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Comprehensive review on the pharmaceutical properties of Dragon fruit (*Hylocereus* spp.)

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Abstract

Dragon fruit (*Hylocereus* spp.), also called Pitaya, a tropical climbing cactus recently introduced to India as an exotic fruit. It is gaining widespread popularity across both rural and urban areas, due to its vibrant colour, delightful taste, high nutritional and medicinal value. This fruit is packed with essential nutrients and minerals, including vitamins, proteins, healthy fats, carbohydrates, fibre. Rich in bioactive compounds, dragon fruit shows significant pharmacological potential, making it a promising therapeutic agent. The fruit exhibits various health profits, such as antianemic, anticancer, antidiabetic, anti-inflammatory, antimicrobial, antilipidemic, antiulcer, antioxidant, liverprotective, anti-infertility, antiageing, cardioprotective, prebiotic, neuroprotective, diuretic and wound healing effects. These properties are due to its diverse phytoconstituents, including polyphenols, betalains, phenols, pectin, aminoacids, triterpenoids, polysaccharides, anthocyanins, saponins and tannins. The fruit's pulp and peel contain compounds like alanine, ascorbic acid, arginine, succinic acid, citric acid, betanin, cobalamin, formic acid, shikimate, pyridoxine, glutamine, fumaric acid, rutin, niacin, malic acid, aspartic acid, betacyanins and fatty acids like oleic acid, glutamate, choline, valine and azelaic acid. Additionally, the seeds are rich in secondary metabolites such as quercetin, catechin, epicatechin, myricetin, rutin, epicatechingallate, epigallocatechin, caffeine and derivatives of gallic acid. Research has identified these bioactive compounds from *Hylocereus* spp., exploring their molecular interactions and shedding light on potential therapeutic applications. Dragon fruit can be enjoyed consuming as fresh or processed into various products, including juice, syrup, jelly, ice cream, jam, wine, yogurt, preserves, candy and pastries. The natural pigments from red or purple dragon fruit varieties serve as a valuable colorant for the food industry. The fruit's peel rich in pectin and betalain is commonly used as a natural thickener, colouring agent and dye. This review underscores the ethnopharmacological significance of dragon fruit, examining its traditional uses, phytochemical composition and biological activities. The mechanisms by which dragon fruit promotes disease prevention highlight its valuable pharmaceutical potential. The documented evidence from various studies suggests that dragon fruit may help to prevent various diseases and holds promise for further therapeutic applications.

1. Introduction

The dragon fruit (*Hylocereus* spp.), a tropical newcomer to India, is a highly valued crop known for its impressive nutritional profile and profitable returns. Belonging to the climbing cactus family, it boasts some of the most striking fruits within the Cactaceae family and exquisite night-blooming flowers affectionately called 'Noble Woman' or 'Queen of the Night.' Some commonly referred are Night blooming cereus, Cinderella plant, Pitaya, Jesus in the cradle, strawberry pear and belle of the night. The fruit has a leathery skin with scaly or spiky ridges, presenting vibrant colours like red, pink or yellow, and is filled with small edible black seeds within its smooth pulp. Dragon fruit has become a sought-after exotic fruit in markets due to its delightful taste, crispy texture and sweet flavour, making it popular with consumers. Its easy cultivation and high profitability have attracted farmers across India, especially given its adaptability to various agroclimatic zones, resilience to abiotic stresses, low water requirements and minimal maintenance needs. It can even thrive in marginal, degraded and arid regions, making it an ideal crop for

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sustainable production. Its short gestation period, size, shape, unique appearance and high market value have sparked interest among global growers (Ibrahim *et al*., 2018). Additionally, dragon fruit is rich in nutrients and antioxidants, particularly phenolic compounds like betalains and provides essential vitamins B, E, and C, along with minerals such as zinc, copper, and iron. The components of dragon fruit are crucial for sustaining human physiological health and show a role in preventing diversity of disorders and diseases, including respiratory, circulatory and cardiovascular conditions, as well as ulcers, diabetes and alzheimer's disease (Thakur, 2023). The rapid shifts in modern lifestyles have contributed to a rise in chronic, non-communicable diseases, with cardiovascular ailments among the leading causes of disability and death. Fruits and vegetables is essential for a balanced diet, as it helps reduces the risks of diabetes, obesity, cardiovascular disease, cancer and serves as a foundational element in many Ayurvedic treatments (Cosme *et al*., 2022; Imaizumi *et al*., 2023; Somraj *et al*., 2024).

2. Origin and distribution

Dragon fruit originates from the subtropical and tropical areas of America, making it a promising choice for commercial cultivation (Dios *et al*., 2014). Most species within the Hylocereus genus are native to South America, Central America and Mexico. While now grown worldwide, it has traditionally been cultivated in Thailand, Sri Lanka, Israel and Vietnam. Currently, dragon fruit is commercially produced in countries like Malaysia, Thailand, Vietnam, Israel, Taiwan, Nicaragua, Australia, and the United States (Merten, 2003); with Vietnam as the leading producer and main exporter, accounting for 55% of the country's export revenue. Introduced to India in the 1990s, commercial cultivation only began in the past decade. The species *Hylocereus undatus*, *H. costaricensis, H. megalanthus* and *H. polyrhizus* (Figure 1) are the most commonly grown in India, cultivated across Gujarat, Andhra Pradesh, Maharashtra, Karnataka, West Bengal, Odisha, Telangana, Uttar Pradesh, North Eastern states, Kerala, Tamil Nadu and Madhya Pradesh. Currently, India produces around 15,000 tonnes across an area of 4,000 hectares, with Mizoram leading in cultivation. India also exports dragon fruit to Dubai in the United Arab Emirates.

