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Nutritional and medicinal properties of fruits and cladodes *Opuntia ficus -indica* (L.) Mill

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Abstract Numerious scientific studies have demonstrated that cacti fruits and cladodes can serve as an efficient source of nutrients and phytochemicals of nutritional and functional significance, including sugars, mucilage, fibers, vitamins, and pigments. Due to their health-promoting properties, cactus products exhibit promising functional characteristics. In this article, we provide an overview of the major active components found in various cactus species worldwide. Historically, cacti have been used to treat diseases and wounds since ancient times, and their use as therapeutic agents in folk medicine especially cladodes and cactus pear fruits remains common. Cacti are traditionally employed as natural remedies in several countries. Over the past few decades, significant progress has been made in characterizing plant constituents and understanding the role of natural molecules in disease prevention. In addition to being a rich source of bioactive substances, cacti are excellent candidates for nutraceutical and functional food preparations. The beneficial properties of cactus products are enhanced by the presence of certain chemical constituents found in their fruits, cladodes, seeds, and flowers. Many of these constituents have the potential to act as health-promoting substances. Recent scientific discoveries have shed new light on the plant compounds responsible for the medicinal properties of cacti.

Keywords: opuntia, medicinal plants, cactus, edible fruits

1. Introduction

Considerable progress has been made in recent decades in characterizing plant constituents and explaining the role of natural molecules in disease prevention. In this context, there are strong recommendations to incorporate fruit and vegetables into the diet, and nutraceuticals have become a market of extraordinary commercial value. The genus *Opuntia*, part of the subfamily *Opuntioideae*, and family *Cactaceae,* includes approximately 200-300 species, primarily growing in arid (less than 250 mm annual rainfall) and semi-arid (250-450 mm annual rainfall) regions (Akacha et al., 2022). These species are native to Mesoamerican but have also been introduced to other continents, particularly *O. ficus-indica*, which was gradually brought to Europe following Columbus's voyage and the subsequent conquest of Mexico by Fernando Cortés. Today, this species is commercially cultivated for the production of fruits and their derivatives, in Italy, Mexico, Chile, Argentina, Israel, South Africa and California (Aliscioni et al., 2021). Traditionally, and still today, other commercial and subsistence agricultural uses are well known, ranging from fodder production to the use of young, tender vegetative organs (cladodes) as vegetables. Additionally, both fruits and cladodes have been widely used in popular medicine across several countries for various medicinal, nutraceutical, and cosmetic purposes (Aruwa et al., 2018). To a large extent, their use remains primarily limited to their countries of origin or those where they were later introduced. In light of climate change and due to its eco logical efficiency in terms of carbon and water footprint, *Opuntia* spp. is becoming increasingly important as a sustainable food production system in areas with scarce ecological resources. The fruits are consumed in the production areas and are also exported to European and North American markets. Clinical interest in the efficacy and safety of the phytochemicals present in the fruits of the *Opuntia* genus has increased in recent years. This growing interest is due to the recognized value of the fruit's colouring complex, betalaine, and an expanding body of scientific and experimental evidence, in addition to long-established empirical and traditional knowledge (Attanzio et al., 2018). For example, this includes the effects of fruit consumption in preventing diseases such as diabetes, treating gastrointestinal disorders, addressing conditions associated with a low dietary intake, and reducing blood glucose levels. Red-fleshed fruits have been shown to contain taurine (7.7-11.2 mg/100 g fresh fruit) in both Sicilian and American or South African cultivars. The presence of total phenolic and polyphenolic compounds (free and conjugated) was also observed in concentrations of 80-90 mg/100 g dry weight, including aromadendrina, taxifolin or dihydroquercetin, isoramnetin, vitexina, kaempferol, quercetin, betalines, betacyanins, etc (Benattia et al., 2019). This review provides a detailed description of the main active components of various species within the genus *Opuntia* sp. pl. studied worldwide. Since antiquity, *Opuntia* sp. pl. plants have been used to treat diseases and heal wounds and have traditionally served as natural medicines in various countries around the world for the treatment of various diseases. Several products that

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utilize the medicinal properties of *O. ficus-indica* (OFI) are currently available on the global market, and there is increasing industrial interest in using OFI-derived products in nutraceuticals. The scientific literature on the medicinal properties of the genus *Opuntia* sp. pl. is constantly expanding, with new findings emerging aboutthe components responsible for these activities.

