

## Nutritional and medicinal use of Cactus pear (*Opuntia* spp.) cladodes and fruits

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## 1. ABSTRACT

Natural products and health foods have recently received a lot of attention both by health professionals and the common population for improving overall well-being, as well as in the prevention of diseases including cancer. In this line, all types of fruits and vegetables have been re-evaluated and recognized as valuable sources of nutraceuticals. The great number of potentially active nutrients and their multifunctional properties make cactus pear (*Opuntia* spp.) fruits and cladodes perfect candidates for the production of health-promoting food and food supplements. Although traditionally appreciated for its pharmacological properties by the Native Americans, cactus pear is still hardly recognized because of insufficient scientific information. However, recent studies on *Opuntia* spp. have demonstrated cactus pear fruit and vegetative cladodes to be excellent candidates for the development of healthy food. Therefore, this review summarizes current knowledge on the chemical composition of *Opuntia* cacti with particular emphasis in its use as food and medicine.

## 2. INTRODUCTION

The growing demand for nutraceuticals is paralleled by an increased effort in developing natural products for the prevention or treatment of human diseases. According to several studies demonstrating both cactus fruit and cladode yielding high values of important nutrients, such as betalains, amino compounds including taurine, minerals, vitamins, as well as further antioxidants, the cactus pear (*Opuntia* spp.) appears to be an excellent candidate for the inclusion in food. Even though Native Americans and ancient medicine have realized its anti-diabetic and anti-inflammatory function, *Opuntia* spp. have hardly been considered in the development of health-promoting food, most probably due to the scattered information available.

In addition, cactus pear has been mainly ignored by the scientific community until the beginning of the 1980s when several studies and reports were published on their biological functions. More recent investigations on the

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**Table 1.** Selected *Opuntia* spp., their synonyms and locations <sup>1</sup>

Subgenus <i>Opuntia</i> <sup>2</sup>		
Species	Common Synonyms	Locations
<i>Opuntia basilaris</i>	Beavertail Cactus	Southwest U.S. and northwest Mexico
<i>Opuntia chlorotica</i>	Pancake prickly pear, clockface prickly pear, flap jack prickly pear	Native to southwest U.S. and the Sonoran an Mojave deserts
<i>Opuntia engelmannii</i>	Engelmann's pear, cow's tongue cactus, Engelmann prickly pear	Mexico
<i>Opuntia ficus-indica</i>	Indian fig, mission cactus, smooth prickly pear	Originally in south-central Mexico; cultivated in warm parts of the world for its edible fruit
<i>Opuntia fragilis</i>	Little prickly pear, Brittle cactus, fragile prickly pear, loose prickly pear	Northern Great Plains and as far west as British Columbia, also found in the southern Great Plains
<i>Opuntia humifusa</i> , <i>Opuntia compressa</i> var. <i>humifusa</i>	Eastern prickly pear, low prickly pear, smooth prickly pear	Throughout the U.S. east of the Great Plains and into southern Ontario
<i>Opuntia leucotricha</i>	Arborescent prickly pear, Aaron's Beard cactus, semaphore cactus, duraznillo blanco, nopal blanco	Mountains of Central Mexico
<i>Opuntia macrocentra</i>	Black spined prickly pear, purple prickly pear	Southwest U.S. and Northern Mexico
<i>Opuntia macrorhiza</i>	Plains prickly pear, starvation prickly pear, delicate prickly pear	Throughout the Great Plains except for the northernmost areas (not found in North Dakota), and extending sporadically eastward as far as Kentucky.
<i>Opuntia microdasys</i>	Bunny ears prickly pear, Angels' wings prickly pear	Mexico (Hidalgo)
<i>Opuntia santa-rita</i>	Santa Rita Prickly Pear	Texas, Arizona and Northern Mexico
<i>Opuntia stricta</i>	Coastal Prickly Pear, Yaaxpakan	Coastal regions
<i>Opuntia polyacantha</i>	Hedgehog prickly pear, grizzly bear prickly pear	
<i>Opuntia phaeacantha</i>	New Mexico prickly pear	
<i>Opuntia lindheimeri</i> , <i>Opuntia engelmannii</i> var. <i>lindheimeri</i>	Texas prickly pear	
<i>Opuntia littoralis</i>	Sprawling prickly pear, coastal prickly pear	
<i>Opuntia erinacea</i>	Grizzly bear <i>Opuntia</i>	
<i>Opuntia pusilla</i>	Creeping cactus	
Subgenus <i>Cylindropuntia</i> <sup>3</sup>		
<i>Cylindropuntia acanthocarpa</i>	Buckhorn cholla, major cholla	
<i>Cylindropuntia arbuscula</i>	Pencil cholla, bush cholla	
<i>Cylindropuntia bigelovii</i>	Teddy-bear cholla	
<i>Cylindropuntia echinocarpa</i>	Silver cholla, golden cholla	
<i>Cylindropuntia fulgida</i>	Jumping cholla	
<i>Cylindropuntia imbricate</i>	Cane cholla, Tree cholla	
<i>Cylindropuntia leptocaulis</i>	Desert Christmas cholla	
<i>Cylindropuntia ramosissima</i>	Diamond cholla	
<i>Cylindropuntia spinosior</i>	Tasajo cholla, morada cholla	
<i>Cylindropuntia stanlyi</i>	Devil cholla, plateau cholla	
<i>Cylindropuntia versicolor</i>	Staghorn Cholla	