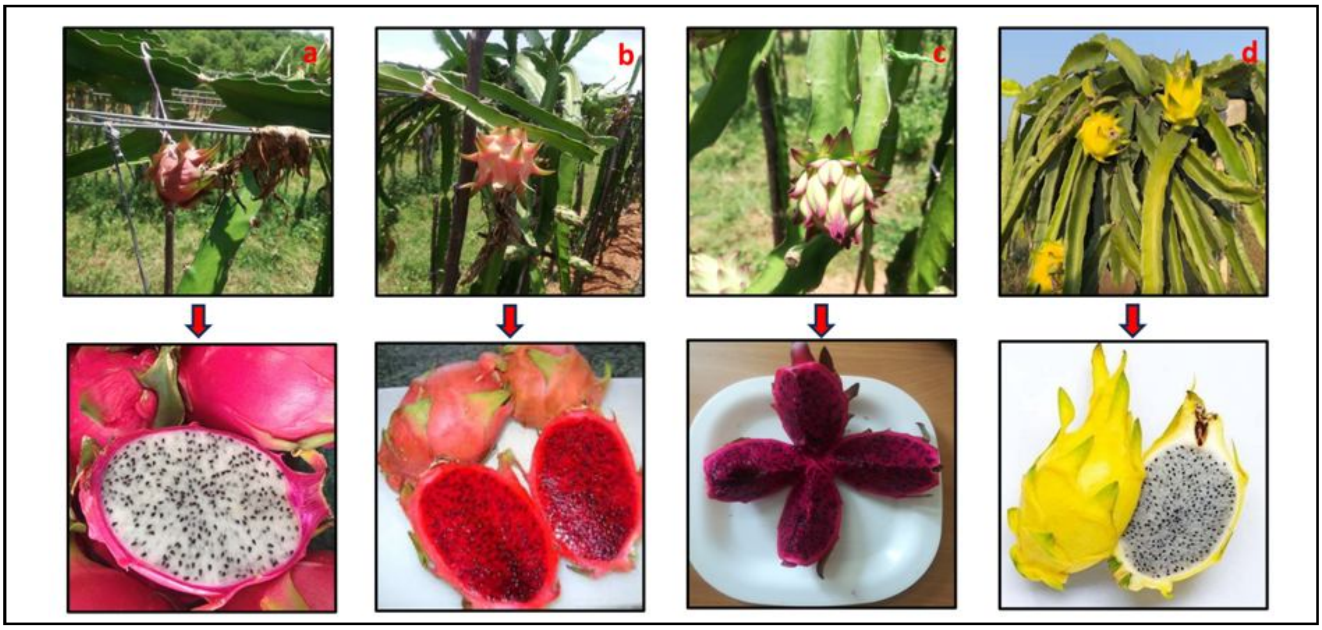

Figure 1: Different *Hylocereus* spp. a. *H. undatus*, b. *H. polyrhizus*, c. *H. costaricencis* and d. *H. megalanthus*.

2.1 Characteristics of Dragon fruit

Dragon fruit (*Hylocereus* spp.) is a commercially valuable crop known for its impressive health benefits and its ability to thrive in water-scarce regions, contributing to an extended shelf life. With outstanding nutritional properties, this crop has attracted farmers across India. One of its major advantages is longevity - once planted, the crop can be maintained for up to 20 years, with around 800 plants per hectare. While the plant begins to bear fruit in its first year, significant yield are typically seen starting from the third year. The plant also has ornamental appeal, showcasing large, creamy-white flowers (up to 25 cm) that bloom at night. With its diverse traits, including variations in shape, thorny structure, skin, pulp color and high genetic variability across species, dragon fruit is taking a promising crop for the future (Huang *et al*., 2021; Joshi and Prabhakar, 2020; Cheok *et al*., 2020).

2.2 Species

The genus *Hylocereus* consists of 16 species native to Latin America. Dragon fruit is generally characterized based on the color of its peel and pulp, with notable species including *H. undatus*, *H. polyrhizus*, and *H. megalanthus*. Among cultivated varieties, *H. undatus* is prominent; it features long green stems with slightly hardened edges over time. The flowers are sizable, growing up to 29 cm in length, featuring outer perianth segments in shades of yellow-green or green and innermost segments are pristine white. The oblong pinkish-red fruit (15-22 cm in length, weighing 300-800 g) has prominent scales tipped in red and green, white flesh, and numerous small black seeds, offering a pleasant taste and texture. *H. polyrhizus*, originating in Mexico and known as Red Pitaya, has a scarlet, oblong fruit (10-12 cm long, weighing 130-350 g) with varying scale sizes, a delightful texture and excellent flavour. Its flowers are also long (25-30 cm) with reddish outer perianth tips, yellowish stigma lobes and margins. *H. costaricensis*, native to Costa Rica, but cultivated in India, produces ovoid, scarlet fruit (10-15 cm in diameter, weighing 250-600 g), with unique pear-shaped seeds and a satisfying taste. It has vigorous vines, thick stems with a waxy coating and flowers similar to *H. polyrhizus*. *H. megalanthus*, native to South America, stands out with its white flesh and yellow skin, presenting an attractive appearance. In India, farmers typically grow three main types: vibrant red interior with rosy outer skin, creamy white interior with a golden outer layer, and pure white interior with a rosy pink exterior (Raj and Dash, 2020). *Hylocereus* species are semi-epiphytic, thriving in partial shade, although, *H.costaricensis*, *H. purpusii* and *H. undatus* can tolerate full sun. However, extreme heat and water scarcity may lead to stem burns and flower bud drop. Being diploid with self-incompatibility, *Hylocereus* benefits from cross-pollination with compatible pollen for larger fruit production.

2.3 Nutritional properties

The entire dragon fruit, or its extracts from plant, animal, or marine sources offers therapeutic and nutritional benefits. This nutritious fruit, with its pulp making up 70-80% of the ripe fruit, is a rich source of calories, proteins, fibre, iron, fats, carbohydrates, vitamins C, B, and E, as well as magnesium, phosphorus and calcium (Table 1). Notably high in iron, dragon fruit aids oxygen transport throughout the body and helps to convert food into energy. It supports heart health, lowers cholesterol, prevents arthritis, relieves asthma, combats ageing and maintain a healthy weight. As a source of carotenoids and vitamin C, it boosts the immune system, guards against infections, and prevents various diseases. The presence of protein contains heart-healthy monounsaturated fats, beneficial omega-6 and omega-3 fatty acids and minimal cholesterol content also supports weight management and reduces the risk of cardiovascular diseases. The red-fleshed variety, *H. polyrhizus*, with its medium-to-large oblong shape and vibrant pink, scaly peel, is visually appealing and packed with betalains, known for their antioxidant properties and as natural food colorants (Ding *et al*., 2009). Dragon fruit is also rich in betacyanin, aminoacids, organic acids, vitamins, dietary fibre and sugars, predominantly glucose, fructose, and oligosaccharides (Hua *et al*., 2018; Hanish, 2022). Antioxidant compounds like polysaccharides and polyphenols serve as natural colorants, such as betanin, used in food products (Khuituan *et al*., 2019). Additionally, dragon fruit is loaded with glucose, thiamine, pyridoxine, niacin, cobalamin, flavonoids, betacyanin, polyphenols, carotene, phosphorus, phenolic phytoalbumin and iron (Purilla Salomi *et al.,* 2021). With a higher fibre content than fruits like mango, orange and banana, it promotes digestion, helps to regulate diabetes, and stabilizes blood sugar levels by minimizing spikes. Its antioxidant qualities also support platelet count; improvement for dengue and malaria patients. In skincare, dragon fruit is utilized in face masks and creams for its skin-tightening and antiageing properties, while the vitamins C and B content aids in treating acne and burns. Known as an "anti-inflammatory fruit," it helps to relieve joint pain in arthritis patients. The antioxidant properties boost immunity, ward off diseases, neutralize toxic substances, facilitate heavy metal detoxification, and promote eye health (Maria *et al*., 2023).