2. Nutritional Aspects

The nutritional composition of fruits and cladodes depends on various factors, including genetic, environmental and crop management conditions, as well as the fruit's ripeness at harvest and subsequent post-harvest management.

2.1. Fruits

Many species within the genus *Opuntia* sp.pl. produce edible fruit. Among them, *Opuntia ficus-indica* is the most widely cultivated, known for its sweet, juicy fruit, which comes in a variety of flesh colours: white/green, yellow, orange, red or purple. The fruits exhibit a variable pulp-to-skin ratio, generally characterized by thin skin. Colored ecotypes may have dual applications: as sources of natural coloring agents derived from betalains and as providers of health benefits due to their antioxidant properties (Butera et al., 2002; Galati et al., 2003a; Kuti, 2004; Tesoriere et al., 2005a; Stinzing et al., 2005 Azeredo, 2009; Fernández-López et al., 2010). The fruit is an oval-shaped berry, weighing on average between 100 and 250 g. The juicy pulp makes up 55-65% of the total fruit weight and contains numerous small, hard seeds, ranging from 100 to over 400 per fruit. Figure 1 illustrates the fruit's composition. It is a non-climacteric fruit with a low respiration rate (Cantwell, 1995) and minimal ethylene production. Additionally, the fruit's pH, acidity, and total soluble solids remain relatively stable during post-harvest storage, although some changes in vitamin C content have been observed depending on storage conditions (Cayupán et al., 2009) (Table 1).

Table 1 Chemical and technological characteristics of O. ficus-indica fruit pulp.

Parameter	Green pulp	Red pulp	Orange pulp
pH	5.3-7.1	5.9-6.2	6.2-6.3
Acidity (% citric acid)	0.01-0.18	0.03-0.04	0.55-0.57
Total soluble sugars(°Brix)	0.17	12.8-13.2	13.5-14.5
Vitamin C (mg/100 g)	4.6-41.0	20.0-31.5	24.1-28.0
β-carotene (mg/100 g)	0.53	---	0.85-2.28
Lutein (μg/g)	26.0	0.15	0.04
Betacyanin (mg/kg)	0.1-0.8	111.0-431.0	2.4-11.0
Betaxanthin (mg/kg)	0.4-3.1	89.4-195.8	16.0-76.3

Source: Askar & El-Samahy, 1981; Pimienta, 1990; Sawaya et al., 1983; Sepúlveda & Sáenz, 1990; Sáenz & Sepúlveda, 2001; Sáenz et al., 2006; Stintzing et al., 2005; Hernández-Pérez et al., 2009; Morales et al., 2009; El Gharras et al., 2006; Coria-Cayupan et al., 2011.

Fruit ripening can begin as early as July in warmer climates of the Northern Hemisphere and in Sicily, extending to November due to a crop management practice that involves removing flowers and new cladodes early in the season, stimulating a second flowering during the summer months. Fruits harvested in the summer are typically firmer and can be distinguished from later-harvested ones by their cylindrical, and in some cases, pedunculate shape. The fruit retains its aroma only when harvested at the proper stage of ripeness, which coincides with the onset of epicarp veraison, when the overcolor covers no more than 25% of the fruit's surface. It can be stored for 4-6 weeks at 6-8°C and 90-95% relative humidity. In a controlled atmosphere, optimal conditions are approximately 5°C, 2% O_2, and 5% CO_2.