<sup>1</sup> According to (3-9); <sup>2</sup> True prickly pears, often difficult to identify, due to hybridization; <sup>3</sup> Chollas

chemical components and the nutritional value of *Opuntia* spp. have attracted attention both in food, nutritional, and even pharmacological science. However, the scarcity of studies into the respective mechanism of positive actions on human metabolism still render cactus products unpopular and thus undeveloped. Therefore, the present review provides an overview on *Opuntia* fruit and cladode constituents including their pharmacological actions described so far to offer a scientific basis for future studies and to achieve a more widespread recognition of this valuable crop.

### 3. BOTANICAL ASPECTS, GEOGRAPHICAL DISTRIBUTION AND PRODUCTION

#### 3.1. Botanical Aspects

The term cactus (*Cactaceae*) refers to a group of approximately 1,600 species in 130 genera subdivided in the three subfamilies Pereskioideae, Opuntioideae and Cactoideae (1). The most common and widespread *Opuntia* genus covered in this review regroups a number of more than 300 species, among which over 100 have been found in wild habitats in Mexico, 60 of them being endemic (2). The prickly pear cactus (*Opuntia* spp.), more recently re-named cactus pear, and the cholla (*Cylindropuntia* spp.) species represent the major branches of *Opuntia* cactus,

some of which are listed in table 1 (3-9). The prickly pear plants are known for (a) their flattened stems, (b) the edibility of their pleasant-tasting fruits, (c) the areoles having minute-barbed spines easily detachable, (d) rudimentary leaves on new pads, and (e) the seeds with a pale covering (1). Cactus pear plants show a widespread and shallow root system ready to absorb water even from mist or a light rain. This allows the plants to take in water and store it sponge-like in the parenchyma. It has been demonstrated that the ability of *Cactaceae* to retain water even under unfavorable climatic conditions (10) is due to the high mucilage production in both cladodes and fruits (11).

From a morphological point of view, the cactus pear plant can be divided into the root, the vegetative part, the fruit and the flower. The vegetative or vegetable part, frequently addressed as pads, joints, or cladodes are modified stems which replace the leaves in their photosynthetic function. They are succulent and bear organs with an ovoid or elongated form of 18–25 cm length. The outer cladode, the chlorenchyma, is crucial for its photosynthetic action; the inner part is composed of a white medullar parenchyma mainly for water storage.

The cactus pear fruit also known as prickly pear, tuna or fico d'india comes in a rainbow of colors from

**Table 2.** Chemical constituents of both despised cladodes and fruit pulp from *Opuntia* spp.<sup>1</sup>

Constituents	Dry weight basis	Fresh weight basis	
	Cladodes	Cladodes (g/100g)	Fruit pulp (%) <sup>2</sup>
Water	-	88-95	84-90
Carbohydrates	64-71	3-7	12-17
Ash	19-23	1-2	0.3-1
Fibers	18	1-2	0.02-3.15
Protein	4-10	0.5-1	0.21-1.6
Lipids	1-4	0.2	0.09-0.7

<sup>1</sup> According to (30), (41) and (42). <sup>2</sup> All of which are similar to other fruits.

white, green, yellow, orange, red, purple, and even brown. Interestingly, the pulp colors do not necessarily correspond with those of the flowers, which may be canary yellow, orange or red-rose like. Fruit weights range from 100 to 150 g, depending on origin, cultivar and edaphic conditions. It is an oval and elongated berry with a thick pericarp and a juicy pulp with many seeds. The pulp is the edible part of the fruit and is mainly composed of water (84-90%) and reducing sugars (10-15%).

Cactus pear fruit seeds exhibit considerable variations in form, size, structure, embryo characteristics, and testa color. They represent about 10-15% of the edible pulp and are usually discarded as waste after pulp extraction. Several authors have reported a great variation in the number of seeds, from 1-5 to more than 2000 per fruit (12-15). This variation is observed within and/or between species depending on factors such as the age and size of the plant, and the number of flowers per plant. Seed vitality under natural or controlled storage conditions will depend on many factors, including seed type, maturity stage, viability and moisture content during storage, temperature and degree of fungal or bacterial infection (14).

Research on *Opuntia* spp. is inflicted with the challenge of their proper identification (16). Therefore, possible markers are being investigated to understand genetic relationships and allow reliable classification (17-19).

