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From waste to wealth: Bioactive compounds from Dragon fruit peel and their application

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Abstract
Dragon fruit (*Hylocereus spp.*) peel, comprising 30-35% of the fruit, is a rich source of bioactive compounds such as betacyanins, phenolics, flavonoids, dietary fiber, and pectin. Once considered waste, it now holds promise for sustainable valorization in food, pharmaceutical, and packaging industries. This review highlights the peel's chemical composition, antioxidant capacity, and therapeutic properties, with emphasis on species like *H. polyrhizus* and *H. undatus*. Green extraction methods, especially ultrasound- and enzyme-assisted techniques, have enhanced bioactive recovery. Applications include natural colorants, dietary fiber supplements, meat fat replacers, bakery enhancers, and cosmetic additives. The peel also serves in active and intelligent biodegradable packaging through pectin, cellulose, and betalain based films. Toxicological studies confirm its safety, reinforcing its potential in circular bio-economy strategies aimed at waste reduction and resource recovery.

Keywords: Dragon fruit, peel, bioatives, application, safety

Introduction
Dragon fruit, also known as pitaya, refers to the edible fruits of several cactus species in the genus *Hylocereus*, most notably *H. undatus*, which typically has white pulp; *H. costaricensis*, known for its red flesh; and *H. megalanthus*, which features a yellow peel and white interior (Masyita *et al.*, 2025) [39]. Native to Central America but widely cultivated in Southeast Asia, Australia, and parts of South America, dragon fruit is recognized for its vibrant appearance, refreshing taste, and rich in nutritional profile, including minerals, vitamins, dietary fiber, and antioxidants (Hoa *et al.*, 2006; Esquivel *et al.*, 2007; Le 2022) [17, 34]. Due to increasing consumer demand driven by its health benefits and exotic appeal, dragon fruit production has expanded significantly in recent years (ICAR, 2020; Karunakaran *et al.*, 2024) [29, 33].

Dragon fruit pulp is widely utilized in the production of various food products such as jam, jelly, ready-to-serve (RTS) beverages, dried pulp powder, chips, yogurt, and other fermented foods (Tarte *et al.*, 2023; Panhal *et al.*, 2018; Vadhel *et al*, 2024; Gorband and Joshi, 2023) [32, 69, 78]. However, during the processing of dragon fruit, the peel is typically discarded as agro-industrial waste (Apriliyanti *et al.*, 2020; Chumroenvidhayakul *et al.*, 2023) [4, 13].

However, along with this growth comes the problem of fruit processing waste. Dragon fruit peel (DFP) constitutes approximately 30 - 35% of the total fruit weight and is typically discarded during consumption or industrial processing (Audina, 2019) [7]. This results in a large volume of organic waste, contributing to environmental pollution and inefficient use of natural resources. In many producing countries, dragon fruit peel is either dumped in landfills or used minimally as animal feed or compost, representing a significant loss of potentially valuable bio resources (Chen,2018; Sagar *et al.*, 2018) [10, 59].

Interestingly, emerging research has revealed that dragon fruit peel is rich in a variety of bioactive compounds, including betacyanins, flavonoids, polyphenols, dietary fibers, and essential minerals (Masyita *et al.*, 2025; Jimenez-Garcia *et al.*, 2022; Joshi *et al.*, 2024 [32]; Nicolas Saldaña *et al.*, 2024) [31, 39, 43]. Betacyanins are water-soluble pigments that exhibit strong antioxidant, antimicrobial, and anti-inflammatory properties, making them attractive for use in food, pharmaceutical, and cosmetic industries (Masyita *et al.*, 2025; Belhadj Slimen *et al.*, 2017) [9, 39]. The peel also contains pectins and polysaccharides that can be harnessed as gelling agents, stabilizers and biodegradable packaging materials, aligning with the growing global interest in sustainable and circular bio-economies (Chua *et al.*, 2020; Syarifuddin *et al.*, 2025) [12, 65].

Valorization the process of converting waste materials into more valuable products has gained momentum as a sustainable approach to managing agricultural and food waste. In the case of dragon fruit peel, valorization not only addresses environmental concerns but also creates avenues for developing functional ingredients, natural pigments, nutraceuticals, and bio-based materials (Le, 2022; Andrade *et al.*, 2024) [3, 34]. This aligns with the principles of waste minimization, resource recovery, and the development of green technologies that support the alignment with the United Nations Sustainable Development Goals (SDGs), especially those promoting responsible consumption and production as well as climate action (UN 2015) [77].