The chemical and nutritional composition of the fruit has been extensively researched (El Kossori et al., 1998; Butera et al., 2002; Feugang et al., 2006; Barbera et al., 1991). Sugars, fibers, mucilage, and pectins are the primary constituents of the pulp, while proteins, amino acids, vitamins, and minerals are present in smaller amounts (Tesoriere et al., 2005b). Additionally, secondary metabolites with antioxidant properties have been identified (Kuti, 2004; Yahia & Mondragón, 2011; Cayupán et al., 2011). The berry is characterised by a high sugar content (12-17%) and low acidity (0.03- 0.12%), with pH values ranging from 5 to 7. Additionally, the total soluble solids content varies from 11.6° Brix to 15.3° Brix, increasing as the fruit ripens (Yahia & Mondragón, 2011). The water content in the pulp and peel varies significantly, ranging from 11.14% to 90.33%, respectively. The primary carbohydrates in the pulp include glucose (29%) and fructose (2-4%), while sucrose is present in very low amounts (0.19%). Fresh weight and sugar content are certainly the parameters that show the greatest sensitivity to changing environmental conditions, whereas the least variable character is the percentage in the pulp. The relative ratio of glucose and fructose varies between species and within the pulp, with average values of 53 % glucose and 47 % fructose of the total sugar content (Kuti & Galloway, 1994). The fruit pulp is also rich in minerals, such as calcium (59 mg 100 g-1) and magnesium (98.4 mg 100 g-1) (Stintzing et al., 2011). The epicarp and pulp components contain mucillage and dietary fibre; mucilage is a hydrocolloid with a high capacity to absorb ac- qua. The total amino acid content (257.24 mg 100 g-1) is higher than the average for other types of fruit; the main amino acids are proline, taurine and serine. OFI fruits contain significant amounts of ascorbic acid, from 180 to 300 mg kg-1 of pulp (Piga, 2004). Tocopherols are found in the lipid fraction of the fruit seed and pulp. Vitamin E isoform homologues γ- and δ-tocopherols are the main components of seed and cellulose oils, respectively, making up to 80 per cent of the total vitamin E content (Ramadan & Morsel, 2003a). Lipids are distributed in the skin, pulp and seeds. The skin of the fruit contains considerable amounts of polyunsaturated fatty acids, especially linoleic acid. It also contains other fat-soluble compounds, such as sterols, beta-carotene and vitamin K1; the main sterol is β-sitosterol (Ramadan & Mörsel, 2003b). The polysaccharides and pectins in the peel have been characterised by Habibi et al. (2004).

2.2. Seeds and seed oil

The fruit of *Opuntia* sp. contains a large number of hard-coated seeds (10-15 g/100 g pulp). Their oil content is relatively low, though of high commercial value in cosmetics. The oil content is 7%-15% of the weight of the whole seed. Unsaturated fatty acids (mainly linoleic acid) account for about 80% of all fatty acids present (Ennouri et al., 2005). The linoleic acid content varies between 61.4 and 68.9 per cent. The concentration of α-linolenic acid in all cultivar is <1%. The oleic acid content varies between 12.5 % and 16.5 % (table 2). Thus, although the seed oil content is relatively low, its fatty acid content indicates a great potential for use in the health and cosmetics industry (Labuschagne & Hugo, 2010). The presence of tocopher-oils, recognised as natural antioxidants, varies between 3.9 % and 50 % (Matthäus & Özcan, 2011; Özcan & Al Juhaimi, 2011) reported that fibres and minerals are also important components in seeds, with 12.5 % crude fibre and high amounts of calcium, potassium and phosphorus, among other minerals. The protein content, around 6 per cent, makes the seeds a source of pro-teins for human consumption (Tlili et al., 2011).

Seed oil for cosmetics is sold at a very high price as organic oil for use in the production of anti-ageing and anti-wrinkle products. New applications are currently being developed by the cosmetics industry. The endosperm of the seed consists of polysaccharides such as ara-binogalactan, while the main component of the seed coat is D-xylan (Habibi et al., 2002). Xylan has been used as an adhesive, thickener and additive in plastics; it is also of increasing interest in the food industry due to its potential in packaging films and food coating; it also acts as an emulsifier and protein foam stabiliser during heating. Nowadays, it can play an important role in the development of new biomedical product designs for new drug delivery systems, especially for controlled drug delivery.

Table 2 Fatty acids (%) in Opuntia ficus-indica seed oil, extracted from fruits from different countries.

Fatty acids (%)	Countries						
	Morocco[1]	Turkey[2]	South Africa[1]	Tunisia[1,3,7]	Germany[4]	Chile[5]	Algeria[6]
Palmitic (C16:0)	11.9	10.6-12.8	13.7	12.2-12.7	23.1	16.2	13.1
Stearic acid (C18:0)	3.4	3.3-5.4	3.38	3.2-3.9	2.67	3.3	3.5
Oleic (C18:1w9)	21.3	13-23.5	15.7	16.4-22.3	24.1	19.9	16.3
Vaccenic (C18:1n-7)	–	5.1-6.3	–	4.8	–	–	5.3
Linoleic (C18:2w6)	60.8	49.3-62.1	64.38	53.5-60.6	32.3	57.7	61.8

Source: [1]Gharby et al., 2015; [2]Mattháus & Özcan, 2011; [3]Tlili et al., 2011; [4]Ramadan & Mörsel, 2003; [5]Sepúlveda & Sáenz, 1988; [6]Chougui et al, 2013; [7]Ouerghemmi et al., 2013