### 3.2. Geographical Distribution

The Cactaceae are one of the most intriguing plant families of the world's arid and semi-arid regions, the latter covering about 30% of the world's continental surface (20). This is due to their peculiar adaptations to water scarcity and sun irradiation, such as (1) CAM metabolism (Crassulacean Acid Metabolism), the reduction of (2) leaf tissues and (3) cuticular waxes covering the cladodes and fruit surfaces, which allow them to grow year-round and stay evergreen despite harsh environmental conditions. The genus *Opuntia* is most widespread, presumably due to its capacity to regenerate either from root calluses, pads, fruits, seeds, tissue culture and grafting (see table 1) (21, 22). It can be encountered from temperate (Italy, Israel), subtropical African and American zones, Asia (China, South Korea) as well as in cold regions with winter snowfalls as in Canada or Argentina (23, 24).

### 3.3. Production

The plant is used mainly for fruit production, although in some countries it is used as a vegetable for

human consumption and also as fodder. The high season for harvesting *Opuntia* cactus fruits is from April to August in Africa and America (25), and November to December in the Mediterranean regions (26).

#### 3.3.1. Cladodes

The weight and length of harvested vegetables vary depending on the specie. However, they generally range from 40-100 g and 11-20 cm in length (27-29), and the plants are generally aged from 1 to 3 years (26). Due to the diurnal acidity modification of cladodes, harvesting a couple of hours after sunshine provides best cladodes for vegetable use, which are turgid, rich in sugars, pro-vitamin A and vitamin C, but poor in nitrogen (26). Furthermore, postharvest technologies have been developed that have been reviewed recently (30).

#### 3.3.2. Fruits

Unfortunately, cactus fruits have a short shelf life from 3-4 weeks, thus limiting long-term storage and worldwide distribution. Typically, a high pH value which varies from 5.3 to 7.1 is found, and the very low acidity (0.05-0.18% citric acid equivalents) compromises extended fruit storage (31, 32). Various efforts to reduce postharvest decay have therefore been carried out, taking into account reduction of microbial contamination while maintaining the nutritional as well as sensorial properties (33-38). Peeled fruits are good for eight days at 4°C when packed in special films (39), while the same temperature was recommended to control microbial spoilage (33). It must be noted that each variety and fruits from different harvest seasons might require changing preharvest treatments and storage conditions (37, 40). Sterilization of processed fruits at greater than 115°C is required to avoid growth of pathogenic micro-organisms (31, 41). Alternatively, after acidification (pH 4.0-4.3), products only require less severe pasteurization temperatures below 100°C for preservation.

## 4. CACTUS CONSTITUENTS

The *Opuntia* cladodes and fruits are known as a source of a varied number of nutritional compounds (table 2). Their concentrations being dependent both on the cultivation site, climate and respective fruit variety (41-55). Cactus pear fruits exhibit an ascorbic acid content of 20 to 40 mg/100 g fresh weight, and a titratable acidity of 0.03 to 0.12% with pH values ranging from 5.0 to 6.6. Its soluble solids content of 12-17% is greater than that present in other fruits, such as prunes, apricots, and peaches (31, 56). Generally, cladodes are rich in pectin, mucilage and minerals, whereas the fruits are good sources of vitamins, amino acids and betalains. While the seed endosperm was reported to consist of arabinan-

**Table 3.** Free amino acids contents in both cladodes (L-amino acids) and fruit pulps from *Opuntia ficus-indica*<sup>1</sup>

Amino acids	Fresh weight basis	
	Cladodes (g/100 g)	Fruit juice (mg/L) <sup>2</sup>
Alanine	0.6	87.2
Arginine <sup>3</sup>	2.4	30.5
Asparagine	1.5	41.6
Asparaginic acid	2.1	Not valid
Glutamin acid	2.6	66.1
Glutamine <sup>3</sup>	17.3	346.2
Glycine	0.5	11.33
Histidine <sup>3</sup>	2.0	45.2
Isoleucine	1.9	31.2
Leucine	1.3	20.6
Lysine	2.5	17.4
Methionine	1.4	55.2
Phenylalanine	1.7	23.3
Serine <sup>3</sup>	3.2	174.5
Threonine	2.0	13.3
Tyrosine	0.7	12.3
Tryptophane	0.5	12.6
Valine	3.7	39.4
Alpha-Aminobutyric acid <sup>3</sup>	Not available	1.1
Carnosine	Not available	5.9
Citrulline	Not available	16.3
Ornithine	Not available	Not detectable
Proline <sup>3</sup>	Not available	1265.2
Taurine <sup>3,4</sup>	Not available	434.3

<sup>1</sup> According to (42) and (45); <sup>2</sup> Mean values for the pulp from three cultivars. Some amino acids present variations of 1.5 to 3 depending on the respective cultivar (42); the total content of free amino acids (257.24 mg/100g) is above average for most fruits except citrus and grape; <sup>3</sup> Amino acids with higher contents in comparison with other fruits (44); <sup>4</sup> 8-12 mg/100 g fruit reported (45).

rich polysaccharides (57), the principal seed coat component was D-xylan (58). In addition to lipids, seeds have been reported to accumulate proanthocyanidins (59). The fruit skin polysaccharide fraction has been subject to thorough investigations (60-63), whereas the pectin substances in fruit pulp remain to be characterized. The flowers predominantly accumulate betalains and colorless phenolics (64-69).