Several innovative extraction technologies, such as ultrasound-assisted extraction (UAE), supercritical fluid extraction (SFE) and enzyme-assisted extraction (EAE) have been explored to maximize the yield and functionality of bioactive compounds from dragon fruit peel (Masyita *et al.*, 2025) [39]. These green technologies offer significant advantages over conventional solvent-based methods by reducing energy input, solvent use, and environmental footprint while enhancing extract purity and stability. Moreover, the application potential of dragon fruit peel extracts has been investigated in diverse sectors from functional foods and dietary supplements to active packaging and cosmetic formulations (Nurliyana *et al.*, 2010; Rifna *et al.*, 2023) [44, 56].

Despite the promising outlook, the commercial exploitation of dragon fruit peel remains limited, primarily due to challenges in standardization, extraction scalability, regulatory compliance, and market integration (Rifna *et al.*, 2023; Masyita *et al.*, 2025; Andrade *et al.*, 2024) [3, 39, 56]. Additionally, inconsistencies in raw material composition, limited awareness among industries, and lack of consumer acceptance further hinder its widespread adoption (Arivalagan *et al.*, 2021) [6]. Therefore, a comprehensive understanding of the compositional characteristics, bioactivities, and valorization pathways of dragon fruit peel is essential to unlock its full potential and support the transition towards a more circular and sustainable agri-food system (Chua *et al.*, 2020; United Nations, 2015) [12, 77].

This review aims to systematically explore the composition, bioactive properties, and industrial applications of dragon fruit peel. It highlights recent advancements in extraction technologies, evaluates its potential uses in various industries, and discusses future perspectives for its commercialization. By compiling and synthesizing existing knowledge, this review seeks to contribute to the growing body of research on fruit by-product valorization and encourage further innovation in the utilization of dragon fruit peel.

2. Bio-chemical Composition and Bioactive Properties of Dragon Fruit Peel and their extraction

2.1 Proximate composition of dried dragon fruit peel

Composition (%)	*Hylocereus Polyrhizus* (Ramil, 2021) [54]	*Hylocereus undatus* (Chumroenvidhayakul *et al.*, 2023) [14]	Selenecereus megalanthus (Morais *et al.*, 2021) [41]	*Hylocereus costaricensis* (Morais *et al.*, 2021) [41]
Moisture	6.72	5.81	9.62	5.25
Fat	0.53	1.06	1.84	1.56
Protein	4.26	6.37	7.48	5.45
Ash	14.7	15.91	19.55	19.23
Carbohydrate	73.8	70.85	70.60	73.38
Total dietary fiber	63.2	65.17	69.06	60.21

Dragon fruit peel is a rich reservoir of valuable phytochemicals. Recent studies have highlighted its abundance of phenolic compounds, which significantly contribute to its antioxidant activity (Sangheetha *et al.*, 2021). It is particularly rich in flavonoids, including quercetin and rutin (Foronda and Cajucom, 2023; Chumroenvidhayakul *et al.*, 2023) [13, 20], and contains betalains red-violet pigments with strong biological activity (Jimenez-Garcia *et al.*, 2022; Mahmud *et al.*, 2023) [31, 40]. The peel is also a good source of dietary fiber and pectin, supporting gut health and enhancing texture in food and dairy products (Reyes-García *et al.*, 2024; Jamilah *et al.* (2011) [30, 55]; Tosh and Bordenave (2020) [75]. Drying techniques significantly affect the retention of these bioactive compounds, with freeze-drying proving superior in preserving antioxidant properties (Quan *et al.*, 2024) [52].

Betacyanins, the primary pigments responsible for the red-violet coloration in *Hylocereus polyrhizus*, are abundant in both the pulp and peel (Ding *et al.*, 2009). Efficient extraction and stabilization are critical for their practical utilization. Li *et al.* (2022) demonstrated that combining UAE (Ultrasound-assisted extraction) with micro-encapsulation using 10% maltodextrin enhanced encapsulation efficiency to 79.88% and preserved the betacyanin and exhibited highest antioxidant activity of 95.32%. Quan *et al.*, (2024) [52] reported that freeze drying retained the highest betacyanin (261.04 mg/100g), flavonoid (88.18 QE/g), phenolic compounds (0.40 mg GAE/g) than the vacuum and tray drying. These findings highlight the necessity of optimizing extraction, processing, and stabilization methods to fully harness the potential of betacyanins for applications in food, cosmetics, and biomedical fields (Mande *et al.*, 2023) [37].