Table 1: Nutritional value of Dragon fruit

Nutrient	Quantity (per 100 g edible portion)	
	Red flesh fruit	White flesh fruit
Moisture	85 - 90 %	85.3%
Protein	0.4 -1.5 g	1.1 g
Fat	0.4 g	1.0 g
Carbohydrates	8.0 - 13.0 g	11.2 g
Total dietary Fiber	2.7 - 3 g	0.57 g
TSS	8 - 12° Brix	14.3°Brix
pH	4.77	4.24
Vitamin B2 (Riboflavin)	0.05 mg	0.5 mg
Vitamin B1 (Thiamine)	0.04 mg	0.02 mg
Vitamin C (Ascorbic acid)	20.5 mg	1.0 mg
Vitamin A	100 IU	100 IU
Vitamin B3 (Niacin)	0.16 mg	2.8 mg
Vitamin E	0.2 µg	0.26 µg
β- carotene	1.5 µg	1.4 µg
Lycopene	3.6 µg	3.4 µg
Calcium (Ca)	1.6 - 6.7 mg	13 mg
Iron (Fe)	0.03 -0.3 mg	0.5 mg
Sodium	14.3-35.6 mg	8.9 mg
Potassium	158.3 - 437.4 mg	231.0 mg
Zinc	0.1- 0.4 mg	0.35 mg
Phosphorus (P)	22.5 mg	27.75 mg

Sources: Agriculture and Food E: Newsletter (2023)

2.4 Therapeutic properties

Dragon fruit is an excellent source of antioxidants that aid to prevent free radicals responsible for cancer and other inflammatory and oxidative diseases (Huang *et al.,* 2021). Its therapeutic benefits extend in treating cardiovascular diseases, diabetes, dyslipidemia, cancer, and metabolic syndrome due to bioactive compounds such as gallic acid, betacyanin, vitamins, potassium, vanillic acid and p-coumaric acid. Known for its high fibre content, dragon fruit supports type 2 diabetes management, lowers colon cancer risk, maintains a healthy body weight, and promotes a balanced gut microbiome while protecting white blood cells from damage. Increasingly, urban consumers are aware of the health benefits of natural products and seek them for health conditions like diabetes, cardiovascular disease, and other stress-related illnesses. The red-fleshed diversities of dragon fruit, rich in antioxidants, manage diabetes, reduce cholesterol, helps in prevention of colon cancer, lower high blood pressure, and neutralize toxic substances like heavy metals. Betacyanin and pectin from dragon fruit, used in food products, have been shown to have antidiabetic effects, helping regulate glycemic response (Poolsup *et al*., 2017; Adeshirlarijaney *et al*., 2020; Luo *et al*., 2021). Dragon fruit exhibits numerous therapeutic properties, including antidiabetic, anaesthetic, anabolic, anticarcinogenic, antimutagenic, antiplatelet, antifungal, anthelmintic, antiviral, cholesterol lowering, styptic, astringent, antiadhesive, antihyperglycaemic, antiparasitic, anticancer, antibacterial, anti-inflammatory, antioxidant and analgesic effects (Sarrah *et al*., 2023). Studies have identified antioxidant-rich compounds in the seeds, such as catechin, epicatechin, epicateching-allate, caffeine, epigallocatechin and gallic acid, known for their potent antioxidant effects in human (Saenjum *et al.,* 2021). Additionally, essential fatty acids, particularly linoleic acid found in the seeds, exhibit a laxative effect helpful for gastroenteritis. Phytochemicals like betacyanins, phenolic compounds, polysaccharides and terpenoids in dragon fruit pulp and peel serve as anti-inflammatory agents and natural antioxidants (Zulkif *et al*., 2020) (Table 2).

Table 2: The bioactive compounds and its therapeutic properties in Dragon fruit

Bioactive compounds/ Phytochemicals in dragon fruit	Therapeutic effects	Therapeutic effects and bioactive compounds	Reference
Alkaloids	Anti-inflammatory	Anti-inflammatory	Heinrich (2021)
	Anticancer		
	Analgesic		
	Antiparasitic	Antimicrobial	Khan *et al.* (2018);
	Anticancer		Sharma *et al.* (2021)
	Antioxidant	Antibacterial agents	Yan *et al.* (2021)
	Anabolic properties	Anesthetic property	Kurek (2019)
	Antidiabetic	Anticancer	Nishikito *et al.* (2023)
Phenols	Antibacterial	Anticancer agents	Isah (2016)
	Antifungal	Antibacterial/Antifungal/ Antiviral	Ecevit *et al.* (2022)
	Antiplatelet	Antiplatelet agents	Khan *et al.* (2018)
Saponins	Styptic and astringent	Anti-inflammatory	Tarte *et al.* (2023)
	Anticarcinogen	Antioxidant	Garzia Cruz *et al.* (2017)
	Antiviral	Anticancer	Zhong *et al.* (2022);
	Antimicrobial		Xu *et al.* (2016)
	Antiadhesive		
	Cholesterol lowering properties	Anti-inflammatory	Sultan and Raza (2015);
Steroid	Antihyperglycemic		Rahman *et al.* (2017)
	Anthelmintic activities	Anabolic properties	Sultan and Raza (2015);
	Antimutagenic		Rahman *et al.* (2017)
	Anesthetic property	Cholesterol powering properties	Dhande *et al.* (2023)
Tannins	Styptic and astringent properties		Garzia Cruz *et al.* (2017)
	Antioxidant		Tarte *et al.* (2023)
	Antibacterial		Nishikito *et al.* (2023)
	Anticarcinogen		
	Antimutagenic		
Terpenoids	Antimicrobial		Sarrah *et al.* (2023)
	Analgesic		
	Antiviral		
	Anti-inflammatory Aantiparasitic		
	Antihyperglycemic		
	Anticancer		
	Antifungal		

