

Prickly Pear as an Immunomodulator

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ABSTRACT

Opuntia ficus-indica, commonly known as prickly pear, is a dicotyledonous species from the Cactaceae family, renowned for its diverse pharmacological properties and nutritional richness. Both the edible fruit and cladodes (flattened stems) are valued for their high content of essential vitamins (C, E, A, B1, B2), minerals (calcium, potassium, magnesium, iron, phosphorus), amino acids (asparagine, alanine, arginine), and macronutrients such as carbohydrates, fibres, and proteins. The plant also harbours potent phytochemicals, including carotenoids, betalains, polyphenols, and flavonoids like quercetin, kaempferol, isorhamnetin, and indicaxanthin, contributing to its anti-inflammatory, antioxidant, antimicrobial, hypoglycaemic, and neuroprotective effects. These attributes make prickly pear an effective natural agent in managing various conditions such as cancer, diabetes, cardiovascular disease, obesity, gastrointestinal disorders, ulcers, and skin ailments. Its cladodes, in particular, have shown notable activity in promoting gastrointestinal health and immune modulation. The concept of immunomodulation regulating immune function using compounds such as interferon- γ , DMG, and plant-based agents has brought attention to natural sources like *Opuntia ficus-indica* for their role in enhancing host defence and correcting immune imbalances. In recent years, the rise in interest toward natural remedies and functional foods has re-established *Opuntia ficus-indica* as a promising candidate in the nutraceutical and health food sectors. However, current studies affirm its potential as a sustainable, multifunctional plant for dietary and therapeutic applications aimed at promoting holistic well-being.

Keywords: Prickly Pear, *Opuntia ficus-indica*, Immunomodulator, Phytochemical

I. INTRODUCTION

The immune system is a highly evolved defence network built up of various organs, cells, and tissues that work collectively to maintain the body secure from microorganisms like viruses or bacteria [1]. The Latin term immune, referring to exempt, is the root of the English word "immunity" [2]. Therefore, an agent that affects the immune system is called an immunomodulator. Immunological adjuvants are specific immunomodulators given in connection with antigens to enhance the immune system's reaction to the vaccine's ingredients [3]. Upon being created in the marrow of the skeleton, immune stem cells can either travel to other parts of the body or stay there until they mature [4]. Two separate but overlapping immune system systems aid in the defence against invasive invaders.

- Cell-mediated defences (cellular immunity)
- Antibody-mediated defences (humoral immunity)

Cell Mediated Immunity: The activity of multiple leukocyte actions, feedback, and interactions—from elementary to complex—leads to cell-mediated immunity (CMI). The T (Thymus) cells, which offer a delayed immunological response, are crucial for this type of immunity. The first time a T lymphocyte comes through contact with specific antigen, it receives sensitized.

Humoral Immunity: Special white blood cells designated as B (bone cell) lymphocytes create circulating antibodies to fight against foreign substances in humoral immunity. The antigen-antibody interaction is the fundamental component of this particular type of immunity [5]. In addition to modulating transcription factors and mediators, immunomodulators mainly target cellular responses (Fig. 1), involving protein synthesis, apoptosis, and antigen presentation [6].