The peel of *Hylocereus undatus* and H. *polyrhizus* is rich in phenolic acids such as gallic, ferulic, caffeic, p-coumaric, chlorogenic, protocatechuic, and syringic acids, as well as flavonoids like quercetin, rutin, and kaempferol. Using LC-ESI-QTOF-MS/MS, Chen *et al.* (2021) [11] identified over 80 distinct phenolic compounds in Australian-grown dragon fruit peel, illustrating its phytochemical diversity. Tang *et al.* (2021) and Nurliyana *et al.* (2010) [44, 67] reported that the peel consistently exhibits higher total phenolic content (TPC) than the pulp. In contrast, Wu *et al.* (2006) [82] measured TPC values in red pitaya peel of 39.7 mg (GAE)/100 g for peel and 42.4 mg (GAE)/100 g on wet basis. Thaiudom *et al.* (2020) [70] further reported TPC values of 40.16 mg GAE/g extract. These data underscore the potential of dragon fruit peel as a valuable source of phenolic compounds for functional foods, nutraceuticals, and natural preservatives.

Flavonoids are another important class of bioactives found in dragon fruit peel. Saenjum *et al.* (2021) [58] identified key flavonoids, including quercetin, kaempferol, and isorhamnetin derivatives, with the peel showing the highest concentration compared to other plant parts. Jimenez-Garcia *et al.* (2022) [31]

also confirmed the presence of myricetin, rutin, and quercetin, with total flavonoid content ranging from 3.0 to 10.5 mg quercetin equivalents (QE)/g dry weight, depending on the species and extraction methods. In a functional application, Gunungpati (2020) [22] reported that red dragon fruit peel added to yogurt contributed 1.03 to 2.45 mg QE/g, demonstrating its ability to retain flavonoid content during food processing. These findings highlight the peel's promise as a source of natural flavonoids with antioxidant and health-promoting effects.

The antioxidant capacity of dragon fruit peel is well-documented through assays such as DPPH, ABTS, BCB, RP, CUPRAC, LIRSA, and FRAP, largely attributed to its high phenolic, betalain, flavonoid, and tannin content (Bassey *et al.*, 2024; Febrianti *et al.*, 2020) [19]. Toding *et al.* (2024) [8, 73] confirmed the peel's strong antioxidant potential in effervescent formulations, with an IC_{50} value of less than 50 ppm. Nurliyana et al. (2010) [44] showed that the DPPH radical scavenging activity of the peel reached up to 87% for both red and white-fleshed varieties, significantly exceeding that of the pulp. Moreover, the peel demonstrated moderate ferrous ion chelating activity, indicative of additional antioxidant mechanisms. Hendra *et al.* (2020) [24] found that dried peel exhibited DPPH activity with an IC_{50} of 159.6 ppm. Wahdaningsih *et al.* (2018) [80] further isolated compounds from red dragon fruit peel with strong antioxidant effects (IC_{50}: 2.95-25.6 µg/mL). These results support the use of dragon fruit peel as a natural antioxidant source.

