

# Antiviral, Antidiabetic, and other Health Effects Of Dragon Fruit and Potential Delivery Systems for its Bioactive Compounds

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**Abstract:** *Dragon fruit (Hylocereus spp.), a tropical fruit of growing nutritional and pharmaceutical interest, is a rich source of bioactive compounds such as betacyanins, betaxanthins, polyphenols, flavonoids, and polysaccharides. These constituents exhibit multiple pharmacological activities, including notable antiviral and antidiabetic effects. Betacyanins have demonstrated inhibitory actions against viral replication by modulating host immune responses and suppressing viral protein expression, while polysaccharides and phenolic compounds contribute to improved glucose metabolism, enhanced insulin sensitivity, and protection against oxidative stress. Beyond these, dragon fruit bioactives display anti-inflammatory, antioxidant, antimicrobial, hepatoprotective, and cardioprotective properties, underscoring their broad therapeutic potential. However, their clinical effectiveness is limited by poor stability, bioavailability, and degradation under physiological and processing conditions. To overcome these challenges, advanced delivery systems such as nanoliposomes, nanoemulsions, biopolymer-based nanoparticles, and encapsulation techniques have been developed to enhance the stability, controlled release, and absorption of these compounds. This review highlights the recent advances in understanding the antiviral and antidiabetic mechanisms of dragon fruit bioactives and explores innovative delivery strategies that can potentiate their health-promoting efficacy in functional foods and nutraceutical formulations..*

**Keywords:** Dragon fruit, Antiviral, Antidiabetic, bioactive compounds, Hylocereus polyrhizus, Betalains, Betacyanin, Delivery systems, Hylocereus species, pitaya

## I. INTRODUCTION

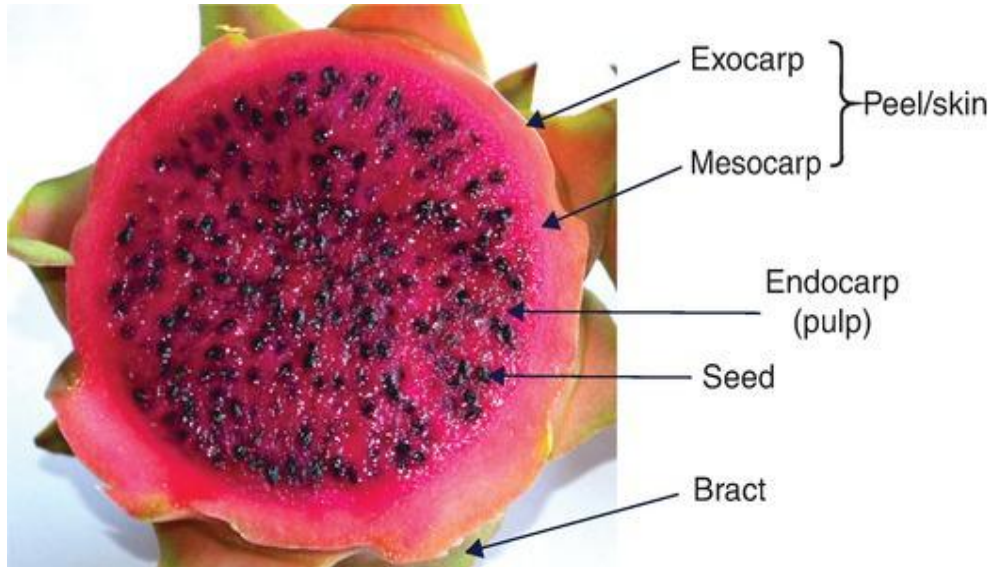
Originating in the tropical regions of Mexico, Central America, and South America, pitaya is a resilient member of the Cactaceae family. While Selenicereus megalanthus (yellow pitaya) and Hylocereus polyrhizus (red or purple pitaya) are additional noteworthy variants, Hylocereus undatus (white pitaya) is the most well-known species. Vitamins B1, B2, and B3, beta-carotene, lycopene, vitamin E, phenolic compounds, ascorbic acid, potassium, magnesium, and carbohydrates are among the many bioactive and useful substances found in abundance in the fruit. (1,2)

Studies on pitaya have highlighted its functional properties, particularly its role in reducing the risk of chronic disease and supporting both physical and mental well-being. The fruits pulp contains antioxidants and oligosaccharides with prebiotic effects, while the peel is especially rich in antioxidants. Additionally, its seeds provide valuable essential fatty acids and phytosterols. (3) Due to its hypoglycemic qualities, dragon fruit may help lower malondialdehyde in the body and control blood sugar levels. Doctors frequently advise people with type 2 diabetes to include dragon fruit in their diet since it helps lower their blood sugar levels to almost normal. Hylocereus polyrhizus has been demonstrated in tests to have a hypoglycemic effect on dyslipidemia mice and to reduce the risk of hyperglycemia in humans when consumed regularly. Particularly in those who consume a lot of calories, the effects help lower blood sugar levels that are elevated and enhance insulin sensitivity. (4)



Furthermore, the fruit contains bioactive compounds with metformin-like activity, which play a significant role in lowering glycemia and reducing insulin resistance, as indicated by the homeostatic model Assessment in type 2 diabetic rat. Betacyanin, the red pigment found in dragon fruit peel, exhibits strong antimicrobial and antioxidant activities. its antimicrobial effects are mediated through mechanisms such as cell wall disruption and the generation of reactive oxygen species. upon interaction with microbial contaminants, dragon fruit extracts activate defense responses, offering antibacterial protection against infections caused by bacteria, fungi, and viruses. (5)