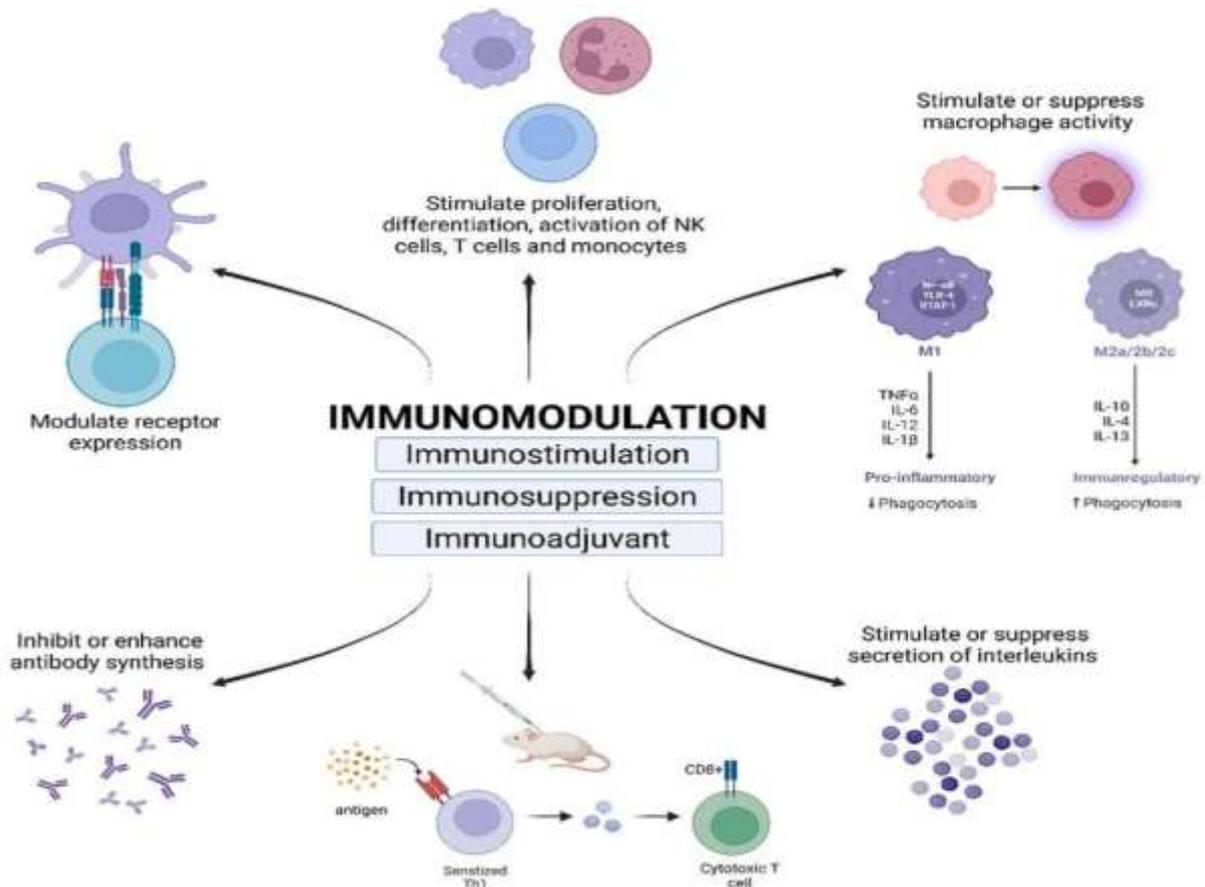


Figure 1: Immunomodulation

Immune stimulation, which enhances the immune system, immunosuppression, which simplifies the immune system, and immunoadjuvants are essential elements of immunomodulatory impacts. As an outcome, each kind of immunostimulant and immunosuppressant serves a distinctive role in producing the desired outcome [7]. Currently, immunomodulatory therapies that are chemically or biologically developed are frequently utilized in research on disease prevention and treatment. Corticosteroids, non-steroidal anti-inflammatory medications, histamine antagonists, monoclonal antibodies, cytokine inhibitors, and cellular signaling are just a few examples [8]. However, immunomodulators originated from ancient or medicinal plant sources having fewer adverse reactions are now becoming frontline medical therapies for autoimmune

disorders, cancer, and infectious diseases due to the significant health hazards presented by these medications [9]. The World Health Organization (WHO) describes a medicinal plant as one that contains components which possess medicinal value or function as precursors for semi-synthesis of chemo-pharmaceuticals in one or more of its organs [10–12].

II. PRICKY PEAR

Synonym: Cactus fruit, Cactus fig, Indian fig, Barbary fig, Tuna cactus, Mission cactus, Smooth Mountain Prickly pear, Tuberos Prickly Pear

Botanical Name: *Opuntia ficus-indica*.

Part used: Fruit (also pads or cladodes).

Table 1: Taxonomical classification of Opuntia ficus-indica

Kingdom	Plantae
Phylum	Tracheophyta
Class	Magnoliopsida
Order	Caryophyllales
Family	Cactaceae
Subfamily	Opuntioideae
Genus	Opuntia
Species	Opuntia ficus-indica

categorized based on taxonomy in Table 1 [13]. While tissues from Opuntia polyacantha and other Opuntia species were previously utilized for their therapeutic properties, they are currently used for their nutritional value qualities [14,15]. a family of cactus that includes more than 1500 species. Tropical and subtropical plants include Opuntia ficus-indica. Its geographic distribution includes Mexico, South Africa, Latin America, and Mediterranean nations, and it can thrive in areas

that are semi-arid or arid. The Nopal cactus is used in tea, jam, juice, and oil produced from prickly pear seeds for health, nutrition, and cosmetic applications. In numerous nations, it has been used as a herbal treatments for several kinds of illnesses. Fruits and flowers of cacti are used as anti-ulcerogenic or antidiarrheal drugs; cladode sap can be utilized to treat whooping cough, and flowers are also used as an oral anti-haemorrhoid drug [16,17,18].