2.2 Extraction of bio-active compounds from dragon fruit peel

Extraction parameters	Optimum condition	Ref.
Feed to solvent ratio: 1:10-30 Solvent system: 30-60% ethanol (v/v) Extraction time: 5-25 min Extraction temperature: 30-50 Extraction tehnique: UAE	50% ethanol, 25 minutes extraction time, with 30 mL/g solvent-to-solid ratio, yielded 39.58 mg GAE/g TPC, 21.42 mg QE/g TFC, and 18.87 mg/100 g of betacyanin.	Raj and Dash (2020) [53]
Feed to solvent ratio: 1:15 to 1:40 Solvent: distilled water pH: 2-6 Extraction time: 10 to 60 min Extraction temperature: 30 - 60°C Extraction tehnique: Conventional	pH 3.6, 30°C, 10 min with 1:15 solvent-to-solid ratio yield betacyanin content of ~72.37 mg/L	Permana *et al.* (2025) [48]
Feed to solvent ratio: 1:10 Solvent: distilled water Extraction time: 20 min with UAE, 2.5 - 12.5 min EAE Extraction technique: UAE (0.5 to 4.5 W/g with 40 KHz) and EAE	7.5 min with UAE yield of 0.34 mg/g	Van *et al.* (2020) [79]
Feed to solvent ratio: 1:10 Extraction temperature: 25 - 100°C pH: 2-12 Extraction time: 1-6 h Extraction technique: conventional	4 hours of extraction time, 25 °C and pH 5 yield 31.02 mg/L of betacyanin.	Sambasevam *et al.* (2020) [60]
Feed to solvent ratio: 1:10 Solvent: ethanol: water 100/0 to 0/100% v/v for conventional and 10/100 for SFE Extraction time: 20 min for conventional and 1.5 h for SFE Extraction technique: conventional and SFE	Supercritical fluid extraction (SFE) at 25 MPa and 50 °C using a co-solvent mixture containing 10% ethanol in water (v/v) yielded 24.58 mg/100 ml of betacyanin. In contrast, conventional solvent extraction with a 50:50 ethanol-to-water ratio achieved a higher yield of 28.44 mg/100 ml of betacyanins	Fathordoobady *et al.* (2016) [18]

In terms of dietary fiber, dragon fruit peel comprises approximately 60.21-69.06% of its dry weight (Ramil, 2021; Chumroenvidhayakul *et al.*, 2023; Morais *et al.*, 2021) [13, 41, 54], with insoluble dietary fiber (IDF) as the predominant fraction, alongside a significant amount of soluble dietary fiber (SDF) (Jamilah *et al.*, 2011) [30]. SDF is linked to prebiotic effects, improved cholesterol and glucose regulation, and anti-inflammatory and anti-carcinogenic activities (Scheppach *et al.*, 2004; Tosh and Bordenave, 2020) [62, 75], while IDF is beneficial for gastrointestinal health by alleviating constipation and diarrhea (Zhuang *et al.*, 2012) [84]. This dual fiber profile makes dragon fruit peel a promising functional ingredient for fiber-enriched foods and nutraceuticals.

2.3 Extraction of pectin from dragon fruit peel

Extraction condition and technique	Optimum condition	Ref.
Solvent: 1% citric acid Solvent ratio: 1:30 Extraction temperature: 65°C and 90°C Extraction time: 90 min	At 90 °C produced yield of 23.24% and DE (Degree of estertification) 68.11%.	Setyajati *et al.* (2023) [64]
Extraction technique: microwave-ultrasound-assisted extraction (MUAE) process combined with a natural deep eutectic solvent (NADES) Solvent ratio: 15-45 (w/v) Water: NADES: 1.5-4.5 Sonication time: 30-90 min Microwave irradiation time: 10-30 min	Liquid-to-solid ratio of 35.25 ml/g, a water/NADES ratio of 3.37 ml/ml, microwave at 240 W for 14.26 min, followed by ultrasonic treatment for 46.07 min yielded 19.39% pectin and DE of 50.77% was achieved.	Tien *et al.* (2022) [72]
Extraction technique: Subcritical water extraction (SCWE) and conventional acid extraction (AE), applied to both fresh peel puree and dried peel powder Solvent ratio: 5-25 (w/v) pH: 2-5 adjusted with citric acid Temperature: 110 - 150°C	Highest pectin yield, approximately 18.9%, was obtained using subcritical water extraction (SCWE) on fresh peel puree under optimal conditions of 120°C, 30 minutes extraction time, and a solid-to-liquid ratio of 1:20 (w/v). The extracted pectin was classified as low-methoxyl, with DE of 8.5% to 50.6%.	Tristanto *et al.* (2024) [76]
Solvent ratio: 1:50 (w/v) Extraction time: 30-90 sec Extraction pH: 1.5-2.0 adjusted with citric acid Extraction technique: conventional heating and microwave-assisted extraction (MAE), power range of 400-800 W	15.1% from red-flesh dragon fruit peel using MAE with 800 W, 90 sec	Dao *et al.* (2021) [16]