#### 4.1. Amino acids, vitamins and carotenes

##### 4.1.1. Cladodes

The fresh young stems are a source of proteins including amino acids, and vitamins (tables 3 and 4) (30, 70-73).

##### 4.1.2. Fruits

Various numbers of amino are also found in cactus fruits (table 3). Vitamins are nutritionally important cactus pear fruit constituents (table 4). The fat soluble vitamin E or tocopherols, and beta-carotene are found in the lipid fraction of both the cactus fruit seed and pulp (52, 74, 75). The vitamin E homologues isoforms gamma- and delta-tocopherol are the main components in seed and pulp oils, respectively, amounting to about 80% of the total vitamin E content (table 5). Similar to beta-carotene, it is predominant in pulp lipids (75). Carotenes and vitamin E improve the stability of the fatty oil through their antioxidative properties (76).

Ascorbic acid, often erroneously addressed as vitamin C, is the third major vitamin in cactus pears. It is important to note that the total vitamin C content of cactus fruits might have been underestimated due to the presence of dehydroascorbic acid that has not been considered so far. Finally, only trace amounts of vitamin B1, vitamin B6, niacin, riboflavin, and pantothenic acid have been reported (42, 77).

Phytochemical investigation of *Opuntia* revealed a great number of amino acids, eight of which are essential (table 3). Cactus fruits contain high levels of amino acids, especially proline, taurine and serine (42, 44, 45), while the seeds are rich in protein (78).

#### 4.2. Minerals, sugars and organic acids

##### 4.2.1. Cladodes

The cladodes are characterized by high malic acid contents oscillating due to a CAM-based diurnal rhythm (30, 50, 51). The mineral and organic acid contents of cactus pads have been reviewed recently (30) (see table 6).

##### 4.2.2. Fruits

Based on various studies on *Opuntia* composition, fruit pulp is considered a good source of minerals (table 6), especially calcium, potassium and magnesium (42, 47, 72, 79). The seeds are rich in minerals and sulphur amino acids (80).

The fairly high sugar content and low acidity (31, 81) render the fruits a delicious, sweet but sometimes a bland taste. The sugar pattern in the fruit pulp is very simple and consists of glucose and fructose in virtually equal amounts (23, 31, 82, 83), while the organic acid pattern is dominated by citric acid (42, 84). Due to the high water content of the fruit, a total caloric value of 50 kcal/100 g is attained, which is comparable to that of other fruits such as pears, apricots and oranges (56, 82). Directly absorbed, high glucose concentrations in cactus fruits represent an energy source instantly available for brain and nerve cells, while fructose being sweeter may enhance the fruit's flavor (85).

**Table 4.** Vitamin and antioxidant contents of both *Opuntia* spp. cladodes and fruit pulp<sup>1</sup>

Compounds	Fresh weight in cactus pear (per 100g)	
	Cladodes	Fruit pulps
Ascorbic acid	7-22 mg	12-81 mg <sup>2</sup>
Niacin	0.46 mg	Trace amounts
Riboflavin	0.60 mg	Trace amounts
Thiamine	0.14 mg	Trace amounts
Total carotenoid	11.3-53.5 µg	0.29-2.37 g
•Beta-carotene	Not available	1.2-3.0 µg
Total vitamin E	Not available	111-115 µg
Vitamin K <sub>1</sub>	Not available	53 µg
Flavonols:		
•Kaempferol derivatives	Not available	0.11-0.38 g
•Quercetin derivatives	Not available	0.98-9 g
•Isorhamnetin derivatives	Not available	0.19-2.41 g

<sup>1</sup> According to (30), (42), (43), (46) and (47); <sup>2</sup> Indicates concentrations higher than that of apple, pear, grape and banana (48) and (49)

**Table 5.** Levels of sterols and fat-soluble vitamin E derivatives in cactus pear (*Opuntia ficus-indica* L.) seed and pulp oils<sup>1</sup>

Components	Seed oil <sup>2</sup> (g/100g)	Fruit pulps oil <sup>2</sup> (g/100 g)
Cholesterol	Not detectable	Not detectable
Campesterol	1.66	8.74
Beta-Sitosterol	67.5	11.2
Vitamin E:		
•Alpha-Tocopherol	0.56	8.49
•Beta- Tocopherol	0.12	1.26
•Gamma- Tocopherol	3.3	0.79
•Delta- Tocopherol	0.05	42.2

<sup>1</sup> From (52); <sup>2</sup> Data are expressed as g/100g of seed or pulp dry weight.