**MORPHOLOGY:-**



**Fig 1:-Morphology of dragon fruit**

**TAXONOMY:-**

Synonyms:-Dragon fruit, pitaya, pitahaya, strawberry pear, night-blooming cereus, Belle of the night, and Cinderella plant. (5)

**Table 1:-Taxonomy**

<b>KINGDOM</b>	plantee
<b>PHYLUM</b>	tracheophyto
<b>CLASS</b>	Magnoliopsida
<b>FAMILY</b>	Cacteaceae
<b>GENUS</b>	Hylocereus
<b>SPECIES</b>	Hylocereus polurhizus

(5)

**TYPES:-**

- 1)Hylocereus undatus  
Red skin, white flesh
- 2)Hylocereus polyrhizus  
Red skin, red flesh
- 3)Hylocereus costaricensis  
Red skin, purple flesh
- 4)Hylocereus megalanthus



Yellow skin, white flesh ( 4)



**Fig 2: -Types of dragon fruit**

**Nutritional value and Importance of Dragon fruit: -**

Dragon fruit and its extracts provide significant therapeutic and nutritional benefits. The pulp, which constitutes 70-80% of the ripe fruit, is rich in calories, proteins, fiber, iron, fats, carbohydrates, and essential vitamins such as C, B AND E, along with minerals like magnesium, phosphorus, and calcium. Particularly high in iron, it enhances oxygen transport and energy production. Regular consumption supports cardiovascular health, lowers cholesterol, prevents arthritis, alleviates asthma, delays ageing, and aids in weight management. Its carotenoids and vitamin C strengthen the immune system, protect against infections, and reduce the risk of various diseases. The protein fraction also contributes beneficial omega-3 and omega-6 fatty acids, monounsaturated fats, and minimal cholesterol, further promoting heart health.

The red fleshed variety, *Hylocereus polyrhizus*, characterized by its medium-to-large oblong shape and striking pink scaly peel, is particularly valued for its betalains, potent antioxidants and natural colorants. Dragon fruit additionally contains betacyanins, amino acids, organic acids, dietary fiber, vitamins, and sugars, mainly glucose, fructose, and oligosaccharides. Other antioxidant compounds such as polysaccharides and polyphenols act as natural pigments, with betanin widely applied in food products. Nutritionally, it is also abundant in glucose, thiamine, pyridoxine, niacin, cobalamin, flavonoids, carotenoids, phenolic phytoalbumins, and iron. With a higher fiber content compared to fruits like mango, orange, and banana, dragon fruit enhances digestion, supports diabetes management, and stabilizes blood glucose levels. Its antioxidant properties improve platelet counts, benefiting patients with dengue and malaria. In skincare, dragon fruit is incorporated into creams and face masks for its skin-firming and anti-ageing effects, vitamins C and B aid in treating acne and burn, known as “anti-inflammatory fruit”, it helps relieve arthritis-related joint pain. Furthermore, its antioxidants strengthen immunity, detoxify harmful substances, neutralize heavy metals, and promote eye health. (6,8)

**Table 2: -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	1.1g
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
Ph	4.77	4.24
Vitamin b2 (Riboflavin)	0.05 mg	0.5 mg
Vitamin b1 (Thiamine)	0.04 mg	0.02mg
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	1.6 – 6.7 mg	13 mg
Iron	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

### Therapeutic properties

Dragon fruit is rich antioxidants that help combat free radicals, which are linked to cancer, inflammation, and oxidative stress. Its bioactive compounds, including gallic acid, betacyanin, vitamins, potassium, vanillic acid, and p-coumaric acid, contribute to therapeutic effects in meaning cardiovascular disease, diabetes, dyslipidaemia, cancer, and metabolic syndrome. Numerous medicinal benefits of the dragon fruit include cholesterol-lowering, styptic, astringent, antiadhesive, antihyperglycemic, antiparasitic, anticancer, antibacterial, anti-inflammatory, antioxidant, analgesic, anticarcinogenic, antimutagenic, antiplatelet, antifungal, anthelmintic, antiviral, and analgesic effects. (6,9)

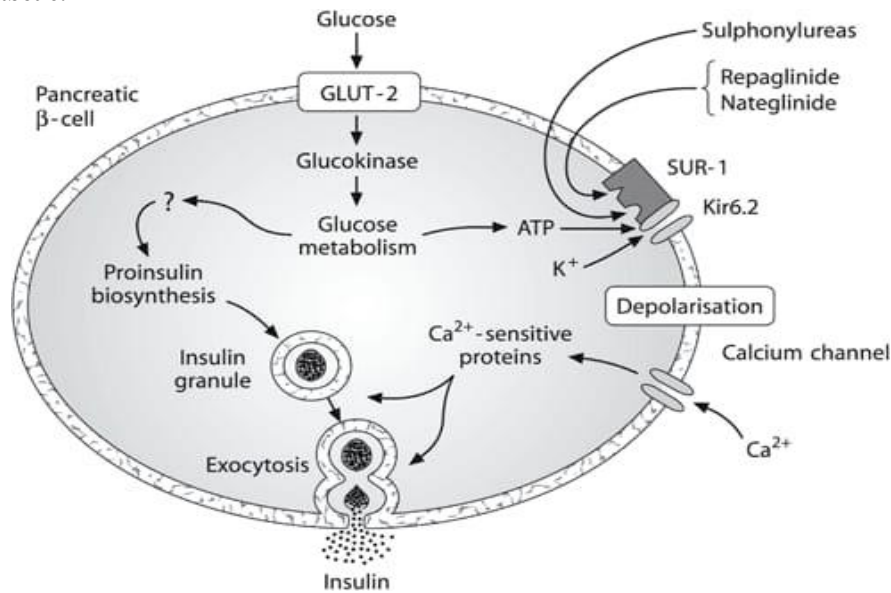
**Table 3: -The bioactive compounds and its therapeutic properties in Dragon fruit**