2.5 Industrial uses

Dragon fruit is low in fat and rich in minerals, it has an ideal sweetness with a brix value of 15-18 °Brix. Consumed fresh or in fruit salads, it is a popular choice in upscale hotels and restaurants. Dragon fruit can be transformed into an array of industrial products, including juice, jam, jelly, syrup, ice cream, wine, yogurt, preserves, candies, pastries and even face masks. Its red and pink pulp is often used to extract natural colorants and the flower buds can be used in salads or soups, dragon fruit serves a diverse range of culinary purposes (Nurul and Asmah, 2014). Phytochemicals extracted from dragon fruit are purified using various techniques, making them a cost-effective and health-promoting natural colorant for products like baked foods, meat, dairy, wine and confectionery. These bioactive compounds positively influence gut microbiota, glycemic response, lipid metabolism, inflammation, microbial development and mutagenicity. The red fleshed varieties contain functional nutrients such as triterpenoids, pectin, polysaccharides, betalains, flavonoids and phenolic acids, which have been associated with glycemic modulation in food processing (Huang *et al*., 2021). Dragon fruit can be processed using methods like dehydration, freezing, chemical preservation, thermal processing, concentration, and fermentation. The primary pigments in red dragon fruit, betalains specifically betacyanins and betaxanthins make it a valuable natural colorant for the food industry, especially from species like *H. monacanthus* and *H. costaricensis*. Mucilage from the fruit peel, with its encapsulating properties, can be optimized for spray drying and used to stabilize active ingredients. Betacyanins from the peel are stable over a pH range of 3.2 to 7.0 and can withstand heating up to 100°C for 10 min between pH 3.7 and 5.5, making the peel suitable for use in mildly heated, low acidity foods. Compounds such as bougainvillein-R-1, isobetanidin, betanin, hylocerenin, phyllocactin, isophyllocactin, isobetanin, betanidin, and isohylocerenine have been isolated from *H. monacanthus*. Additionally, certain *H. costaricensis* clones are high in isobetanin and betanin, while others contain more hylocerenin and phyllocactin (Tanmoy and Mahabub, 2023).

3. Phytoconstituents

Dragon fruit is rich in bioactive compounds, including saponins, terpenoids, flavonoids, pyridoxine, cobalamin, phenolics, carotene, betalains, alkaloids, polyphenols, steroids, fatty acids, sterols, tocopherols, tannins and flavonoids (Singh and Kumar, 2023; Nishikito *et al*., 2023). It also contains essential vitamins like thiamine, niacin, ascorbic acid and riboflavin, along with minerals and beneficial compounds such as lycopene, β-carotene, gallic acid, p-coumaric acid, vanillic acid, β-amyrin, and p-hydroxybenzoic acid (Hossain *et al*., 2021). Additionally, dragon fruit has been found to contain alkaloids, flavonoids, saponins, anthocyanins, terpenoids, carbohydrates, phenols, tannins, coumarins, quinones, triterpenoids, cardiac glycosides and steroids, which exhibit anticancer activity, particularly against human liver cancer (HepG-2) cells (Padmavathy *et al*., 2021) (Table 3; Figure 2).

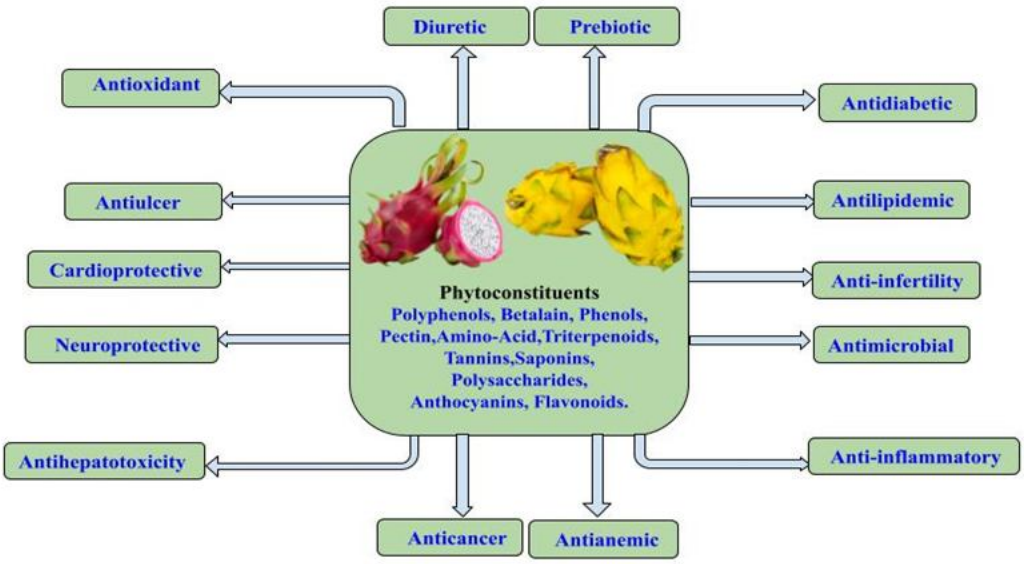

Figure 2: Different phytoconstituents and pharmaceutical properties of *Hylocereus* spp.

3.1 Polyphenols

Polyphenols in dragon fruit promote the growth of beneficial gut bacteria such as *Barnesville, Bifidobacterium* and *Lactobacillus* while inhibiting harmful microbes like *Escherichia coli* (Luo *et al*., 2021). These plant-derived antioxidant compounds, *viz*., flavonoids, phenolic acids, stilbenes and lignins aid in reducing the risk of chronic diseases, including cancer and cardiovascular issues, by neutralizing free radicals (Wan *et al*., 2021). Dragon fruit also modulates postprandial hyperglycemia by inhibiting α-amylase and α-glucosidase, impacting starch digestion through polyphenol interactions (Quek and Henry, 2015).

In red dragon fruit pulp, the concentrations of flavonoids, total phenolic acids and betacyanins are approximately 31.2 mg citric acid equivalent/100 g, 20.40 mg betacyanin equivalent/100 g and 48.30 mg gallic acid equivalent/100 g, respectively (Arivalagan *et al*., 2021). The seeds and peel have even higher levels of total polyphenols and betacyanins compared to the pulp (Saenjum *et al*., 2021). The seeds contain flavonoids and total phenolics at 264.4 mg quercetin equivalent/g and 375.1 mg gallic acid equivalent/g, respectively, while the pulp contains 193.8 mg QE/g and 294.8 mg GAE/g. The anthocyanin levels in red dragon fruit peel (135.4 mg cyanidin chloride equivalent/g) are lower than those in the pulp (159.7 mg CCE/g).

Research has also identified various polyphenols in dragon fruit, such as gallic acid, ferulic acid, caffeic acid, sinapic acid, vanillic acid, salicylic acid, p-coumaric acid, protocatechuic acid, t-cinnamic acid, o-coumaric and syringic acid. Flavonoids such as quercetin, catechin, epigallocatechin gallate, epicatechin, quercetin-3-glucoside, kaempferol-3-glucoside, procyanidin B1, rutin, and procyanidin B2 are also present, along with anthocyanins like pelargonidin-3-glucoside, cyanidin-3-glucoside, and delphinidin-3-glucoside (Saenjum *et al*., 2021; Arivalagan *et al*., 2021).