2.3. Cladodes

The cladodes are the organs, ovoid or elongated in shape, that make up the structure of the plant, combining the structural function with the photo-synthetic function. *Cactaceae*, in fact, have only ephemeral leaves. The cladodes also have the function of increasing the plant's water capacity, holding more than 90% water in their tissues, the parenchyma and collenchyma. The parenchyma is the true water 'storehouse' of the plant, capable of losing up to 80% of its water content without collapsing and giving it up, to a large extent, to the collenchyma, responsible for the photosynthetic function, which even under strong stress conditions maintains its function thanks to the passage of water between the two tissues. Young, tender cladodes, called nopalitos, are eaten as fresh vegetables; they are used as an ingredient in a wide range of dishes, including sauces, salads, soups, snacks, pickles, drinks, pastries and desserts (Sáenz-Hernandez et al. ,2002). The main components of cladodes are carbohydrates and polymers consisting of a mixture of mucilage and pectin. The chemical composition of fresh mucilage of young cladodes was reported by Sáenz- Hernandez et al. (2002):

- moisture 91% (water weight [ww])
- total carbohydrates 4.5 %.
- protein 1.5% (wx on dry basis [DB])
- fat 0.2% (ww DB)
- ash 1.3% (ww DB), of which 90% calcium Guevara Figueroa et al. (2010) analysed theproximal composition of *Opuntia* sp. In addition, 100 g of cladodes contain 11 mg of vitamina C and 30 µg of carotenoids.

Mucillage is a polysaccharide; it is found in specialised cells storing water or free inside cells or intracellularly in the tissues of the chlorenchyma and parenchyma dried mucilage comprises on average: 5.6 % moisture; 7.3 % protein; 37.3 % ash; 1.14 % nitrogen; 9.86 % calcium; 1.55 % potassium (Sepúlveda et al., 2007).

Based on its chemical composition, mucillagine is considered a polymer (similar to pectin), consisting of arabinose, galactose, xylose and rhamnose as neutral sugars, and a small amount of galacturonic acid (Medina-Torres et al., 2000; Madjdoub et al., 2001). In addition to the direct consumption of tender shoots, mature cladodes are milled to make flour and other products. OFI flour is a rich source of dietary fibre up to 43% DB (Sáenz-Hernandez et al., 2002); it can be used to replace or supplement food recipes containing flour from other sources.

3. Bioactive Phytochemicals

Opuntiae are also important sources of bioactive components; excellent substances and candidates for nutraceutics and functional food preparation. The fruits, cladodes, seeds and flowers all have high chemical constituents, which add value to cactus products.

3.1. Fruits

Prickly pear fruits exhibit high antioxidant activity, attributable to the presence of vitamin C, flavonoids and betalains (Galati et al., 2003a; Kuti, 2004). Betalains are nitrogen-containing pigments and can be classified as red betacyanins and yellow betaxanthins (e.g. indicaxanthin). The chemical structure of these pigments is derived from the condensation of betalamic acid with various amino acids and, depending on the compounds that join this structure, betaxanthins, which give rise to the yellow colour, and betacyanins, which give rise to the red-violet colour, are formed. Betalaines are the main pigments responsible for the colours of ripe fruit and are an important factor in consumer acceptance The concentration of pigments depends on various types of factors, in particular the ripeness of the fruit (Cayupán et al., 2011). In the cultivars “Red” and “Yellow” cultivated in Sicily, betanin and indicaxanthin are present, respectively; the latter accounts for 99 % of the betalaines in the fruit of the “White” variety, while the ratio betanin: indicaxanthin varies from 1:8 in the “Yellow” fruit to 2:1 in the “Red”. The antioxidant activity in the fruit is twice that of pear, apple, tomato, banana and white grapes, and is similar to that of red grapes and grapefruit (Butera et al., 2002). Betacyanins are ammonium conjugates of betalamic acid with cyclo- DOPA; betaxanthins are conjugates of betalamic acid with amino acids or amines. These pigments not only provide colour: their antioxidant properties are greater than those of ascorbic acid pigments (Butera et al., 2002; Stintzing et. al., 2005a). In contrast to anthocyanins (another group of natural red pigments), betalains are stable over a wider pH range and are therefore more appropriate for use as food colourants in low-acid environments (Stintzing et al., 2001). Due to their broad structural, and thus colour diversity, betalaines are a very promising source of natural dyes for use as functional dyes. Compared to red beets, the fruit of OFI not only offers a wider range of colours, but also has technical advantages: absence of geosmin (an organic compound with a distinct earthy taste and aroma); low nitrate levels; and the absence of microbial contamination of the soil.