Bioactive compounds/phytochemicals in dragon fruit	Therapeutic effects	Therapeutic effects and bioactive compounds
Alkaloids	Anti-inflammatory Anticancer Analgesic Antiparasitic Anticancer Antioxidant Anabolic properties Antidiabetic Antibacterial Antifungal	Anti-inflammatory  Antimicrobial Antibacterial agents Anticancer
Phenols	Antiplatelet Styptic and astringent Anticarcinogen Antiviral	Anticancer agents Antibacterial/Antiviral/Antifungal Antiplatelet agents
Saponins	Antimicrobial	Anti-inflammatory





**MOA of Antidiabetic: -**



**Fig 3: - Mechanism of action of antidiabetic (10)**

**Produces Antimicrobial Activity: -**

The fruit's peel and pulp, particularly that of *H. polyrhizus*, can also have antifungal properties against *Rhizoctonia Solani*, *Botrytis cinera*, and *Candida albicans*. *Staphylococcus aureus* and *Escherichia coli* are two gram-positive and gram-negative bacterial species that are inhibited in their growth by the *Undatus* seed. (4)

**Anti-inflammatory activity:** -Dragon fruit has anti-inflammatory and antioxidant qualities since it includes phytoconstituents as squalene and batalains. Encapsulation or the application of an impermeable protective shell can increase the effectiveness of batalains, which are extremely unstable and prone to destruction under temperature, light, pH, and oxygen exposure. The pulp and peel of dragon fruit are rich in anthocyanin, which inhibits the synthesis of reactive oxygen and nitrogen atoms. According to scientific studies, dragon fruit has anti-inflammatory properties that can provide relief from severe pain in the joints, bones, and muscles. Therefore, if a patient has rheumatoid arthritis and is experiencing chronic pain, the doctor advises them to eat dragon fruit. (6)

**Antioxidant Activity: -**

Prior research revealed that quercetin and catechin, two important flavonoid components, were present in red dragon fruit. and white dragon fruit's betalain, which has strong antioxidant properties. The plant uses phenolic chemicals as a defensive strategy against many stressors. Phenolic chemicals are frequently the focus of several studies. Flavonoid chemicals and other phenolic compounds have different levels of antioxidant efficacy. *Hylocereus* species, especially *H. polyrhizus*, are rich in betalains and other bioactive compounds such as vitamins, flavonoids, and phenolic substances, all recognized for their strong antioxidant potential. Notably, the peel contains higher levels of flavonoids than the pulp, while the oil extracted from the seeds and peel of *H. undatus* serves as an excellent source of antioxidant compounds. (11,13)



**MOA of Antioxidant: -**

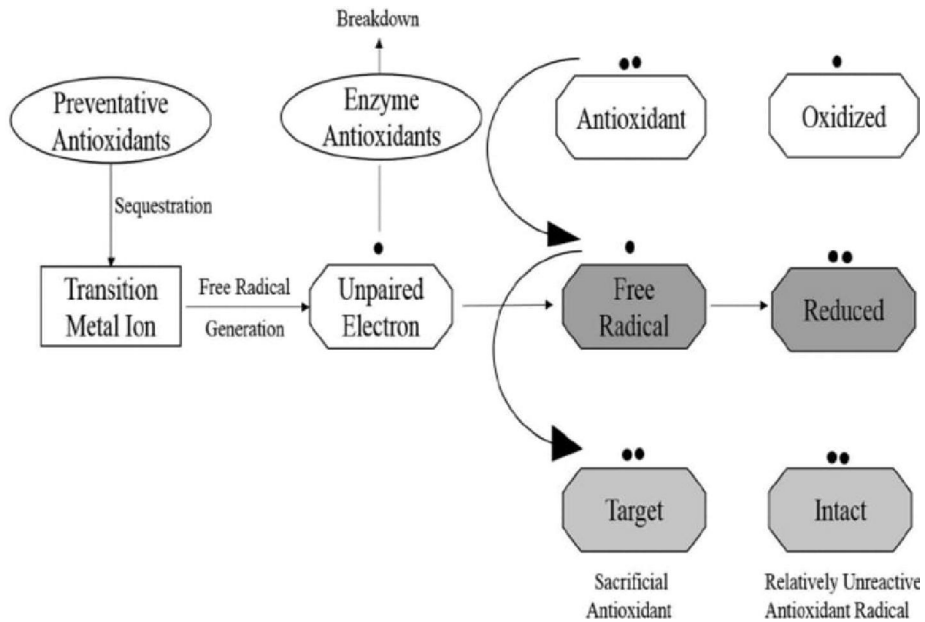


Fig 4: - MOA of antioxidant (10)