III. MORPHOLOGICAL FEATURE



Figure 2: Opuntia ficus-indica

Table 2: Morphological Features

SR NO.	FEATURES	DESCRIPTION
1	Habit	Perennial, succulent shrub, ranging from low-growing to tree like forms.
2	Cladodes[Pads]	Flat, segmented, fleshy stem segments, often oval or paddle-shaped.
3	Spines	Sharp, needle-like structures arising from areoles, varying in number and length depending on the species.

4	Glochids	Small, barbed bristles also arising from aerosols, easily detach and can cause skin irritation.
5	Areoles	Small, specialized spots on the cladodes where spines, glochids and sometimes flowers or new cladodes develop.
6	Leaves	True leaves are small and scale like, quickly withering away.
7	Flowers	Typically large, solitary and bisexual with numerous tepals (petal like structures) and stamens.
8	Fruit	A freshly berry, often pear-shaped, with a range of colours (yellow, orange, red, purple) depending on the species and maturity.
9	Seeds	Small, hard and numerous in the fruit.
10	Root system	Spreads horizontally with a fibrous root system.

IV. NUTRITIONAL PROFILE

In particular, several authors have reported that prickly pears contain appreciable quantities of soluble fibres and antioxidant compounds, such as ascorbic acid, phenols, flavonoids [19]. Prickly pears are rich in pigments of betalain derivatives, such as betacyanin, responsible for the fruit's purple red colour, or betaxanthin, responsible for its

yellow-orange colour [20]. Prickly pears are also a good source of minerals, particularly calcium, magnesium, potassium and phosphorus [21,22]. Generally, spines are composed of 96.00% polysaccharides, which are further divided: 49.70% cellulose and 50.30% arabinan. The rest are fats, ash-powder, and crude-waxes, and the residual is lignin[23].

TABLE 3: Chemical constituents and fruit pulp products of the prickly pear fruit, primarily from *Opuntia ficus-indica*. According to [24,25,26].

CONSTITUENTS	FRUIT PULP
Water	84-90
Carbohydrates	12-17
Ashes	0.3-1
Fiber	0.02-3.15
Protein	0.21-1.6
Lipid	0.09-0.7

4.1 Carbohydrates

In the pulp of *Opuntia ficus-indica* fruit, glucose and fructose are the major monosaccharides, whereas glucose is the main monosaccharide in the fruit peel. As a result of the high invertase activities in *Opuntia ficus-indica* fruits pulp, sucrose is converted to monosaccharides; therefore, sucrose is a minor sugar in *Opuntia ficus-indica* fruits pulp. Besides the ethanol-soluble carbohydrates found in the peel and pulp, the amount of monosaccharides gives

Opuntia ficus-indica its sweet flavour. [27, 28, 29, 30,31,32].

4.2 Fiber

Humans may consume rich, edible fiber products originating from *Opuntia ficus-indica*. *Opuntia ficus-indica* seed is an abundant source of fiber as it offers more fiber than fruit peel. likewise insoluble as well as soluble fibers have been produced by the peel and seeds of *Opuntia ficus-indica* fruit [29, 30, 31]. Whereas the fruit pulp of

Opuntiaficus-indica has an impressive amount of pectin (about 70% of the total fiber), the amount of cellulose of the fruit skin and seeds approximately 71.0% and 83.0%, respectively. Cellulose, hemicellulose, pectin, and lignin represent the key fiber components of Opuntiaficus-indica fruit pulp, which boasts a raw fiber count of 20 g/100 g db [30,31,33,34].

4.3 Amino Acid

Glutamate is the fundamental amino acid that occurs in cactus cladodes, with leucine, lysine, valine, arginine, phenylalanine, and isoleucine that which follows. In contrast, glutamic acid, typically varies between 15.73% to 20.27%, is an essential amino acid that exists in cactus seeds. Unexpectedly, proline and taurine contribute to 46% and 15.78% of the total amino acid content in cactus fruit, respectively, which makes them the two most frequently occurring amino acids [35, 36].