The presence of phenolic substances has also been detected in fruit pulp. Kuti (1992) reported an antioxidant effect due to the main flavonoids found in cactus fruits (e.g. quercetin, kaempferol and isorhamnetin derivatives). Flavonol derivatives found in *Opuntia* sp. have been reviewed by Stintzing et al. (2005a). The skin has a higher phenolic presence than the pulp (Stintzing et al., 2005b). Lee et al. (2002a) found that flavonoids in cacti are also effective in protecting plasmid DNA from damage induced by hydroxyl radicals.

3.2. Cladodes

Other functional components, such as chlorophyll derivatives, amino acids and flavonoids, are found in cladodes. Guevara Figueroa et al. (2010) analysed cladodes of *Opuntia* sp. from Mexico and assessed the polyphenolic and flavonoid profiles in both fresh cladodes and their transformation derivatives. The presence of five main flavonoids (isoquercitrin, isorhamnetin-3-O-glucoside, nicotiflorin, rutin and narcissin) was observed in all varieties and kaempferol-3-rhamnosyl glucoside (nicotiflorin) was predominant.

3.3. Flowers

OFI flowers accumulate betalains as well as colourless phenolic compounds (Ahmed et al., 2005). The chemical composition of *O. ficus-indica* and *O. stricta* flowers extracted at four flowering stages was studied by Ammar et al. (2012), who verified the anti-radical, antibacterial and antifungal activity in both ethanol and hexane extracts. The phenolic content varies considerably depending on the flowering phase, and these active constituents are at their peak during the post-flowering phase. De Léo et al. (2010) reported the chemical profile of *O. ficus-indica* flowers extracted in methanol. The volatile fraction in flowers of three *Opuntia* species, obtained by aqueous distillation, was characterised and assayed as an antimycoticous agent (Bergaoui et al., 2007). In the flowers, nine different compounds were identified, including: isoarmetin 3- Q-robino bioside, which represents the largest component (52.22%), followed by disoarmetin 3-0-galacto- side (11.98%), lysoarmetin 3-0-glucoside (8.86%), quercetina 3-0-rutinoside (8.67%), quercetin 3- 0-glucoside (5.47%), canferol 3-0-rutinoside (4.89%), canferolol 3 O-arabinoside (3.96%) and, finally, two unidentified compounds with a percentage of 1.88% and 2.07% respectively.

4. Bioactive Phytochemicals

Prickly pear plants have been used by ancient civilisations to treat diseases and heal wounds for thousands of years. The origins and history of their medical uses are particularly linked to the Mesoamerican civilisation, especially the Aztecs. There are, in fact, several codices and images that describe this particular aspect of the species as being so important that Oviedo Yvalde (1515) was able to state that 'what the Christians who are in those Indies call a soldering tree and a comforter, and with much reason, for what has been seen and experienced many times of its properties and effect. Of the tree, or plant, by which the rottures, which occur in the person of man, are welded'.

But there is a lot of historical evidence testifying to the use of the cladodes, fruits, flowers and seeds of the *Opuntiae*, made by the natives for their nutritional qualities and healing properties. Several studies show that fruits and cladodes have high levels in mineral elements and vitamins, as well as antioxidants. Flowers, fruits, cladodes, roots and seeds are excellent sources of phytochemicals of nutraceutical importance (El Mostafa et al., 2014; Nazareno, 2014).