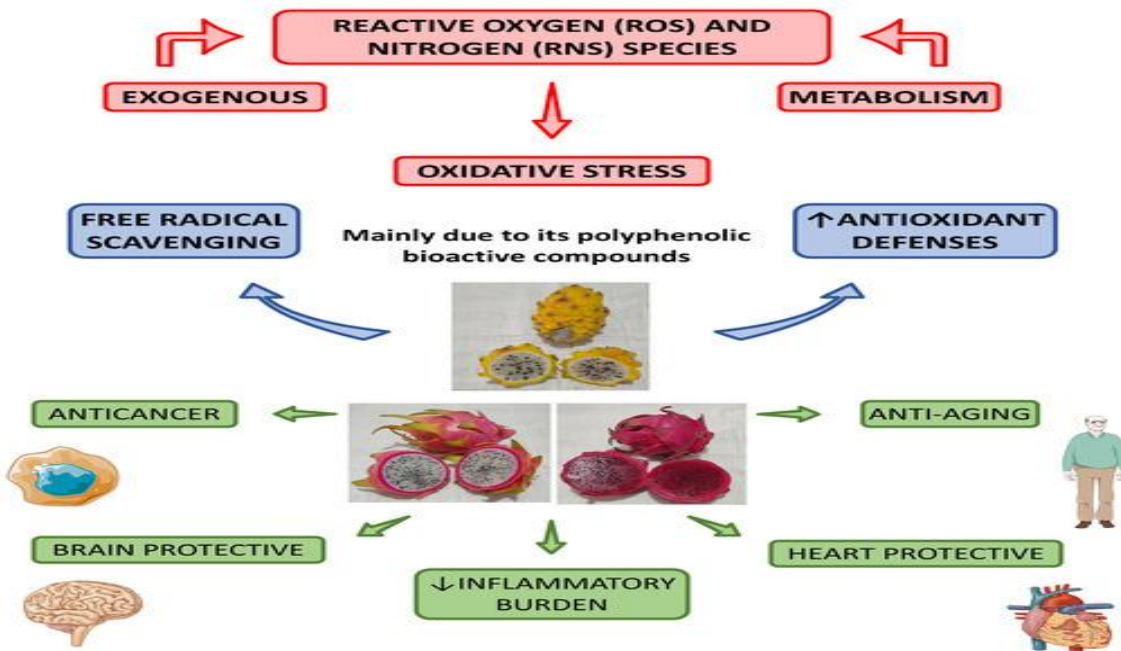


Fig 5: - Antioxidant effects of hylocereus species & its health effects (12)



**Diuretic Activity:** -The fruit and leaves have inherent diuretic qualities. The diuretic action is caused by saponins. In addition to protecting plants, these secondary metabolites give them a waxy covering that increases yield. Chronic kidney disease can be avoided with the use of saponins such Lupane, glycine, betulinic acid, and oleanolic acid. (14)

**Hepato protective effects:** -

investigated how red dragon fruit extract affected the liver damage brought on by hyperlipidemia and membrane lipid peroxidation. In hyperlipidemia conditions brought on by a high-fat diet, red dragon fruit extract daily demonstrated promoting effects in reducing lipid peroxidation damage to the liver cell membrane. (15)

**Neuroprotective effects:** -

Aging-related problems are exacerbated by heavy metals, particularly copper, which are associated with neurodegeneration and elevated free radicals. The impact of pitaya (*Hylocereus undatus*) on copper toxicity in zebrafish was investigated by Tamagno et al. (2022). Results indicate that red pitaya pulp may help with aging-related disorders by lowering cortisol levels, anxiety, and aggression while also enhancing cholinergic and antioxidant system activities. (15)

**Protection of kidney health:** -

examined the potential protection of *Hylocereus polyrhizus* extract against sodium nitrate-induced oxidative kidney injury. Red dragon fruit extract was administered four hours before exposure to sodium nitrate at doses of 250, 500, or a combination of the two. Alongside histological analyses of kidney samples, researchers measured oxidative stress markers such as glutathione, catalase, and malondialdehyde (MDA). The findings showed that oral administration of *Hylocereus polyrhizus* aqueous extract at both doses considerably reduced renal damage caused by sodium nitrate. Reduced MDA levels and elevated glutathione and catalase activity demonstrated this protective effect. The extract's capacity to prevent oxidative kidney injury was shown by histological analysis, which further verified reduced tissue damage. (15)

**Utilization of dragon fruit:** -

Pitaya fruit is well-known around the world for its delightful flavour, juice, and captivating colours. Both its raw and dry forms are consumed. Because of its inherent coloring ability, it can be used to make a wide variety of drinks. While dried sections of *Hylocereus* species are used as traditional or local medicine, fresh fruits, new flowering buds, and young shoots are also utilized as vegetables. The fruit's peel has a high betalain and pectin content, which makes it a natural food thickener.

The raw and processed fruits are used to make a variety of preparations, including candies, jams, jellies, ice creams, and shakes. Additionally, fruits are offered as pickles and soups. Because of their ability to moisturize the skin, plant stem and skin pulps are also employed in the cosmeceutical business, primarily in the preparation of beauty soups.