3.2 Betalain

Betalains are pigments derived from tyrosine in various vegetables and fruits and are categorized into two main groups: betacyanins, which produce red-purple hues and betaxanthins, which give a yellow-orange color. The distinctive color of dragon fruit is due to these hydrosoluble betalain pigments containing nitrogen in their structure. Betalains exhibit antioxidant, anti-inflammatory and anticancer properties (Yong *et al*., 2018). In dragon fruit, the betacyanin compounds include phyllocactin, isobetanin, hylocerenin, betanin, isohylocerenin, and isophyllocactin. The stability of encapsulated betacyanins in alginate microbeads has been studied, demonstrating improved pH, temperature, and storage stability for these pigments (Fathordoobady *et al*., 2021). Major betalains in the peel, including betanin, phyllocactin, and their isomers, were more stable when encapsulated, whereas non-encapsulated betacyanins degraded at pH levels above 5 and temperatures over 60°C. Additionally, citramalic acid was identified in the pulp of dragon fruit (Hua *et al*., 2018).

3.3 Phenols

Phenolic compounds are a key group of phytochemicals present in the flesh of dragon fruit. These include compounds like vanillic acid, p-coumaric acid, hydroxytyrosol, gallic acid and tyrosol, which exhibit antiallergenic, antioxidant, antimicrobial, antithrombotic, antilipidemic and cardioprotective properties (Balasundram *et al.,* 2006). Studies on *Stenocereus pruinosus* varieties with orange (SpO) and red (SpR) flesh, and *S. stellatus* with white (SsW) and red (SsR) flesh, examined betalain and phenolic compound concentrations, which vary with flesh color. In red-fleshed varieties, betalains were more concentrated than phenolics, though the phenolic compounds demonstrated strong antioxidant potential in dragon fruits (García Cruz *et al.,* 2017).

3.4 Pectin

Pectin, a natural polysaccharide found in the peel of dragon fruit (making up about 35% of cell walls), serves as a natural gelling and inspissation agent widely used in the food industry for producing fruit juices, jams, jellies, and fermented dairy products. It is rich in galacturonic acid and consists of both low-methoxy and high-methoxy pectin. In dragon fruit peel, galacturonic acid is the predominant monosaccharide (39.11%), followed by rhamnose (14.47%) and mannose (17.78%) with the lowest crystallinity achieved at a microwave intensity of 300 W (Rahmati *et al.,* 2019). The highest yield of pectin (7.5%) was obtained at an extraction temperature of 45°C, with a 20 min extraction time and a solid-to-liquid ratio of 24 g/ml in dragon fruit peel (Thirugnanasambandham *et al*., 2014).

3.5 Aminoacids

Amino acids, the structure blocks of proteins, are abundant in dragon fruit, with 15 key types, including alanine, tyrosine, glutamic acid, isoleucine, alanine, arginine, glutamine, proline, phenylalanine, valine, methionine, acetamide, leucine, serine, threonine, and tryptamine. Essential aminoacids such as tryptophan, methionine, lysine, valine, phenylalanine, leucine, histidine, isoleucine, and threonine cannot be synthesized by the body and must be obtained through diet, making dragon fruit a valuable source (Terriente and Castellari, 2021). Notably, phenylalanine is the most plentiful amino acid in dragon fruit, with levels of 183 mg/g, as reported by Wu *et al.* (2020). Research shows dragon fruit contains 18 aminoacids, eight of which are essential (Arivalagan *et al*., 2021). This nutrient profile underscores dragon fruit's value, aligning well with your research interest in bioactive compounds and their physiological benefits, especially considering the focus on their role against pathogens and chronic diseases.

3.6 Triterpenoids

Triterpenoids, a cluster of phytochemicals commonly found in vegetables and fruits, exhibit anticancer and antioxidant properties. Plant-derived triterpenoids act as cytotoxic agents against tumor cells, aiding in the prevention of breast cancer. These compounds inhibit cell proliferation and migration, promoting apoptosis a natural process that removes anomalous or unnecessary cells thereby aiding in the destruction of cancer cells (Li *et al*., 2020). The red variety of dragon fruit contains four main triterpenoids: β-amyrin (15.87%), α-amyrin (13.90%), γ-sitosterol (9.35%), octacosane (12.2%) and amounting to 29.77% of the total triterpenoid content, compared to 23.39% in white pitaya. Additionally, the peel contains terpenoids like limonene, carvone, retinoid, lutein and lycopene, along with the red pigment betacyanin (Joshi and Prabhakar, 2020).

3.7 Polysaccharides

In dragon fruit, glucose, fructose, and oligosaccharides are the primary carbohydrates. Polysaccharides, a type of long-chain carbohydrate made up of hundreds of monosaccharides linked by glycosidic bonds, are present and commonly used as stabilizers, thickeners and gelling agents in food products (Wu *et al*., 2020). The main monosaccharides in dragon fruit include galactose (22.55%), rhamnose (16.53%) and galacturonic acid (42.56%). Heat reflux extraction has been found to minimize the bioactivity loss of purified polysaccharides caused by high temperatures; an ultra-high-pressure enzymatic approach is preferred for extracting polysaccharides from dragon fruit peel (Castro Enríquez *et al*., 2020). In the cell wall, the total pectin content is reported at 50.23%, with water-soluble pectin as the largest component, followed by oxalate-soluble pectin. This pectin has potential as substitutes for marketable gums in food and cosmetic applications (Montoya *et al.,* 2014).

3.8 Anthocyanins

The peel of red dragon fruit contains anthocyanins such as malvidin, cyanidin and delphinidin. Specifically, anthocyanins like pelargonidin 3-glucoside, cyanidin 3-glucoside, and delphinidin 3-glucoside have been identified in both the peel and pulp of dragon fruit. Extracts rich in cyanidin 3-glucoside from dragon fruit inhibit the production of inducible nitric oxide synthase (iNOS), reactive nitrogen species (RNS), cyclooxygenase-2 (COX-2), and reactive oxygen species (ROS) without causing cytotoxic effects (Saenjum *et al.,* 2021).

3.9 Flavonoids

Dragon fruit is rich in flavonoids, including kaempferol, quercetin, isoflavones, naringenin, and isorhamnetin, which protect cells against damage from free radicals (Mande *et al*., 2023). The total flavonoid concentration in red dragon fruit extract is 0.75 mg EQ/100 g of fresh weight, while red dragon fruit powder has a total flavonoid content of 210.02 mg/100 g. The antioxidant activity of red dragon fruit is significantly linked to the presence of flavonoids, such as myricetin, kaempferol and quercetin (Pasko *et al.,* 2021). Vitamin C also plays a role in neutralizing free radicals due to its chromophore group, which can scavenge free radicals. This property extends to the flavonoid group, as its structure contains an OH group capable of capturing free radicals and maintaining stability through resonance, which preserve balance in the flavonoid structure despite binding to free radicals (Rubiati *et al*., 2023). Thin layer chromatography (TLC) analysis of *H. undatus* pulp, peel, and spines has identified various flavonoid compounds with antioxidant, anti-inflammatory and anti-cancer properties (Venkateswara Rao *et al*., 2023).