4.4 Vitamins

One of the significant chemical compounds in Opuntiaficus-indica is vitamins. Vitamins comprising vitamin C, ascorbic acid, total vitamin E, α -tocopherol, β -tocopherol, δ -tocopherol, γ -tocopherol, and vitamin K exist in various proportions in the portions of the Opuntiaficus-indicaplant. The pulp of Opuntiaficus-indica includes a greater quantity of α -tocopherol than other forms of vitamin E. inversely, vitamin K has a role as a cofactor in the synthesis of the proteins that make up the bone matrix and coagulation factors. Furthermore, the pulp oils and seeds of Opuntiaficus-indica fruit have high levels of vitamin K [30,31,36,38].

4.5 Minerals

The pulp of Opuntiaficus-indica is regarded as a fruitful source of minerals [31], including potassium, calcium, sodium, and magnesium (Table 4).

Table 4 :Component part of minerals.

Component	Opuntiaficus-indicapart	
	Pulp	Peel
Magnesium	1.05-25	1.47
Sodium	0.06-1.29	0.11
Potassium	11.1-158	0.48
Calcium	0.69-40.9	1.52
Manganese	0.10-4,89	0.13
Iron	0.20-3.35	0.47
Zinc	0.07-1.63	0.13
Copper	0.001-0.14	0.19
Phosphorus	0.006-0.26	0.53
Molybdenum	<0.31 ^{DM}	<0.34 ^{DM}

V. CHEMICAL CONSTITUENT

5.1. Fatty acids

Opuntia ficus indica seed oil's designation as a polyunsaturated oil is corroborated through its compositional analysis

[43].The predominant fatty acid in these oils remains linoleic acid, which will be followed by oleic acid and palmitic acid [44].Figure 1 indicates the main fatty acids, palmitic acid, and linoleic acid identified in oil seeds from Opuntia ficus indica.likewise t

These oils have been determined to contain negligible levels of myristic acid, palmitoleic acid, stearic acid,

linoleic acid, vaccenic acid, arachidic acid, linolenic acid, behenic acid, and lignoceric acid [45].

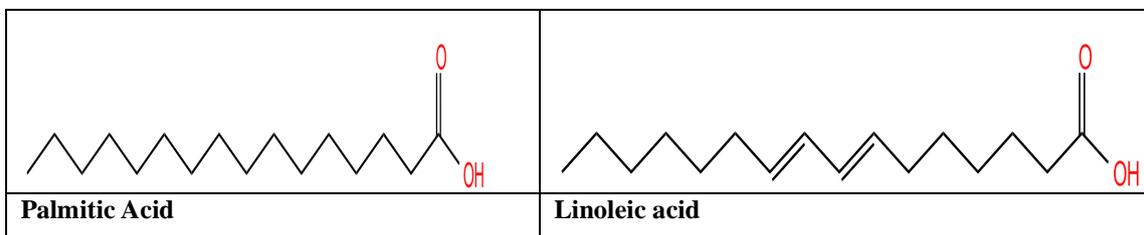


Figure 3: Main fatty acid, linoleic acid, and palmitic acid of *Opuntia ficus-indica*

5.2. Vitamin E

The eight fat-soluble compounds that compose vitamin E include four tocopherols and four tocotrienols.

The eight different molecules that make up vitamin E have been split into two primary groups: tocopherols and tocotrienols. Alpha (α), beta (β),

gamma (γ), and delta (δ) are the four types that belong into each group [Fig2]. Tocopherols, additionally referred to as vitamin E, are rich in cactus seed oil, with α - and γ -tocopherol functioning as the key ingredients.

Combined, these two compounds account for around 80% of the vitamin E content [46].