**Table 6.** Mineral contents of *Opuntia* spp. spineless cladode<sup>1</sup> and fruit pulp<sup>2</sup>

Components	Dry weight in cladode (g/100g DW)	Fresh weight in fruit pulp (mg/100g)
Calcium (Ca)	5.64 (5.6)	12.8-59
Magnesium (Mg)	0.19 (0.2)	16.1-98.4
Potassium (K)	2.35 (2.3)	90-220
Phosphorus (P as PO <sub>4</sub> )	0.15 (0.1)	15-32.8
Sodium (Na)	0.4 (0.4)	0.6-1.1
Ferrous (Fe)	0.14 µg (trace)	0.4-1.5

<sup>1</sup> Adapted from (51). The numbers in parenthesis represent the percentage of dry weight (DW); <sup>2</sup> From (47) and (50)

#### 4.3. Lipids

Several authors have suggested cactus pear as a new source of fruit oils (52, 75, 84, 86-89). Fruit pulp provides lower yields of oil (0.1-1.0%), representing about 8.70 g total lipid/kg pulp dry weight compared to 98.8 g total lipids/kg for seeds (52). Furthermore, it has been shown that the seed oil contains a significant amount of neutral lipid (87.0% of total lipids), while the polar lipids are at higher levels in pulp oil (52.9% of total lipid). Both oils are a rich source of essential fatty acids and sterols. Linoleic acid, as well as beta-sitosterol and campesterol (90% of the total sterols), are the major constituents of the fatty acid and sterol fractions, respectively. Finally, the peel fraction contains 36.8 g lipids per kg (75). It is important to remember that fat soluble vitamins such as alpha-, beta-, delta-, and gamma-tocopherols, vitamin K1 and beta-carotene are associated with the cactus fruit seed and pulp oils, and will prevent the lipid fractions from oxidative damage (table 5). This fact corroborates the understanding that whole fruit consumption is more reasonable than the ingestion of fruit isolates.

The fatty acid composition of prickly pear seed oil is similar to sunflower and grape seed oils as reported by (90). Notwithstanding, the levels of total lipids, sterols and fat soluble vitamins may depend on the fruit cultivar, degree of ripeness and fruit processing, and/or storage conditions.

#### 4.4. Phenolic compounds

Phenolics comprise a wide variety of compounds, divided into several classes such as hydroxybenzoic acids, hydroxycinnamic acids, anthocyanins, proanthocyanidins, flavonols, flavones, flavanols, flavanones, isoflavones, stilbenes and lignans, that occur in a great number of fruits (grapefruits, oranges, berries, dark grapes, apples, etc.) and vegetables (onions, broccoli, cauliflower, Brussels sprouts, tomatoes, peppers, etc.), wine, tea, chocolate and other cocoa products in varying quantitative and qualitative amounts (91-94).

##### 4.4.1. Cladodes

The phenolic composition and their specific effects on human metabolism have been recently reviewed (30).

##### 4.4.2. Fruits

The presence of phenolics has been detected in cactus pulp fruit (45, 46, 95, 96). Kuti (96) has reported an antioxidative effect due to the major flavonoids encountered in cactus fruits (quercetin, kaempferol and isorhamnetin; table 4). There is clear evidence that these compounds are more efficient antioxidants than vitamins, since phenolic compounds are able to delay prooxidative effects on proteins, DNA and lipids by the generation of stable radicals (97). Furthermore, *O. ficus indica* polyphenolic compounds have been shown to induce a

**Table 7.** Potential products and by-products from cactus pear fruit and cladode <sup>1</sup>

Products from		By-products from
Fruits	Cladodes	Fruits and cladodes
Juice, nectar, pulp, puree	Lacto-fermented pickles	Oil from seeds
Jam, jelly	Candy	Oil from fruit pomace
Fruit leather	Jam	Pigments from peel
Syrup, sweetener	Flour	Pigments from pomace
Bioethanol, wine, “colonche”	Cooked vegetable	
Canned fruit	Ethanol	Dietary fiber and mucilage from
Frozen fruit	Edible coating	Cladodes
Juice concentrate		
Spray-dried juice powder		

<sup>1</sup> According to (30), (52), (81), (82), (105) and (107-116)

hyperpolarization of the plasma membrane and to raise the intracellular pool of calcium in human Jurkat T-cell lines (98). Flavonol derivatives detected in *Opuntia ssp.* have been recently compiled (30, 99). When fruits are investigated, it must be taken into account that higher phenolic contents are expected in the peel, rather than the pulp. Consequently, from a nutritional point of view processing both peel and pulp appears to be advantageous.

#### 4.5. Betalains

The most obvious feature of cactus pear fruits and flowers are the yellow (betaxanthins) and red (betacyanins) betalains, nitrogen-containing vacuolar pigments that replace anthocyanins in most plant families of the Caryophyllales including the Cactaceae (100). While their characterization in cactus flowers has been scarce (101), their identification in cactus pear fruit has been of renewed interest recently (43, 102, 103). In addition to color, the same pigments have shown antioxidant properties being higher than for ascorbic acid (43, 46).