Fruit pulp, plant pieces, and garbage can all have a variety of negative health effects on *Hylocereus* species. various nutraceutical activities are detected and beneficial products such as beverages, powder, dried chips, yogurt and other fermented products are processed these days. (16,17)



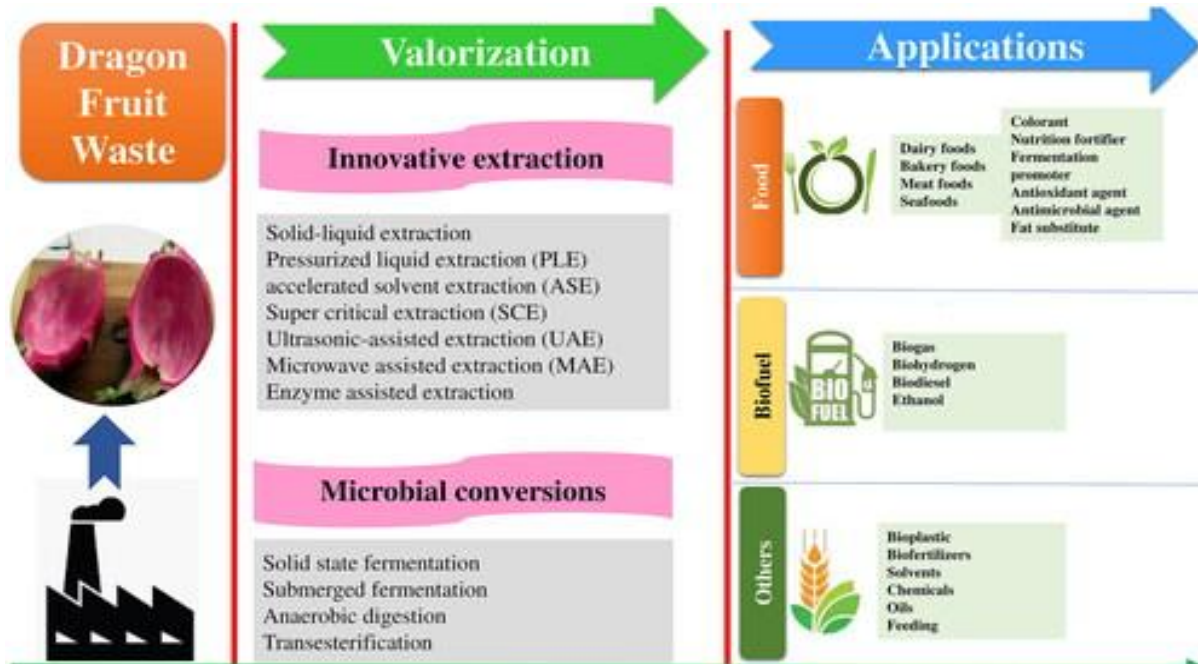


Fig 6: -Dragon fruit waste utilization and its application (12)

**Recent Regulatory development:** -According to regulatory standards, herbal pharmaceuticals are limited to traditional medicines that principally employ the processing of medicinal plants for therapeutic purposes. According to a current WHO definition, traditional medicine (including herbal drugs) includes therapeutic techniques that have been used for hundreds of years, before modern medicine developed and spread, as well as others that are still in use today. The FDA and EMEA have evaluated and shown a great deal of interest in the regulatory frameworks that govern the research and use of botanical drugs in recent years. (18)

**Storage and shelf life of dragon fruits: -**

In order to maintain the quality of harvested dragon fruit, the optimal storage conditions are 10 °C and 93% relative humidity (RH), which encourage a longer storage life of approximately 15 to 17 days. Any deviation from this temperature can result in negative effects like excessive softening and damage, while a higher temperature can cause the fruit's spines to turn yellow and its overall freshness to decrease. Implementing suitable refrigeration methods that efficiently preserve the fruits' freshness is crucial to ensuring dragon fruit's eligibility for export worldwide. Maintaining quality is crucial because of the fruits' short shelf life and vulnerability to mold growth while being stored. The possibility of peppermint oil as a substitute method to prolong the shelf life of dragon fruit by avoiding surface damage has been thoroughly examined by researchers. According to the study, employing essential oil vapor—especially peppermint oil—helps preserve the fruit's firmness, the bract's green hue, and important characteristics including its titratable acid value and total phenolic content. Even after 21 days of storage, this beneficial effect persisted, outperforming the results shown in the control group. (19,20)

**In-vitro anti-cancer and anti- diabetic studies of betaxanthin and betacyanin: -**

Building on the extensive bioactive profile described in the section above, subsequent studies have used sophisticated computational, in vitro, and molecular docking techniques to investigate the possible medicinal and health-promoting uses of these chemicals, especially betacyanin and betaxanthin. Two naturally occurring bioactive pigments found in dragon fruit, betacyanin and betaxanthin, were first built as ligand molecules and then their geometry was optimized using the Avogadro software's steepest descent method. In order to achieve very stable conformations, a subsequent



quantum chemical optimization was carried out using the ORCA 5.0 computational tool at the B3LYP/def2-SVP level of theory. DNA topoisomerase 1 (PDB ID: 1T8I), Cyclin-Dependent Kinase 6 (PDB ID: 1XO2), and pancreatic Alpha-Amylase (PDB IDs: 5EOF and 5NN8) utilizing Autodock vina v.1.1.1 (21) were the primary human therapeutic protein targets against which the optimized structure was docked.