Used as a dietary supplement, OFI fruit reduces oxidative stress. The effect of betalaines on oxidative stress in humans was studied by Tesoriere et al. (2003, 2004, 2005a), who reported that ingestion of OFI fruit produced a decrease in markers of oxidative stress, inhibited LDL oxidation and resulted in increased oxidative haemolysis resistance of red blood cells in ex vivo experiments. Budinsky et al. (2001) demonstrated that regular consumption of *O. robusta* reduced oxidative damage. Zou et al. (2005) studied the usefulness of prickly pear pulp extract in suppressing carcinogenesis in cultured human cancer cell lines in vitro and in an ex vivo animal model. Results showed that the extract inhibited the growth of bladder and cervical cancer cells and suppressed tumour growth in animals inoculated with ovarian cancer cells. The antiproliferative effects of betanin on human chronic myeloid leukaemia (K562 cell line) were reported by Sreekanth et al. (2007). Extracts of *O. humifusa* pulp have been tested against breast cancer and on human glioblastoma cell lines (Hahm et al., 2010). Emerging evidence points to remarkable anticancer activities exhibited by OFI fruit extracts. The chemopreventive and anticancer activities of crude extracts of fruits belonging to the *Cactaceae* family, as well as their main active components, are well reviewed by Harlev et al. (2013). In vitro studies of the interaction between purified betalains and hypochlorous acid and human myeloper-oxidase revealed the anti-inflammatory action of these fruit pigments (Allegra et al., 2005). Recently, significant anti-inflammatory effects of indicaxanthin, present in yellow-fleshed fruits, were reported in an animal model (Allegra et al., 2014). The anti-ulcerogenic and anti-gastritis effects of OFI fruits were studied in rats by Lee et al. (2001) and Galati et al. (2003a). Hepatoprotective activity related to the consumption of *O. ficus-indica* juice and fruit extract has been demonstrated in rats (Galati et al., 2005; Alimi et al., 2012). Kim et al. (2006) demonstrated the neuroprotective action of *O. ficus-indica* fruit extracts against ectoxin-induced neuronal oxidative lesions in cortical cells of mice. They also reported in vivo experiments in which methanolic extracts of OFI fruits reduce neuronal damage derived from global ischaemic events in gerbellines, attributing these effects to the anti-oxidative action of bioflavonoids. Wolfram et al. (2002) showed that the ingestion of 250 g day^{-1} of *O. robusta* fruits produced an anti-hyperlipidemic and cholesterol-lowering effect in non-diabetic hyperlipidemic subjects, there is also evidence of effects on glucose metabolism. The cholesterolaemic-lowering action can be partially explained by the presence of fibre (pectin) contained in the fruit. Although the hypoglycaemic mechanism is not yet clear, the fruits seem to promote both in diabetics and non-diabetics a faster and better entry of glucose into the cell. The improvement of platelet function due to regular consumption of OFI fruits (250 g per day^{-1}) in healthy volunteers and in patients with mild familial hypercholesterolaemia was described by Wolfram et al. (2003). Ingestion of the fruit induces beneficial actions on the cardiovascular system by decreasing platelet activity and improving the haemostatic balance.

4.1. Cladodes

Administration of *O. ficus-indica* cladode extract to hypercholesterolaemic rats results in a marked decrease in cholesterol and triglyceride levels in samples of their plasma. An anti-hyperlipidaemic and cholesterol-lowering effect is has been observed in guinea pigs, rats and mice (Galati et al., 2003b; Oh & Lim, 2006). Diabetes experiments on non-insulin-dependent patients have confirmed the hypoglycaemic effects of administering *Opuntia streptacantha* cladodes. Furthermore, the consumption of young cladodes reduces obesity and blood sugar levels. The anti-obesity, hypoglycaemic action and anti-diabetic effects have all been observed in rats and humans (Bwititi et al., 2000; Frati Munari et al, 2004; Yang et al., 2008). Galati et al. (2001) proposed that *O. ficus-indica* cladodes stimulate a protective response in the gastric mucosa, preventing the development of ethanol-induced ulcers (preventive treatment) and promoting faster recovery (curative treatment) (Table 3). The cytoprotective effect of *O. ficus-indica* cladodes is attributed to the physicochemical properties of the mucilage (Galati et al., 2001). *O. ficus-indica* cladodes produce cellular protection by increasing the mucus secretion of the gastric mucosa of rats suffering from ethanol-induced ulcers (Galati et al., 2002). The administration of cladodes is recommended for both preventive and curative treatments of gastric ulcers (Lee et al., 2002a). The plant extract of *Opuntia ficus-indica* may also alleviate the symptoms of excessive alcohol consumption (Wiese et al., 2004). Furthermore, the protective effect of *Opuntia* *ficus- indica* cladodes juice against Ni-induced toxicity is reported by Hfaiedh et al. (2008). Experimental exposure to Ni leads to increased lipid peroxidation, loss of membrane integrity and alterations of the cellular antioxidant system. There are indications that cladode juice can prevent oxidative stress and decrease oxidative stress-related parameters in rats; regular ingestion of cladode juice can also counteract the peroxidative effects of Ni. Similar protective effects against oxidative damage induced by various toxic substances are also reported by Ncibi et al. (2008) and Zourgui et al. (2008). The neuroprotective action against neuronal oxidative lesions of flavonoids contained in the cladodes of O. ficus-indica were found to be effective in mouse cortical cells and against global ischaemia (Kim et al., 2006). Cladode extracts may have a hepatoprotective effect against aflatoxicosis in mice, probably acting to promote antioxidant defence systems (Brahmi et al., 2011). Experiments have also been conducted on the antiviral action of cladode and fruit extracts of OFI and related species. Extracts of *O. streptacantha* cladodes show antiviral properties against DNA-attacking viruses, such as herpes, and against ribonucleic acid (RNA) viruses, such as influenza type A, and finally against human immunodeficiency viruses such as HIV-1. The active ingredient was located in the outer part of the non cuticular and attributed to a protein with unknown mechanisms of action (Ahmad et al., 1996).