In conclusion, the specific particularities of cactus pear make it useful in several arenas: nutrition, traditional medicine and further industrial applications (104, 105).

### 5. CACTUS UTILIZATION FOR FOOD, MEDICINAL AND INDUSTRIAL APPLICATIONS

The nutritional and pharmacological properties of cactus pears are quality attributes that may contribute to their increased consumption in the future (106). However, the fruits' short shelf-life requires adequate processing techniques to provide products of high nutritional quality even in the countries where *Opuntia* cultivation is not possible. Consequently, numerous strategies have been proposed which, however, have not entered industrial production (table 7) (30, 52, 75, 81, 82, 105, 107 -116).

#### 5.1. Nutritional use

Cacti have long been considered an important nutritional source in Latin America (bread of the poor) among which *Opuntia* has gained highest economic importance worldwide. It is cultivated in several countries such as Mexico, Argentina, Brazil, Tunisia, Italy, Israel and China. Both fruit and stems have been regarded to be safe for food consumption (72). The stems also serve as animal fodder and for hosting the cochineal insect *Dactylopius coccus costa* to exploit anthrachinone-derived pigments (30).

During drought periods, the spineless shrub of *Opuntia ficus indica* cactus plays a significant role in providing valuable nutrients for farming bovine, ovine and caprine animals. By feeding despined cactus stems, only limited amounts of conventional feeds such as concentrates, hay and straw are required (117). The use of cactus as a supplement to native forage in animal meat production is common during the dry season in some countries such as Tunisia, Brazil and Mexico where a significant acreage of more than 50,000 ha is dedicated for cactus production for fodder use (118-120). The digestibility of cactus cladodes decreases with age and only those aged from 1 to 3 years appear suitable for animal feed.

Both the cladodes and fruits are frequently consumed both fresh and processed in Latin America (104), whereas only the fresh fruits are more widespread on European and North-American markets (95).

#### 5.1.1. Cladodes

In Mexico, where the consumption of cactus pear is deeply embedded in culture, the cactus pads are commonly known as *nopales* or *pencas* when whole, or *nopalitas* when cut into small pieces or as fresh young cladodes from 3-4 weeks of age. They are regularly served with meals, similar to green beans (30). The reported heat-resistance of cactus pear extract antioxidants, suggests the capability of these antioxidants to maintain their activity well after harvest and during adequate storage (121).

#### 5.1.2. Fruits

The *Opuntia* fruit can be considered a valuable source for food supplementation. Far from being frequent, canned or bottled cactus pear juice, as well as pulp are exclusively encountered in specialized markets in Mexico and in the southwestern United States of America.

The nutritional changes of cactus pear upon processing have, only recently, been addressed (45, 113). While a total loss of GSH and beta-carotene was noted, and vitamin C together with cysteine contents decreased, betalains, taurine and vitamin E were less susceptible to decay. During storage of minimally processed cactus fruits at 4°C, polyphenolics decreased after 6 days while vitamin C contents remained stable (122).

#### 5.2. Medicinal use

As with numerous fruits and vegetables (123-130), cactus plants have also been reported to be beneficial to health (131). These effects are demonstrated in the

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treatment of several diseases. However, most accessible information on pharmacological studies deal with cactus stems rather than the fruit, the former being even less frequently encountered in non-producing countries.

### 5.2.1. Anti-cancer effect

Most recent studies suggests that the cactus pear fruit extract (i) inhibits the proliferation of cervical, ovarian and bladder cancer cell lines *in vitro*, and (ii) suppresses tumor growth in the nude mice ovarian cancer model *in vivo* (132). These experiments showed that inhibition was dose- (1, 5, 10 and 25% cactus pear extract) and time- (1, 3 or 5 days treatment) dependent on *in vitro*-cultured cancer cells. The intra-peritoneal administration of cactus extract solution into mice did not affect the animal body weight, which indicated that cactus did not have a significant toxic effect in animals. More importantly, tumor growth inhibition was comparable to the synthetic retinoid N-(4-hydroxyphenyl) retinamide (4-HPR), which is currently used as a chemopreventive agent in ovarian cancer chemoprevention (133-135).

Growth inhibition of cultured-cancer cells was associated with an increase in apoptotic cells and the cell cycle arrest at the G1-phase. Moreover, the induced-growth inhibition seems dependent on the P53 pathway, which is the major tumor suppressor. Annexin IV was increased and the VEGF decreased in the tumor tissue obtained from animals having received the cactus solution (132).

The mechanism of action as well as the component(s) by which cactus pear extract exerts these effects is not yet elucidated. However, first an extrinsic effect through an activation of membrane death receptors such as tumor necrosis factor, nuclear factor kappa B, Fas appears to be feasible. Secondly, intrinsic actions via the mitochondria, playing a pivotal role by releasing a number of molecules favorable to the induction of apoptosis such as Bax, AIF, cytochrome C, reactive oxygen species such as anion superoxide may be considered. Further investigations are needed to identify the potential active component(s) and the respective underlying mechanisms.