While ligand data were handled using the Gasteiger charge method, protein preparation entailed assigning Kollman unified atom charges and converting them into PDBQT format using Auto Dock tools v.1.5.4. (22) All other docking parameters were left at their normal settings, and a grid spacing of 1 Å was used. Significant binding affinities were revealed by docking tests. With human DNA topoisomerase 1, betacyanin betaxanthin and betaxanthin showed a docking score of -9.138 kcal/mol and -7.137 kcal/mol, respectively, indicating a good potential for anticancer uses. Betacyanin and betaxanthin demonstrated their potential as cell cycle modulators by achieving binding scores of -8.537 and -8.324 kcal/mol, respectively, against Cyclin-Dependent Kinase 6, which controls G1 phase cell cycle progression and is overexpressed in a number of malignancies. Additionally, with docking scores of -8.836 and -7.849 kcal/mol for pancreatic Alpha-amylase and -7.775 and -6.697 kcal/mol for Acid-Alpha-Glucosidase, respectively, the ligands demonstrated notable inhibition profiles against human pancreatic Alpha-amylase and human lysosomal acid-alpha-glucosidase, two essential enzymes in carbohydrate metabolism associated with diabetes mellitus.

The structural characteristics of betacyanin and betaxanthin, specifically their broad hydrogen bonding capacity, conjugated  $\pi$ -systems that facilitate  $\pi$ - $\pi$  stacking, and their amphiphilic nature that permits a variety of interactions with hydrophilic regions of the receptor active sites, are responsible for the strong binding affinities. Interestingly, in similar computational models, the binding affinities of betacyanin against topoisomerase I (-9.138 kcal/mol) are similar to those of common chemotherapeutic agents like camptothecin derivatives, indicating that these natural compounds may be useful scaffolds for future drug development. Using a combination of high-throughput docking simulations and quantum chemical optimization, this study is the first to thoroughly investigate the multi-target inhibitory potential of betacyanin and betaxanthin against molecular targets linked to diabetes and cancer. To confirm our computational results and demonstrate the clinical utility of these pigments derived from dragon fruit as innovative therapeutic agents, more study utilizing in vitro enzyme inhibition assays, cancer cell line investigations, and animal models is advised.

(23)

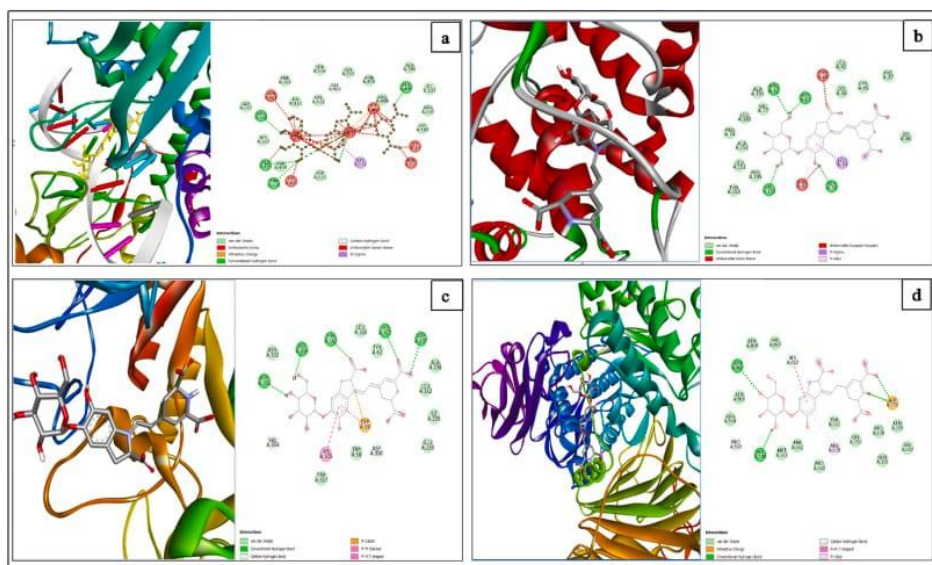


Fig 7: -molecular docking of betaxanthin with a) Human DNA Topoisomerase I [1T8I], b) human cyclin-dependent kinase 6 [1XO2], c) human pancreatic alpha-amylase [5EOF), d) Human pancreatic alpha -amylase[5NN8]. (23)