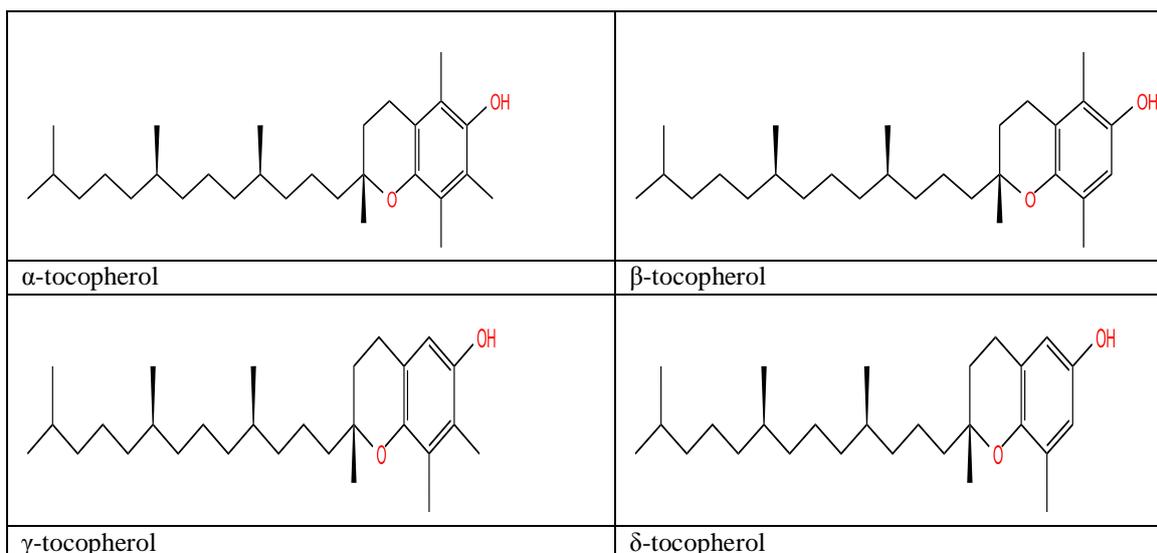


Figure 4: Structures of tocopherol substituents.

By successfully controlling peroxide radicals in unsaturated lipids, tocopherols function as antioxidants [47]. These bioactive ingredients can be synthesized and utilized in functional juice products due to they serve as potent free radical scavengers and natural antioxidants [48].

5.3. Betanin

Food colorants are vital components of modern processed foods, and because of its nutritious qualities, betanin is a notable natural pigment with significant utility [49]. There are actually two main types of this water-soluble coloring agent: yellow-orange betaxanthin and

reddish-violet betacyanin. With many kinds of pharmaceutical properties, including antioxidant, antilipidemic, antibacterial, antitumor, antiviral, and anticancer characteristics, betanin is crucial for improving human health. These properties, in particular its antibacterial, anticancer, antilipidemic, and antioxidant qualities, are particularly visible in the context of *Opuntia ficus-indica* [50]. One great source of consumable betanin that has potent antiproliferative effects is *Opuntia ficus-indica*. Plants involve pigments termed betanin and isobetainin, which are representatives of the betalains class of chemicals. These pigments, which offer beets their reddish-

violet color are capable of being used in a variety of food preparation coloring applications and might offer beneficial health effects. One of betanin's isomers is isobetanin. Isomers are compounds that have different structures yet the same molecular formula. The position of particular atoms or groups within the molecular structure makes a difference (Fig. 3). Prickly pear pulp extracts enriched with betalains have shown potential as antibiotics for healing gastrointestinal and urinary tract wounds,

infections, and inflammation. Moreover, significant inhibitory actions against cervical cancer cells and ovarian tumors have been noted. For betanin stability, a pH range of 5.5 to 5.8 is optimal. The stability of betanin can be impacted by high water activity, high temperatures, extended exposure to oxygen, and light in the presence of oxygen. On the contrary hand, it is extremely durable under low humidity [51].