### 5.2.2. Anti-oxidant properties

The antioxidative action is one of many mechanisms by which fruit and vegetable substances might exert their beneficial health effects (45, 136-139). The presence of several antioxidants (ascorbic acid, carotenoids, reduced glutathione, cysteine, taurine and flavonoids such as quercetin, kaempferol and isorhamnetin) has been detected in the fruits and vegetables of different varieties of cactus prickly pear (table 4) (45, 46, 96, 140). More recently, the antioxidant properties of the most frequent cactus pear betalains (betanin and indicaxanthin) have been revealed (43, 46, 95, 139, 141, 142).

Numerous *in vitro* studies have demonstrated the beneficial effect of colorless phenolics and betalains (46, 76, 121, 139-143). These are generally attributed to the ability of antioxidants to neutralize reactive oxygen species such as singlet oxygen, hydrogen peroxide or H<sub>2</sub>O<sub>2</sub>, or

suppression of the xanthine/xanthineoxidase system, all of which may induce oxidative injury, i.e. lipid peroxidation.

Polyphenolics are antioxidants with well-known cardioprotective, anticancer, antiviral and antiallergenic properties (144, 145). Especially with green tea polyphenols (i.e. epigallocatechin-3-gallate or EGCG), their beneficial effects have been reported in several types of cancers or tumors (146). Polyphenols are also potential modulators of the transcription factors' activities (147, 148), which is more likely through a calcium-dependent pathway. Indeed, cactus polyphenolics induce a rise of the intracellular pool of calcium ions from the endoplasmic reticulum and thus perturb the expression of the interleukin 2, which is associated with the S-phase transition in human Jurkat T-cells (98). These effects remain to be verified in cancer cells.

### 5.2.3. Anti-viral effect

An interesting study by Ahmad *et al.* (149) demonstrated that administration of a cactus stem extract (*Opuntia streptacantha*) to mice, horses, and humans inhibits intracellular replication of a number of DNA- and RNA-viruses such as Herpes simplex virus Type 2, Equine herpes virus, pseudorabies virus, influenza virus, respiratory syncytial disease virus and HIV-1. An inactivation of extra-cellular viruses was also reported by the same authors. However, the active inhibitory component(s) of the cactus extract used in this study was not investigated, and as of yet, no further study dealt with this specific topic.

### 5.2.4. Anti-inflammatory effect

Numerous studies have evoked the analgesic and anti-inflammatory actions of the genus *Opuntia* by using either the fruit extract from *Opuntia dillenii* (150), the lyophilized cladodes (151), or the phytosterols from fruit and stem extracts (140). Park *et al.* (152) identified beta-sitosterol as the active anti-inflammatory principle from the stem extract. Gastric lesions in rat animal studies were reduced both by stem and fruit powders (153, 154). Finally, betanin and indicaxanthin stimulated an inhibitory effect on the chlorination activity of myeloperoxidase at neutral rather than at pH 5 (155).

### 5.2.5. Anti-diabetic (type II) effect

The prickly pear cactus stems have been used traditionally to treat diabetes in Mexico (156). Nowadays, *Opuntia spp.* is amongst the majority of products recommended by Italian herbalists that may be efficacious in reducing glycemia (157). Some studies have demonstrated the hypoglycemic activity of the prickly pear cactus extract on non-diabetics and diabetic-induced rats or diabetic humans (158-162). In a study on rats, the combination of insulin and purified extract of cactus (*Opuntia fuliginosa* Griffiths) was found to reduce blood glucose and glycated hemoglobin levels to normal (162). In this study, the oral dose of extract (1 mg/kg body weight per day) necessary to control diabetes contrast with the high quantities of insulin required for an equivalent hypoglycemic effect. A recent study has shown that a supplementation of rats' diets with cactus seed oil (25

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mg/kg) decreases the serum glucose concentration, which is associated with a glycogen formation in the liver and skeletal muscle (163). These observations were explained by a potential induction of insulin secretion, converting glucose to glycogen.

Except for one study (72), similar research on fruit components are lacking. In the future, it should be remembered that a clear differentiation between stem and fruit components are required to pin down the most pharmacologically active plant parts.

### 5.2.6. Anti- hyperlipidemic and hypercholesterolemic effects

Experimental evidence suggest that cactus pear reduces cholesterol levels in human blood and modify low density lipoprotein (LDL) composition (30, 42, 104, 164, 165). Galati *et al.* (166) have found that the cholesterol, LDL and triglyceride plasma levels of rats were strongly reduced after 30 days of a daily administration (1 g/kg) of lyophilized cladodes of *Opuntia ficus indica* L. Mill. Sterols which comprise the bulk of the unsaponifiables in many oils are of interest due to their ability to lower blood LDL-cholesterol by approximately 10–15% as part of a healthy diet (167). Recently, Ennouri *et al.* (163) observed a decrease in plasma total cholesterol and LDL (VLDL) cholesterol with no effect on HDL-cholesterol concentrations after addition of seed oil (25 g/kg) to the diet in rats.