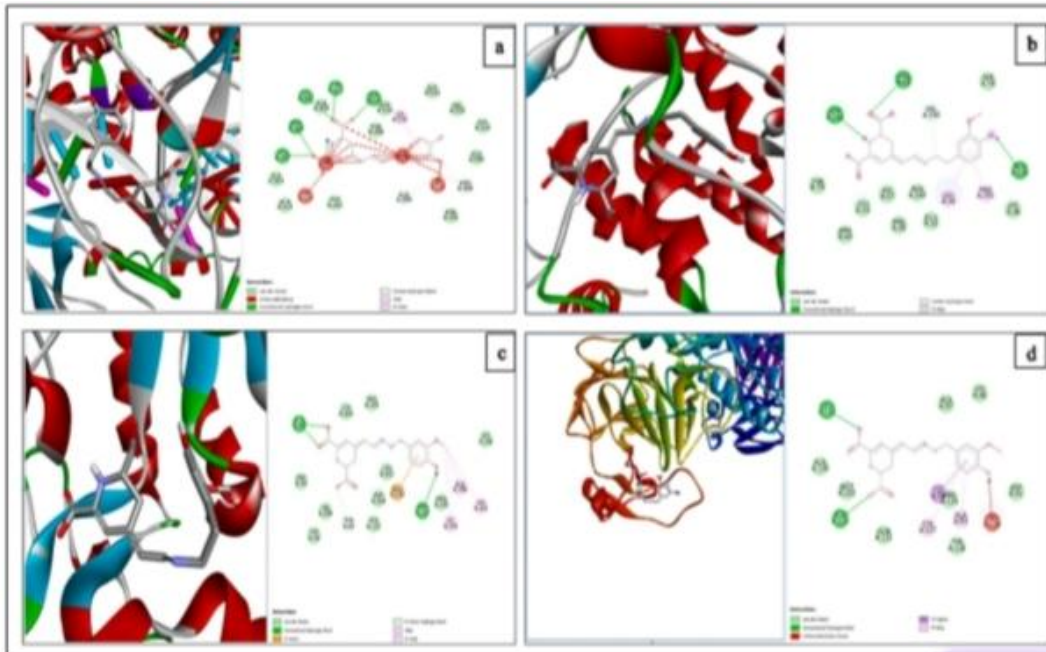


Fig 8 : -molecular docking of betacyanin betaxanthin with a) Human DNA Topoisomerase I [1T8I], b) human cyclin dependent kinase 6 [1XO2], c) human pancreatic alpha-amylase [5E0F], d) human pancreatic alpha-amylase [5NN8]. (23)

**Table 4: -Molecular docking score for betacyanin and betaxanthin with human cyclin-dependent kinase 6.**

Sr. No.	Ligand	Docking Score	No. of hydrogen bonds Donar	No. of hydrogen Bonds Donar	P value
1	Betacyanin	-8.537	8	12	-3.6983
2	Betaxanthin	-8.324	2	8	-1.3139

**Antiviral properties of dragon fruit: -**

Research has shown that dragon fruit contains compounds with antiviral properties, which may help protect against viral infections.

**Scientific evidence supporting antiviral claim: -**

Studies have demonstrated that extracts from dragon fruit exhibit antiviral activity against various viruses, including:

Influenza virus

Herpes simplex virus

HIV

These studies suggest that dragon fruit may be a useful adjunct to traditional treatments for viral infections.

**Key compounds Responsible for Antiviral effects: -**

The antiviral properties of dragon fruit are attributed to its high content of:

Flavonoids: a class of compounds known for their antiviral and antioxidant effects.

Phenolic acid s: have been shown to exhibit antiviral activity against various viruses.

Betacyanins: a type of pigment responsible for the fruits red colour, which may also contribute to its antiviral effects.

**Precautions and potential interactions with medications:**

While dragon fruit is generally considered safe, it may interact with certain medications, such as:



Blood thinners: - dragon fruit high vitamin K content may interact with blood thinners, such as warfarin.

Diabetes medications: - dragon fruits natural sugars may affect blood sugar levels and interact with diabetes medications. (24,25)

**Selection of selection: -**

Randomized Controlled Trials (RCTs) that examined the impact of the genus *Hylocereus* on human health were included in this review. Additionally, both in vitro and in vivo research were taken into account. Pitaya, dragon fruit, *Hylocereus*, *H. undatus*, *H. polyrhizus*, or *H. megalanthus*, as well as health, glycemia, blood pressure, cholesterol, lipids, body mass index, obesity, body weight, or cardiovascular disorders. RCTs, quasi-experimental research, placebo-controlled studies, and in vitro and in vivo models were all required for admission. Only complete texts were included. Articles written in languages other than English, Spanish, and Portuguese, as well as editorials, case reports, and poster presentations, were excluded. The discussion segment benefited from the review texts.

**Evaluation of Quality: -**

The Cochrane Handbook for Systematic Reviews of Interventions was followed in evaluating the presence of risk of bias in the RCTs, including detection, study selection, and reporting biases, in order to conduct a quality assessment.(26) Furthermore, the Systematic Review Centre for Laboratory animal Experimentation RoB tool (SYRCLE'S recommendations) was used to evaluate the presence of risk of bias in the included animal research (detection, study selection, and reporting biases). (27)

**Assessment of Technological Applications and Economic Importance: -**

To further explain the potential technical uses of pitaya and the plant's economic significance, additional research articles, reviews, and meta-analyses were assessed.

Other studies, including reviews, meta-analyses, and research investigations, were assessed to further characterize the potential technical uses of pitaya and the economic significance.

**Delivery systems for *Hylocereus* compounds: -**

With the increased incidence of chronic degenerative diseases, consumers are increasingly interested in nutritional, healthy, and safe food. For these reasons, the demand for natural products has increased substantially. For example, the search for pigments to substitute artificial colorants or additives in food products has been a desired target. Moreover, natural compounds may also be associated with anti-inflammatory and antioxidant actions that would meet the need for prevention and, or, as adjuvants in treating many chronic conditions [28,29]. On the other hand, bioactive compounds may not have the necessary bioavailability to reach target tissues in the body and rapidly undergo degradation under many types of storage, processing, or the gastrointestinal environment, due to oxygen, temperature, pH, light, and enzyme exposure. The possible effectiveness of bioactive compounds depends on their bioavailability, and, for these reasons, this is an obstacle to overcome. (30,31)

The incorporation of nanoliposome phospholipids enhanced the stability of betanin and increased the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity in gummy candies compared to those containing free betanin. (32) Similarly, encapsulated betalains in water-in-oil-in-water (w/o/w) double emulsions demonstrated superior encapsulation efficiency and emulsion stability. Betacyanin, a hydrophilic bioactive pigment extracted from red dragon fruit, possesses significant potential as a functional food ingredient or nutraceutical. developed a water-in-oil-in-water nanoemulsion system encapsulating red dragon fruit extract, ensuring its antioxidant functionality. Additionally, betalain microencapsulation using potato succinylated starch improved the stability of stored yogurt.