3.10 Saponins

Saponins are water and ethanol-soluble but not ether-soluble, which exhibits foaming properties. Dragon fruit stem extract, often in gel form, contains lignin or cellulose, which serve as moisturizing and antiseptic agents for the skin. This effect is attributed to active compounds like triclosan, an antimicrobial and cleansing agent (Imam *et al*., 2019). However, dragon fruit gel is highly sensitive to environmental factors like oxygen, carbondioxide, water vapour and light, which can lead to browning reactions. The saponin concentration in dragon fruit stem extract is approximately 5.651% per 100 g. The red dragon fruit stem contains the highest levels of secondary metabolites such as flavonoids (0.74%) and alkaloids (4.21%), while the fruit flesh contains saponins (0.45%) and the roots contain steroids (2.54%). Red dragon fruit having antioxidant activity has been reported at 78.23% in the flesh, 79.13% in the stem, 8.64% in the root and 11.24% in the peel (Rubiati *et al*., 2023).

3.11 Tannins

Flavonoids, tannins, carotenoids, alkaloids, polyphenols, saponins, steroids, terpenoids, and betalains are bioactive compounds extractable from all parts of the dragon fruit plant (Venkateswara Rao *et al*., 2023). Studies indicate that dragon fruit pulp has a higher total phenolic content and greater antioxidant capacity than the peel, while the peel contains more tannins and flavonoids than the pulp. These findings suggest that Australian dragon fruit peel by-products and pulp residues are promising sources of phenolic compounds for applications in the food, cosmetic, nutraceutical industries and pharmaceutical. Tannins in dragon fruit are found as both condensed and hydrolyzable forms; condensed tannins include anthocyanidins and proanthocyanidins, while hydrolyzable tannins include ellagitannins and gallotannins, which exhibit antibacterial, antiviral, anti-inflammatory and anticancer properties. Additionally, phytosterols such as hydroxytyrosol and tyrosol, along with fatty acids like palmitic acid and linolenic acid are found throughout the fruit (Mande *et al*., 2023).

Table 3: Phytoconstituent present in different parts of Dragon fruit

Phytoconstituent	Part used	Therapeutic activity	References
ρ coumaric acid	Pulp and seed	Antilipidemic Antidiabetic	Tarte *et al.* (2023)
β-carotene	Pulp	Antioxidant Antidiabetic	Joshi and Prabhakar (2020)
Gallic acid	Peel, pulp and seed	Prevent obesity Antioxidant Antidiabetic	Joshi and Prabhakar (2020)
Anthocyanins	Peel and pulp	Antioxidant Anti-inflammatory	Nishikito *et al.* (2023)
Vanillic acid	Peel and pulp	Anti-inflammatory Antioxidant Antiproliferative Antidiabetic	Nishikito *et al.* (2023)
ρ-hydroxybenzoic acid	Peel and pulp	Antioxidant	Nishikito *et al.* (2023)
Ascorbic acid	Peel and Pulp	Antioxidant Anticancer Antilipidemic	Mande *et al.* (2023)
Quercetin	Peel and pulp	Anti-inflammatory Antidiabetic Antioxidant	Nishikito *et al.* (2023)

4. Pharmaceutical properties

4.1 Antianemic activity

Dragon fruit contains essential nutrients, such as vitamin C, vitamin E, vitamin B12, thiamine, and riboflavin, along with iron, an important precursor for erythropoiesis, as reported by Tenor *et al.* (2012). A study examining the effects of dragon fruit on postpartum mothers at risk of anaemia revealed that daily intake of 400 ml of *H. polyrhizus* fruit juice (extracted from 500 g of dragon fruit) over 14 days significantly improved haemoglobin, hematocrit and erythrocyte levels compared to the control group (Rahmati *et al.*, 2019). The high vitamin C content in dragon fruit, critical for its antianemic properties, promotes the absorption of iron, including non-heme iron, necessary for effective blood production (Table 4).

4.2 Anticancer activity

Research has shown that bioactive compounds, including polyphenols, flavonoids and betanins in *H. undatus* and *H. polyrhizus*, contribute to anticancer properties, effective against breast cancer, liver cancer and malignant cells (Table 4). In *H. polyrhizus*, the natural antioxidant lycopene plays a role in preventing cancer by reducing free radical formation. According to Divakaran *et al.* (2019), nanoparticles in dragon fruit inhibit the growth of MCF-7 breast cancer cells, human gastric cancer cells and human prostate cancer cells. Additionally, colon cancer cells (Caco-2) are inhibited due to increased lactobacillus activity, which boosts the production of acetic, butyric, and lactic acids while reducing *Bacteroides* and *Clostridium*. The peel contains bioactive compounds like alpha-amyrin, beta-carotene, betacyanin, beta-sitosterol, beta-amyrin, flavonoids and phenolic acids, which exhibit a stronger inhibitory effect on melanoma and cancer cells than the flesh, although both the flesh and peel are rich in antioxidants and polyphenols (Nishikito *et al.*, 2023). Similarly, crude peel extracts from *C. maxima*, including the flavonoid NAR, have shown potential as candidates for future breast cancer therapies (Flama *et al.*, 2024).

4.3 Antidiabetic activity

The unique blend of bioactive compounds, such as flavonoids and polyphenols, along with both soluble and insoluble dietary fibres in dragon fruit, makes it a valuable dietary intervention for individuals with diabetes. Dragon fruit aids in glycemic control by slowing glucose absorption, enhancing insulin sensitivity, improving lipid profiles and promoting satiety. Additionally, it helps in reducing oxidative stress and inflammation associated with diabetes-related complications. As part of a diabetes friendly diet, it can be consumed in moderation for effective diabetes management (Indranil Chatterjee *et al.*, 2024). With its low glycemic index (GI), dragon fruit stabilizes blood glucose levels over time. Its high antioxidant content, vitamins C and E, and phytochemicals like betalains and flavonoids mitigate oxidative stress and inflammation, improving diabetes related complications such as neuropathy and cardiovascular disease (Saenjum *et al.,* 2021). Betalains in dragon fruit specifically reduce inflammation, manage blood glucose levels and enhance insulin sensitivity. Additionally, omega-3 fatty acids and polyunsaturated fats present in the fruit reduce increasing HDL cholesterol while reducing LDL cholesterol, thus supporting cardiovascular health in diabetics. Abnormal lipid profiles often marked by high cholesterol and triglycerides are common in diabetes and increase cardiovascular risk. Phongtongpasuk *et al.* (2016) noted that regular consumption of dragon fruit improves insulin sensitivity in type 2 diabetes, leading to better glycemic control and reduced reliance on external insulin. Consuming fresh dragon fruit lowers calorie intake and body weight, thereby decreasing obesity-associated risks of type 2 diabetes. The fruit's highwater content also helps to prevent hyperglycemia-induced dehydration. Studies have demonstrated that dragon fruit intake reduces HOMA-IR (Homeostasis Model Assessment-Insulin Resistance) and glycemia in individuals with type 2 diabetes diabetes and can even serve as an alternative to metformin for insulin resistance (Poolsup *et al.,* 2017; Putri *et al.*, 2017). Wound healing is a common issue in diabetes; gallic acid in dragon fruit shows promise as a wound healing agent in both normal and hyperglycemic conditions (Joshi and Prabhakar, 2020). The presence of keratinocytes and fibroblasts in gallic acid supports wound healing by promoting cellular repair (Mande *et al.,* 2023). This wound healing effect is further aided by antioxidants, including phenolic compounds and flavonoids, which protect DNA from damage (Tarte *et al*., 2023).