5.4. Polyphenols

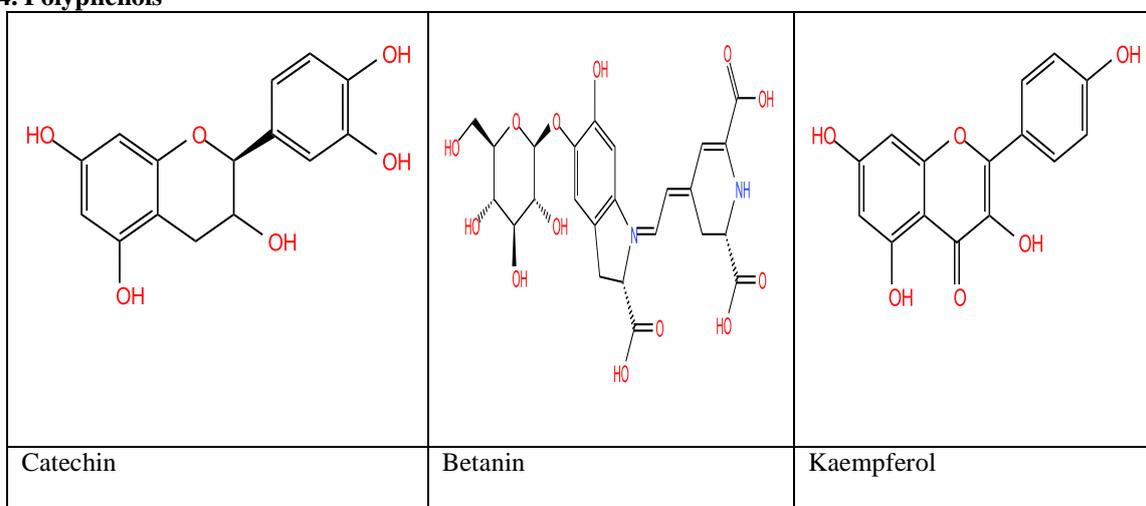


Figure 5: structure of polyphenol

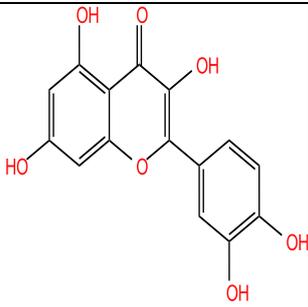
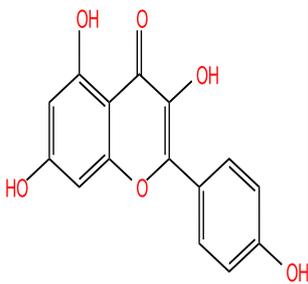
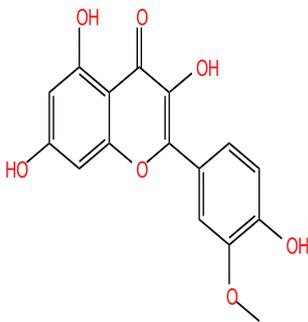
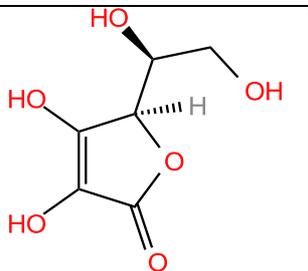
Opuntia ficus-indica special position as a polyphenol-rich plant has been recognized by detailed phytochemical checks, with these compounds attaining central significance as vital components. Depending on their established antioxidant effects [52], extracts from *Opuntia ficus-indica* appears to possess the ability to eliminate free radicals and thus convert them into safer and more stable form. This approach delivers powerful antioxidant benefits by efficiently interrupting the chain reaction of radical propagation. Flavonoids, tannins, coumarins, and more recently, procyanidins, belong to a broad range of phenolic antioxidants which possess the

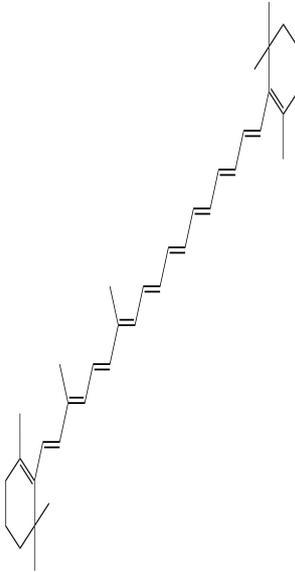
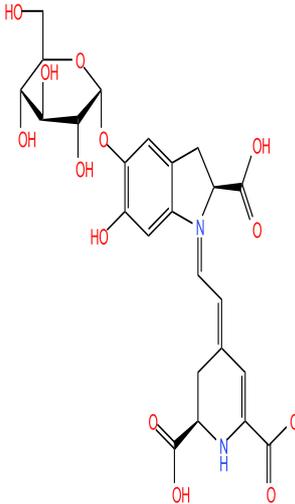
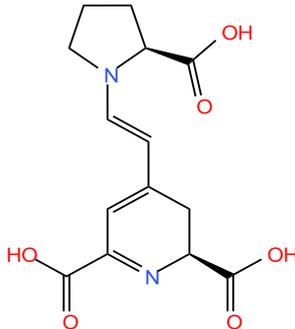
ability to neutralize radicals in a dose-dependent manner [53,54]. Quercetin, rutin, naringin, catechins, caffeic acid, gallic acid, chlorogenic acid, catechol, cinnamic acid, 3-phenylpropionic acid, psoralen, syringic acid, sinapaldehyde, 3'-O-methylcatechin, (+)-gallo-catechin, bisdemethoxycurcumin, and 4'-O-methyl-()-epicatechin 3'-O-glucuronide represent a few of the more prevalent phenolic compounds discovered [53,55]. Three compounds—catechins, kaempferol, and rutin—were successfully extracted from *Opuntia ficus-indica* stems through spectral analysis and chemical evidence [56].