Overall, the effects of cactus are generally attributed to the high fiber content of the cladodes, although other active ingredients (such as beta-carotenes, vitamin E and beta-sitosterol) may be involved.

### 5.2.7. Further positive health effects

Cactus fruits, cladodes or flower infusions have been traditionally used as folk medicine to treat other ailments such as ulcers (151, 154, 166), allergies (168), fatigue and rheumatism, and as an antiuric and diuretic agent (169). Alleviating effects towards alcohol hangover symptoms have been addressed recently (170) and were associated with reduced inflammatory responses after excessive alcohol consumption. Amongst the flavonoids extracted from either the cactus stem or fruit, quercetin 3-methyl appears to be the most potent neuroprotector (143). The cactus flower extract was able to exert an effect on benign prostatic hyperplasia (BPH) through the inhibition of aromatase and 5 $\alpha$  reductase activities, both of which are involved in androgen aromatization and testosterone reduction (171). A diuretic effect was reported to be promoted by ingestion of flower, cladode and especially fruit infusions in a rat feeding trial (169). Though *Opuntia spp.* glochids may induce dermal irritations, peeled *Opuntia* fruits or cladodes appear to be non-allergenic (172). More recently, Galati *et al.* (173) reported a protective effect of cactus juice against carbon hydrochloride (CCl<sub>4</sub>)-induced hepato-toxicity in rats.

## 5.3. Further uses

### 5.3.1. Cladodes

Further uses of the cactus plant have been suggested and recently reviewed, such as cladode pulp use

for the production of shampoos, conditioners, face and body lotions, soaps, hair gels and sun protectors or bioethanol production (30, 105, 174-176). In addition, veterinary phytotherapy including *Opuntia spp.* (177) appears to be a promising field of research and a worthwhile application.

### 5.3.2. Fruits

Natural colorants from plant sources are receiving growing interest from both food manufacturers and consumers in the continuing replacement of synthetic dyes. Betalains present in fruit peel and pulp, but also in the flowers represent a potential healthy alternative. Because of the wide range of colors available, cactus fruits are highly appreciated in the countries of origin, e.g., Mexico, Argentina, and southern Italy (178, 179) for different purposes. Unfortunately, fruits are still considered a specialty in Western industrial countries, and processed products based on cactus are extremely rare. Therefore, a number of studies have recently dealt with the practical relevance of cactus fruit processing to open up ways for increased *Opuntia* fruit commercialization, such as juice and concentrate production for food coloring purposes (113).

Juice obtained from the strained pulp is suggested to be a good source of natural sweeteners and colorants (42, 102, 180, 181). Cactus pear represents a viable alternative to red beet for food coloring purposes: it neither exhibits negative sensorial impact nor high nitrate levels, but offers a broad color range. Both the particular ratio of betaxanthins and betacyanins, as well as their total concentrations, has shown to determine their visual appearance covering a broad coloring range from bright yellow to red-violet (43, 182). Total color yield depends on the respective species and clone investigated and may range from 5 to 110 mg/100g (43, 102). Therefore, cactus pear juice preparations are expected to be a suitable coloring foodstuff for low acid products such as ice-cream or yogurt (183).

For complete exploitation of the fruit and resulting wastes, the residual seeds may be used for oil extraction (52, 77), whereas the peels are considered a rich source of pectin, polyunsaturated fatty acids, natural antioxidant vitamins and sterols (75).

## 6. CONCLUSIONS AND PERSPECTIVES

From the presented data, it appears that *Opuntia spp.* has been subject to intensive exploitation due to its great compositional diversity. Nowadays, this hidden knowledge needs to be discovered and re-evaluated. Sophisticated analytical approaches and innovative processing technologies will open new avenues to further promote the use of cactus pear stems, fruits and flowers in food, medicine, cosmetic, and pharmaceutical industries. An increasing demand would help encourage farmers to increase their acreage and thus also help to counterbalance erosion (26) and increasing atmospheric CO<sub>2</sub> levels (184-186). Although much research still needs to be done, concerted actions of taxonomists, plant breeders,



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agriculturists, food technologists, nutritionists and pharmacologists will help discover and understand the big potential of the *Opuntia* cactus. The exact botanical classification of the respective *Opuntia* spp. under investigation and the growing location and time of harvest are prerequisites for analytical and pharmacological studies. The exact plant parts used in the extraction and processing conditions need to be accurately documented to allow proper data evaluation.

## 7. ACKNOWLEDGEMENTS

This work was supported by NIH/NCI CA75966.

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**Key Words:** Cactus, Medicine, Opuntia, Cladode, Fruit, Food, Industry, Prickly pear, Review

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