4.4 Anti-infertility activity

Dragon fruit extract has been shown to enhance testicular tissues and support sperm motility. Gallic acid, a powerful antioxidant present in white dragon fruit, has the potential to improve sperm quality by boosting motility, morphology and quantity in the epididymis (Barcenas, 1994).

4.5 Anti-inflammatory activity

Dragon fruit contains phytoconstituents such as betalains and squalene, which contribute to its anti-inflammatory and antioxidant properties. Betalains are highly unstable and prone to degradation under temperature, light, pH, and oxygen exposure, but their effectiveness can be enhanced through encapsulation or by applying an impermeable protective layer. This helps preserve their structure and boosts their ability to reduce free radicals, thereby diminishing inflammation through anti-inflammatory action (Tarte *et al.,* 2023; Mande *et al.,* 2023). Dragon fruit pulp reduces inflammation by affecting cyclooxygenase and lipoxygenase enzymes, which subsequently block pathways that lead to the production of leukotrienes and prostaglandins. Betalain in red dragon fruit peel also inhibits the transcription factor NF-κB, preventing the activation of inflammatory genes like IL-1β and TNF-α (Suastuti *et al.,* 2018; Safira *et al.*, 2021).

4.6 Antimicrobial activity

Betacyanin, the red pigment in dragon fruit peel, possesses both antimicrobial and antioxidant properties (Table 4). It kills microbes through mechanisms like cell wall lysis and reactive oxygen species production (Tarte *et al.*, 2023). Dragon fruit extracts trigger a defense mechanism upon contact with microbial contaminants, providing antibacterial action against diseases caused by bacteria, fungi, and viruses. An inhibitory effect against *Pseudomonas aeruginosa* was observed when *H. polyrhizus* peel was extracted with chloramphenicol and silver nanoparticles from the peel showed activity against both Gram-positive and Gram-negative bacteria (Joshi and Prabhakar, 2020). Additionally, hexane, chloroform and ethanol extracts from *H. undatus* peel demonstrated antibacterial effects in a disc diffusion assay, showing inhibition zones of 7-9 mm against both Gram-negative and Gram-positive bacteria (Hitendraprasad *et al.,* 2020).

Studies found that dragon fruit extracts exhibit antimicrobial effects against organisms like *Escherichia coli* and *P. aeruginosa*. For *Escherichia coli* and *Staphylococcus aureus*, the minimum inhibitory concentration was 50 µl in *H. undatus* seeds, and hexane, chloroform, and ethanol extracts from the peel inhibited both Gram-negative and Gram-positive bacterial growth (Sushmitha *et al*., 2018).

Betalain, a natural pigment that imparts colour to dragon fruit flowers and fruits, contains bioactive compounds like polyphenols and flavonoids, which have antioxidant and antifungal activities (Luu *et al*., 2021). The antifungal properties of dragon fruit peel extracts were tested on pathogens like *Candida albicans* using the Resazurin Microtiter assay, which measured total phenolic and flavonoid contents (Hendra *et al*., 2020). Ethyl acetate extracts, rich in gallic acid and quercetin, showed the highest antifungal inhibition at 500 ppm. Gowda and Sriram (2023) reported that synthesized silver and silver chloride nanoparticles from dragon fruit peel biowaste demonstrated effective antifungal activity against *Colletotrichum truncatum* spores, showing potential as antifungal agents for controlling chilli anthracnose disease.

4.7 Antilipidemic activity

Dragon fruit peel powder exhibits antilipidemic properties, effectively improving lipid profiles by reducing total cholesterol, triglycerides and LDL-c while raising HDL-c levels in individuals with normal cholesterol who are pre-diabetic or have type 2 diabetes. This improvement helps lower the risk of cardiovascular diseases, prevents hyperlipidemia, and supports overall health (Hernawati *et al.,* 2018). Hyperlipidemia, characterized by high cholesterol and saturated fat levels in the blood, elevates cardiovascular disease risk. Polyphenols in *H. polyrhizus* reduce cholesterol and triglyceride levels while enhancing HDL cholesterol, aiding in hyperlipidemia prevention (Mande *et al*., 2023). Additionally, its hypolipidemic properties prevent atherosclerosis, and the octadecadienoic acid in dragon fruit, a fatty acid, contributes to hypocholesterolemic effects (Kylanel *et al.,* 2020).

4.8 Antioxidant activity

H. polyrhizus contains high levels of betalains, along with other beneficial compounds like vitamins, phenolics and flavonoids which contribute to its antioxidant properties found in the fruit pulp (Garcia Cruz *et al*., 2017). Phenolic compounds, including tannins, stilbenes, lignans, phenolic acids, and flavonoids, along with vitamin C and alkaloids in dragon fruit, exhibit natural antioxidant (radical-scavenging) properties. These antioxidants protect against cell damage from free radicals, lowering the risk of various diseases in humans, plants, and animals. Studies show that pre-diabetic and normocholesterolemic individuals who consume red fleshed dragon fruit exhibit lower total antioxidant levels. However, antioxidant activity is higher in *H. polyrhizus*, which has a high phenolic content (15.92 mg/g), reducing oxidative damage. Oil extracted from dragon fruit peel and pulp is a valuable source of antioxidants, with the peel containing higher flavonoid content than the pulp (Manihuruk *et al.,* 2017). Additionally, dragon fruit with red peel has more antioxidants than varieties with white pulp, and cyanidin 3-glucoside-enriched extracts from waste biomass are used in nutraceutical and nutricosmetic products as natural pharmaceutical components (Saenjum *et al*., 2021).

4.9 Antiulcer activity

Quercetin, a flavonoid phytocompound found in the peels of *H. polyrhizus*, exhibits antiulcer activity. Research by Safira *et al.* (2021) demonstrated that quercetin relieved distress occurs in 35% of instances occur within 2-4 days, while 90% are seen within 4 -7 days. The antiulcer properties of dragon fruit extract work by inactivating the COX-1 and COX-2 pathways, which helps reduce oxidative stress (Islam *et al*., 2013). Additionally, carbohydrates in dragon fruit extracts aid in treating gastrointestinal disorders (Kylanel *et al*., 2020).