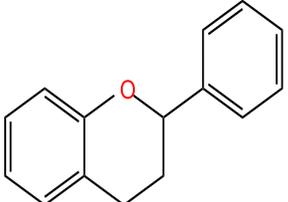
VI. BIOACTIVE COMPOUNDS

TABLE 5: Bioactive Compound Of Prickly Pear

Bioactive Compound	Structure	Effect On Human Body	References
Quercetin		Quercetin is a powerful nutritive polyphenol having anti-proliferative, anti-oxidative and anti-inflammatory outcomes.	[57]

			
Kaempferol		It has been narrated that kaempferol-provoked stimulation of antioxidant enzyme. The enzyme performs crucial part in H460 removal of cancerous cells.	[58]
Isorhamnetin		Prickly pear contains phenolic acid and isorhamnetin (flavonoid) in form of glycosides. Both phenolic acid as well as isorhamnetin glycoside have anti-hypercholesterolemic properties.	[59]
Ascorbic acid		Vitamin C is the third main vitamin in prickly pear comprising of antioxidant properties.	[60]

<p>Carotenoids</p>		<p>Carotenoids are worth able in sustaining better health and disease control. Lycopene is beneficial to diminishes the chances of Prostate, breast, lung and digestive tract cancers.</p>	<p>[61]</p>
<p>Betanin</p>		<p>Chromo-alkaloids acquire antioxidant and anti-inflammatory properties. The high free radical scavenging capacity of betanin is due to its phenolic and cyclic amine molecules. Both betanin and Indicaxanthin possess synergistic effect with α-tocopherols. Betanin also behave as an oxidation retarder.</p>	<p>[62]</p>
<p>Indicaxanthin</p>		<p>Indicaxanthin is a reducing and amphipathic molecule, that moves into numerous cells including Red-blood cells via separating membrane. Indica-xanthin also responsible to defend cell against oxidative damage.</p>	<p>[63]</p>

Flavonoids		<p>Flavonoids are naturally occurring phenolic antioxidants having antiviral, anti-carcinogenic, anti-allergic, anti-proliferative and anti-inflammatory properties. flavonoids are used in the treatment of bacterial and viral contagions, different types of allergies and vascular fragility as well as in pathological syndrome of gastric and duodenal ulcers.</p>	[64]
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VII. MEDICINAL USES

7.1 Health-improving effects of insoluble dietary fibre

Consuming fiber from your diet offers many different kinds of health benefits.

The tissue of *Opuntia* spp. has several technological uses and is commonly used to treat a variety of diseases, notably diabetes, obesity, heart disease, gastric ulcers, and inflammatory ulcers, since it contains antioxidants, pigments, or phenolic acids [65,66].

7.2 Health-enhancing effects of soluble dietary fibre

The soluble fiber enhances the viscosity of the stomach's contents, which has been linked to a slower rate of gastric emptying, a lower intestinal transit, a faster rate of starch breakdown, and a faster rate of glucose absorption. Their solubility, viscosity, and fermentability are some of the physical and chemical properties which influence their therapeutic properties [67]. *Opuntia ficus-indica* tissue's dietary fiber, protein, mineral, and phytochemical profiles are the main reasons for its beneficial nutritive potential. Blood glucose and cholesterol levels alter as a result of these actions [68,69].

7.3 Impact on weight control

Dietary fiber constituents as gum, mucilage, and pectin fiber complex from *Opuntia ficus-indica* may be the origin of this discovery. These constituents have a tendency to bind to lipids and produce an insoluble lipid-fiber complex that is eliminated by feces [70].

7.4 Effects on glucose reduction

Following exercise, the impact of *Opuntia ficus-indica* cladode upon young volunteers were investigated. *Opuntia ficus-indica*, on the opposite hand, raised insulin concentration and dropped glucose levels as compared to the placebo [71]. Its anti-diabetic properties are affected by

viscosity and the cladode maturity stage. One possible explanation for the hypoglycemic effect of nopal is its high fiber content, namely its pectin content [72].