Applications of cladode and fruit extracts of OFI and *O. streptachanta* can inhibit the replication of DNA and RNA viruses. An international patent (Skinner & Ezra, 1993) claims that cladodes extracts have an effect against herpes simplex and influenza A viruses. Chlorophyll derivatives have been proposed as the active compounds responsible for this efficacy (Table 3 and Table 4).

Table 3 Medicinal properties of cactus products.

Cactus, parts and activities	Studies and Bibliographical References
Antiviral action	
O. streptacantha cladode extract	Inhibition of intracellular virus replication and extracellular virus inactivation (Ahmad et al., 1996)
Opuntia sp. cladodes	Guinea pigs (Fernández et al., 1994)
Anti-hyperlipidemic effect and reduction of cholesterol levels	
O. robusta fruits	Hyperlipidaemic non-diabetic humans (Wolfram et al., 2002)
O. ficus-indica cladodes	Rats (Galati et al., 2003b)
O. ficus-indica seeds and seed oil	Rats (Ennouri et al., 2006a, b, 2007)
O. ficus-indica var. saboten	Mice (Oh & Lim, 2006)
Anti-obesity factor	
Opuntia sp. cladodes	Humans (Frati Munari et al., 2004)
O. megacantha	Diabetic rats (Bwititi et al., 2000)
O. lindheimeri	Diabetic pigs (Laurenz et al., 2003)
Hypoglycaemic and anti-diabetic effect	
O. ficus-indica, O. lindheimeri, O. robusta, fruits	Diabetic rats (Enigbocan et al., 1996)
O. streptacantha	Humans (Lozyoa, 1986)
O. monacantha cladodes	Diabetic rats (Yang et al., 2008)
O. ficus-indica seeds and seed oil	Rats (Ennouri et al., 2006a,b)
O. streptacantha	Humans (Munari et al., 1992)
O. filiginosa fruits	Rats (González et al., 1996)
Anti-inflammatory action	
O. humifusa extracts, *O. ficus-indica* indicaxanthina	Nitric oxide-producing cells (Cho et al., 2006; Allegra et al., 2014)
Healing properties	
O. ficus-indica cladodes	Humans (Hegwood, 1990)
Neuroprotectors	
O. ficus-indica var. Saboten extract	Primary cortical cells (Dok Go et al., 2003)
O. ficus-indica fruit extract	In vitro studies on cultured mouse cortical cells (Kim et al., 2006)

Table 4 Medicinal properties of cactus products.