Although the applications of nanoparticles in areas such as distribution, labeling, and thermal processes have expanded, their biological and environmental relevance has also gained recognition. Consequently, plant-based or bio-compound-mediated synthesis of nanoparticles has attracted growing interest. Gold nanoparticles (25.31 nm) synthesized using



*Hylocereus polyrhizus* pulp-seed oil extract served as both reducing and stabilizing agents, demonstrating remarkable physiological stability and blood biocompatibility. This green synthesis approach provides an eco-friendly alternative to chemical methods and holds promise for diverse medical and biological applications.

The nanoparticles were evaluated through several biological assays, including anti-inflammatory, antioxidant, anti-diabetic, and anti-Alzheimer analyses, along with cytotoxicity testing. The anti-diabetic activity, assessed across concentrations of 50–200 mg/mL, showed significant inhibition of the  $\alpha$ -amylase enzyme. The highest anti-inflammatory effect was recorded at 400 mg/mL, with inhibition rates of  $50.51 \pm 1.32\%$  for COX-1 and  $58.74 \pm 0.76\%$  for COX-2. Antioxidant activity increased proportionally with concentrations ranging from 100 to 500 mg/mL of extract and pulp-seed oil. In the anti-Alzheimer study, inhibition of acetylcholinesterase and butyrylcholinesterase reached  $69.11 \pm 1.12\%$  and  $64.78 \pm 0.71\%$ , respectively, at 400 mg/mL, displaying dose-dependent responses. Furthermore, the nanoparticles exhibited dose-dependent cytotoxicity against HepG2, HCT-116, and MCF-7 cell lines, indicating potential use in colon and breast cancer therapies. Overall, these findings suggest that gold nanoparticles derived from red pitaya extract could serve as effective biomedical vectors for drug or gene delivery systems and as biosensors suitable for blood-contact applications. (33,3)

#### **Ethnomedical uses of *Hylocereus polyrhizus*: -**

*Hylocereus polyrhizus* (red pitaya) possesses significant ethnomedicinal and industrial potential owing to its diverse bioactive compounds. The fruit peels have shown promise as natural alternatives to synthetic sunscreen agents due to their biologically active constituents, making them valuable in the cosmetic industry. (38) Lipsticks formulated from *H. polyrhizus* extracts contain betalain pigments, which exhibit potent antioxidant and antibacterial activities. (39,40)

In silico and molecular docking studies further support the therapeutic potential of this species. Compounds such as 4-prenylresveratrol, vicenin, and luteolin demonstrated strong interactions with target molecules, indicating anti-glycation and antioxidant effects that could contribute to preventing and managing diabetes and age-related disorders. Ethnomedicinally, *H. polyrhizus* has been recognized for its antioxidant, anticancer, antibacterial, hepatoprotective, antidiabetic, and wound-healing properties. Traditionally, it has been employed in treating ailments such as cough, diabetes, asthma, hyperactivity, tuberculosis, mumps, bronchitis, and cervical lymph node tuberculosis. (41)

Beyond medicinal applications, red dragon fruit also enhances the fermentation rate, lactic acid production, total phenolic content, antioxidant activity, and sensory quality of yoghurt. Additionally, pitaya has long been used as a natural coloring agent in food products. Extracts from the albedo portion of the fruit have been processed into natural coloring powders, while betalains—secondary metabolites derived from L-tyrosine—serve as widely recognized natural food dyes. (35,42,43)

#### **Prospects for processing dragon fruit in the future: -**

A wider range of dragon fruit-based items, such as juices, jams, jellies, dry snacks, and creative culinary creations, are anticipated in the future. It is anticipated that producers would look into creative ways to smoothly integrate dragon fruit into a variety of culinary and drink categories. Extracts from dragon fruit might be useful as supplements or added to diets designed to provide certain health advantages.

Dragon fruit cultivation holds global importance due to its nutritional and medicinal potential. The plant thrives in arid regions with minimal water, making it suitable for areas unsuitable for other fruit crops. Every part of the plant—cladodes, flowers and fruits—contains bioactive compounds with therapeutic properties, including antihypertensive and antioxidant effects, attracting pharmaceutical and nutritional interest. Despite its economic and functional benefits, dragon fruit remains underrecognized in the global market. Further research and promotion are needed to enhance its commercial value, and its low nitrogen requirements make it feasible for organic cultivation using local composts and fertilizers. (36,37)



## II. CONCLUSION

Dragon fruit (*Hylocereus* spp.) represents a promising functional food with a rich profile of bioactive compounds such as betalains, polyphenols, flavonoids, and polysaccharides, which contribute to its diverse pharmacological properties. Extensive research highlights its antiviral, antidiabetic, antioxidant, anti-inflammatory, and anticancer effects, positioning it as a valuable natural resource for health promotion and disease prevention. Betacyanins and betaxanthins, in particular, exhibit strong free radical scavenging and enzyme-modulating activities that may play crucial roles in mitigating oxidative stress-related disorders and improving metabolic health.

However, the stability, bioavailability, and targeted delivery of these compounds remain key challenges. Emerging nanotechnological approaches, including liposomes, nanoemulsions, and biopolymeric nanoparticles, have shown potential in enhancing the protection, controlled release, and absorption of dragon fruit bioactives. Future research should focus on optimizing these delivery systems, validating their efficacy through clinical trials, and exploring synergistic effects with other natural compounds.

Overall, integrating dragon fruit and its encapsulated bioactives into nutraceuticals, functional foods, and therapeutic formulations offers a sustainable and innovative pathway toward improving public health and combating lifestyle-related diseases.

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