7.5 Hepatoprotective effects

Previous study shows that soluble fibers enhance NAFLD biomarkers through altering the hepatic production of lipids and improving intestinal permeability. Since nopal has been eaten, it is less than the control. The authors suggest that additional bioactive substances and dietary fiber that include nopal may also be relevant. NAFLD biomarkers are improved by soluble fiber's altered hepatic production of lipids and improved intestinal permeability [73,74].

7.6 Antioxidant activities

Prickly pear fruit extracts exhibited effectiveness as a natural antioxidant in lipid and water-based conditions [75]. A variety of antioxidant-dependent characteristic assays, including the reactivity against radicals and the localization, distribution, and destiny of antioxidant-derived radicals when utilized with other antioxidant substances, have been employed to assess the antioxidant potential of cactus fruits [76, 77, 78]. Many human diseases are triggered by oxidative stress. Bioactive substances have a significant function as antioxidants. They are the most potent plant antioxidant source to minimize tissue damage carried on by oxidative stress in chronic illnesses [79, 80].

7.7 Anticancer action

An extract from cactus pear fruit suppressed the growth of a variety of human cancer cell lines, including cervical, ovarian, and bladder cancer cell lines. In the meantime, extracts may prevent the growth of tumors in the animal model of ovarian cancer in vivo in naked mice. [81]. The anti-cancer effects of cactus pear extracts have

been proven to be adaptable to three different human cancer cell types: cervical, bladder, and ovarian. In this study, cervical cancer cells responded more effectively than cells from bladder and ovarian malignancies. They discovered that 1% cactus pear fruit extract diminished 40–60% of cervical cancer cells [82].

7.8 Antiviral action

When offered to mice, horses, and humans, cactus fruit extract suppressed both the intracellular and extracellular replication of specific DNA and RNA virus. Further, the cactus extract has been shown to block HIV-1, influenza, respiratory syncytial sickness virus, pseudorabies virus, and Herpes Simplex Virus type 2 in horses. [83].

7.9 Inhibition of inflammation

In cactus pear fruit, betanin and betaxanthin decreased the chlorination activity of myeloperoxidase at neutral pH rather than pH 5 [84, 85]. Betanin content, betaxanthin, indicaxanthin, and betacyanin are the primary components involved in the health benefits and beneficial activity, which enhance cells' resistance to oxidative stress [86,87].

7.10 Potential antimicrobial

Essential oils, on the other hand, have an intense antibacterial effect on many different kinds of bacteria, including spoilage microorganisms, postharvest pathogens, and foodborne pathogens [88]. With the disc-diffusion test, for example, the essential oil of the fruit of *Opuntia stricta* exhibited an antibacterial activity at levels ranging from 20–40 mg/mL against *Candida albicans* and gram-positive bacteria (*Escherichia coli*, *Bacillus licheniformis*, *Pseudomonas aeruginosa*, and *Bacillus cereus*) [89].

VIII. CONCLUSION

In the growing fields of sustainable agriculture and functional foods, prickly pears (*Opuntia* spp.), specifically *Opuntia ficus-indica*, are becoming more attractive resources. This plant has tremendous potential for enhancing human health since it is rich in beta-lains, polyphenols, antioxidants, and other bioactive compounds. Consuming rich in nutrients fruits like prickly pears offers a thorough, food-based method for disease avoidance and management, compared with standard pharmaceutical addresses that can cause negative side effects.

Its inclusion in daily diets as a food that enhances health is facilitated by the fruit offers a full nutritional profile, which involves its pulp, skin, and seeds. Due to its ability to manage inflammation and oxidative stress, regular use could potentially extend lifespan while improving health. By fixing carbon dioxide at night, *Opuntia* species use Crassulacean Acid Metabolism (CAM) for maximum the use of water, showing its ecological responses to arid and semi-arid circumstances. They are particularly relevant in light of water scarcity and climate change due to this property. The Food and Agriculture Organization (FAO) has identified *Opuntia* as a vital crop in water-limited areas due to its agronomic potential. Currently grown for animal feed and human consumption, *Opuntia* species are additionally being researched for their industrial byproducts and secondary metabolites. The compositional variety, medicinal properties, and broad spectrum of applications of *Opuntia* fruits, extracts, and biowastes are presented in this review, highlighting their significance in the food innovation, pharmaceutical, and nutraceutical sectors. Additional description of the therapeutic mechanisms, standardization of processing approaches, and formulation modification for broader use as health-promoting products should be the objectives of future research.

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