4.10 Cardioprotective activity

The antithrombotic effects of *H. polyrhizus* flesh, due to its polyphenol compounds, provide cardioprotective benefits (Kylanel *et al.*, 2020; Wulandari *et al.,* 2020). Dragon fruit's polyphenols and antioxidants act as key cardioprotective agents, and its soluble dietary fibre reduce serum cholesterol levels in rats. This information could guide food scientists in developing cardioprotective products from dragon fruit, leveraging high polyphenol and antioxidant content. Utilizing specific thermal processing techniques would preserve these biologically active compounds, enhancing their nutritional value (Alireza *et al*., 2011).

4.11 Prebiotic activity

The ethanolic extract of *H. undatus* flesh contains 85% diverse oligosaccharides that act as prebiotics in the stomach, supporting digestion. Beneficial bacteria like *Lactobacilli* and *Bifidobacteria* utilize these prebiotics to aid digestion and strengthen the immune system. The fibres in dragon fruit also act as prebiotics, supporting the growth of beneficial gut microbiota and supporting overall health. This fruit is rich in monosaccharides, minerals, and macronutrients, along with bioactive compounds like sterols and carotenoids, which reduce the risk of coronary diseases as also reported in sand pear (Shubham *et al*., 2024).

4.12 Antihepatotoxicity activity

The hepatoprotective effects of dragon fruit are attributed to bioactive compounds such as triterpenoid glycosides, tannins, saponins, and flavonoids, which protect the liver by preventing lipid peroxidation and subsequently enhancing serum glutamic-oxaloacetic transaminase (SGOT) and serum glutamic-pyruvic transaminase (SGPT) levels (Cahyati and Putriningtyas, 2021). In *H. polyrhizus*, tocopherols and phenolic compounds protect the liver from damage triggered by carbon tetrachloride and reduce hepatic injury (Hendra *et al*., 2020; Safira *et al*., 2021). In addition, a study on the methanolic extract of dragon fruit revealed its effectiveness in protecting the liver from acetaminophen-induced damage, as shown by levels of serum enzymes, including aspartate aminotransferase, alanine aminotransferase, total bilirubin and alkaline phosphatase (Sushmitha *et al.,* 2018).

4.13 Neuroprotective activity

Neuroprotection refers to the mechanisms that safeguard the central nervous system (CNS) against both chronic neurodegenerative disorders and acute conditions (such as trauma or stroke), including alzheimer's, dementia, parkinson's and epilepsy. Essential fatty acids and phytochemicals like flavonoids, phenols and anthocyanins present in dragon fruit prevent neurodegenerative diseases (Chen *et al*., 2019; Safira *et al*., 2021; Singh and Kumar, 2023).

4.14 Diuretic activity

Dragon fruit leaves and fruits contain saponins known for their diuretic effects. Compounds like betulinic acid, lupane, glycine, and oleanolic acid have been shown to aid in the prevention of chronic kidney disease. Additionally, methyl ester, 9,12,15-octadecatrienoic acid and 9,12-octadecadienoic acid possess diuretic properties (Kylanel *et al*., 2020; Safira *et al*., 2021).

Table 4: Pharmaceutical activity and the action of phytochemicals in Dragon fruit

S.No.	Pharmaceutical activity	Mechanism of action	Reference
1	Antianaemic activity	Rich in vitamin C, dragon fruit aids in non-heme iron production, essential for blood formation, and its high iron content regulates erythrocytes and hemoglobin in anaemic patients and pregnant women.	Singh and Kumar (2023)
2	Antidiabetic activity	Soluble dietary fibers and antioxidants in dragon fruit help lower insulin resistance.	Luu *et al.* (2021)
3	Anticancer activity	Flavonoids, polyphenols, beta-amyrin, and lycopene target tumorigenic pathways to inhibit breast cancer cell growth.	Singh and Kumar (2023)
4	Anti-inflammatory	Squalene and betalains function as antioxidants with anti-inflammatory properties, minimizing inflammation by targeting free radicals and inflammatory mediators.	Mande *et al.* (2023)
5	Antimicrobial activity	Betacyanin and secondary metabolites, such as flavonoids, enhance the plant's cellular defence against viruses, bacteria, and fungi	Singh and Kumar (2023)
6	Antilipidemic activity	Reduces triglycerides, total cholesterol and LDL levels, preventing atherosclerosis with hypolipidemic and anti-obesity effects.	Luu *et al.* (2021)
7	Antioxidant activity	Vitamin C, gallic acid, and alkaloids help shield cells from damage caused by free radicals; giving dragon fruit peel strong antioxidant properties and effective radical-scavenging abilities.	Singh and Kumar (2023)
8	Antiulcer activity	Quercetin in the peel extract effectively treats ulcers within days to a week.	Safira *et al.* (2021)
9	Anti-infertility activity	As an antioxidant, gallic acid improves sperm motility, size, and count within the epididymis.	Safira *et al.* (2021)
10	Antihepatotoxicity activity	The methanolic extract shows significant hepatoprotective potential, particularly effective against silymarin, with antioxidant properties.	Islam *et al.* (2013)
11	Neuroprotective activity	Flavonoids, fatty acids, and anthocyanins counter lead toxicity, supporting brain tissue recovery and safeguarding against further degradation.	Safira *et al.* (2021); Elgazar *et al.* (2023)
12	Diuretic activity	Saponins, methyl ester, and 9,12,15-octadecatrienoic acid exhibit diuretic effects and are used for treating chronic kidney disease.	Sushmitha *et al.* (2018); Safira *et al.* (2021)
13	Wound healing activity	Soluble mediators, including cytokines and growth factors, support the repair of wounds or damaged tissue	Mande *et al.* (2023)
14	Antiageing activity	Betalains, including betacyanin and betaxanthin, act as antiageing agents by neutralizing free radicals associated with aging and cardiovascular issues.	Safira *et al.* (2021)

5. Conclusion

Dragon fruit stands out as an exceptional fruit with substantial therapeutic and nutritional value, packed with phytochemicals that contribute to its pharmacological benefits. Each part of the fruit offers a wide range of health advantages, from blood sugar regulation to immune system support. Additionally, dragon fruit's antibacterial, antifungal and neuroprotective possessions make it a promising therapeutic agent for various health conditions. With its growing economic and nutritional importance, further research is essential to uncover its full potential. Beyond being a delightful tropical treat, dragon fruit is a valuable asset for enhancing overall health. This review highlights the effective use of dragon fruit parts and its bioactive compounds, emphasizing its therapeutic potential for managing chronic diseases and diverse health issues. The review aims to be a valuable resource for researchers exploring dragon fruit applications. Developing purification methods for these phytochemicals is essential for their use in food products, beyond the consumption of whole dragon fruit.

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Conflict of interest

The authors declare no conflict of interest relevant to this article.

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