactions with drugs and intestinal homeostasis.	[28,72]
Flowers	Effect in the benign prostatic hyperplasia therapy.	[82]

5.6 Energy Production

Jigar et al. [71] studied the assessment of cladodes from *O. ficus indica* in five combinations with or without cow dung for biogas production. The co-digestion of cow dung and cladodes in biomass is one way to addressing the problem of lack of enough feedstock for biogas production. If suitable materials for co-digestion, such as manure, are not available, cladodes can be digested alone and is an alternative opportunity to people who have not access to cow dung.

6. CONCLUSION

Opuntia sp. is an important palm plantation extremely tolerant to dry conditions and water deficiency. In addition, it is an alternative sustainable cultivation system and landscape conservation. Therefore, *Opuntia* sp. is a promising plant due to its effective food production, including all vegetable parts, since water resources are more limited and global desertification may become a reality.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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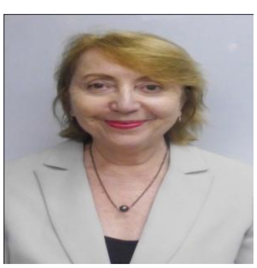

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