Anti-ulcerogenic and anti-gastritis effects	
O. ficus-indica cladodes	Rats (Galati et al., 2001, 2002)
O. ficus-indica fruit juice	Rats (Galati et al., 2003a)
O. ficus-indica var. Saboten	Rats (Lee et al., 2002a)
O. ficus-indica fruits	Rats (Lee et al., 2001)
Decreasing effect on oxidative stress in humans	
O. ficus-indica fruits	Human (Tesorieri et al., 2004); in vitro LDL (Tesorieri et al., 2003) human cells ex vivo (Tesorieri et al., 2005b)
O. robusta fruits	Humans (Budinsky et al., 2001)
Symptoms of alcohol hangover	
O. ficus-indica plant extract	Humans (Wiese et al., 2004)
Protection against nickel-induced toxicity	
O. ficus-indica cladode extract	Rats (Hfaiedh et al., 2008)
Protection against oxidative damage induced by zearalenone	
O. ficus-indica cladodes	Mice (Zourgui et al., 2008)
Diuretic effect	
O. ficus-indica cladodes, flowers and fruit not marketable	Rats (Galati et al., 2002)
DNA damage reduction	
O. ficus-indica fruits	Human peripheral lymphocytes (Siriwardhana et al., 2006)
Anti-cancer properties	
O. ficus-indica fruits	Ovarian and cervical epithelial cells, as well as ovarian, cervical and bladder cancer cells (Zou et al., 2005), ovarian cancer cells (Feugang et al., 2010); leukaemia cell lines (Sreekanth et al., 2007)
O. humifusa fruits	Human cell lines for breast cancer and glioblastoma (Hahm et al., 2010; Harlev et al., 2013)
Opuntia spp. juice	Cangerogenic cells of the prostate, colon, breast and liver (Santoscoy et al., 2009)
Hylocereus spp. extracts	Antiproliferative action in vitro (Kim et al., 2011; Wu et al.2006; Jayakumar & Kanthimathi, 2011)
O. humifusa fruits	Decreased number of papillomas and epidermal hyperplasia in mice (Lee et al., 2012)
Liver protection	
O. ficus-indica extract and juice	Liver (Galati et al., 2005; Alimi et al., 2012; Brahmi et al., 2011; Ncibi et al. 2008)
Anti-clastogenic capacity	
Cactus juice	Mice (Santillán et al., 2013)
Increased bone density	
O. humifusa dried cladodes	Rats (Kang et al., 2012)
Improved insulin sensitivity	
O. humifusa dried cladodes	Rats (Kang et al., 2013)

5. Perspectives

Opuntiae and in particular *Opuntia ficus-indica* can be considered an important source of bioactive energy and excellent candidates for nutraceuticals and the preparation of functional foods. There is much scientific and experimental evidence revealing a high content of certain chemical constituents in fruits, cladodes, seeds and flowers, which may add value to OFI-based products. In addition, some constituents show promising characteristics as promoters of health substances. Several patented products are currently available on the nutraceutical market. The fruits are processed to make sweets, syrups, spreads, jams and jellies. The natural juice is rich in vitamine C, flavonoids and antioxidants, and as an anti-ageing and anti-inflammatory agent. It is also considered to promote optimal cell health and detoxify the body. There is potential to further exploit the functional properties of products based on *Opuntia* sp. derivatives in the food, cosmetic and pharmaceutical sectors, but more investment in scientific research is certainly needed to find new active ingredients. Although the beneficial properties associated with the consumption of fruit and vegetative organs of *Opuntiae* have been known since ancient times, the progress made by scientific research is very recent but very significant, compared to the lack of scientifically based knowledge existing only a decade ago. Also lacking is in-depth research into the mechanism of action of the pharmacological effects of its active ingredients. Cladodes have health-promoting properties and can be used dehydrated or powdered to prepare pills and capsules. The seed oil, on the other hand, is used in cosmetics. Furthermore, antioxidant formulations must be tested for possible synergistic effects between the components. have only recently been scientifically proven. Finally, there is a lack in the field of pharmacodynamics and pharmacokinetics or safety aspects of *Opuntia*. Despite being one of the most curative genera, there are gaps in many aspects of the disease that require further investigation, particularly in chronic diseases, to identify its exact mechanisms and potential therapeutic value.

6. Conclusions

Scientific research indicates that both the fruit and cladodes of *Opuntia ficus-indica* can be effectively utilized to obtain important nutritional and functional nutrients and phytochemicals, such as sugars, mucilage, fiber, vitamins, and pigments. Recent studies highlight the promising functional characteristics of *Opuntia ficus-indica* products due to their health-promoting properties. Historically, cactus plants have been employed as natural medicines for treating diseases and healing wounds. This paper provides detailed descriptions of the major active components across different species of *Opuntia ficus-indica*. Many countries have traditionally used cacti in natural medicine to address a variety of health issues, and cladodes and fruits of *Opuntia ficus-indica* continue to be used as therapeutic agents in folk medicine. Significant progress has been made in recent decades in understanding the plant's constituents and how natural molecules contribute to disease prevention. Besides being a valuable source of bioactive substances, *Opuntia ficus-indica* is also an excellent candidate for nutraceuticals and functional foods. Research has demonstrated that certain chemical compounds in prickly pear fruits, cladodes, seeds, and flowers can enhance the value of these products and exhibit potential health-promoting functions. Ongoing research into medical prickly pears continues to uncover new discoveries about their plant components.

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Ethical Considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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