Solvent ratio: 1:24 Extraction technique: Conventional extraction with ammonium oxalate 0.5 - 2 g Extraction pH: 4.9 Extraction temperature: 90°C, Extraction time: 90 min	The highest yield was obtained at 0.5 g of ammonium oxalate (26.64%).	Alia (2018) [2]
Solvent ratio: 1:25 Extraction pH: 2 to 5 adjusted with citric acid Extraction time: 30 to 120 min	The highest yield was obtained 120 min of extraction time with pH 3.5 and high degree of esterification was obtained at pH 5.	Tang *et al.* (2011) [68]
Solvent ratio: 1:40 Microwave-assisted extraction at power levels of 300-600 W with 5-10 min	Highest yield of 23.11% achieved at 600 W for 10 min.	Tongkham *et al.* (2017) [74]
Solvent ratio: 1:14.25-17.75 Extraction pH: 3.0-4.0 adjusted with citric acid Extraction temperature: 75°C Extraction time: 30-120 min	pH 4.0 with 120 min exhibit highest DE of more than 70%. pH of 3.5 3 with 60 min pectin yield of pectin 14.86%	Woo *et al.* (2010) [81]

Peel powder as a multifunctional ingredient in developing healthier, value-added food products. Peel flour enhances antioxidant and functional properties in bakery products like cookies with incorporation of 2% of dragon fruit peel powder without compromising the sensory and texture of the final product (Chumroenvidhayakul *et al.*, 2023) [13]. Peel extracts exhibit skin-protective antioxidant properties. Yuliawati *et al.* (2020) [83] formulated body butter with peel methanolic extract, showing favorable physical and biological activity. Pectin derived from dragon fruit peel has demonstrated favorable physicochemical characteristics, including high galacturonic acid content (73.26%), desirable gelling and emulsifying properties making it a viable alternative to conventional pectin sources such as citrus or apple (Liu *et al.*, 2023; Muhammad *et al.*, 2014; Septian *et al.*, 2024) [42, 63, 85].

In addition to antioxidant activity, dragon fruit peel exhibits anti-inflammatory and antibacterial properties. Foronda and Cajucom, (2023) and Manihurk *et al.* (2017) [20] demonstrated antibacterial activity against E. coli and S. aureus. Chumroenvidhayakul *et al.* (2025) [13] found that dragon fruit peel (DFP) has potential as a functional dietary supplement for supporting the prevention and management of metabolic disturbances and liver dysfunction caused by high intake of fat and fructose. Nurmahani *et al.* (2012) [45] confirmed the antibacterial efficacy of peel extracts from H. *polyrhizus* and H. *undatus* against multiple pathogens minimum inhibitory concentration of 1.25 to 10 mg/ml. Manihuruk *et al.* (2017) [38] demonstrated that applying peel extract to beef sausages reduced microbial growth while serving as a natural antioxidant and colorant. Hendra *et al.* (2019) [24] also observed strong antibacterial effects of pigment extracts, particularly against S. aureus, B. subtilis, E.coli, V. alginolyticus highlighting the contribution of betacyanins to antimicrobial activity. These findings support the potential of dragon fruit peel as a natural antibacterial and preservative agent in both food and therapeutic applications.

3. Application

3.1 Functional Applications

Dragon fruit peel powder has been successfully applied in various food products such as chicken and fish nuggets, mushroom nuggets, ice cream, and meat products due to its high fiber, antioxidant content, and natural pigments. In chicken nuggets, the addition of H. *undatus* peel powder improved moisture retention, emulsion stability, dietary fibre, cooking yield, inhibited microbial growth and oxidation without compromising texture and sensory qualities (Madane *et al.*, 2020) [36]. Similarly, in mushroom nuggets, the use of *Hylocereus polyrhizus* peel powder served as a natural colorant and functional fiber source, contributing to both nutritional and aesthetic improvements (Puspita, 2021) [50]. In the dairy sector, peel powder incorporated into low-fat ice cream improved antioxidant capacity, melt resistance, and overall sensory appeal, with 8% found to be the optimal level (Hafids *et al.*, 2019) [23]. Additionally, blending dragon fruit peel puree with soy whey in ice cream formulations enhanced functional properties without sacrificing taste with 10:90 ratio of soy whey and puree of dragon fruit peel (Putra *et al.*, 2024) [51]. In meat applications, red dragon fruit peel powder was used to replace pork back fat in alpaca sausages, achieving up to 65.7% fat reduction while preserving desirable texture and flavor (Corimayhua-Silva *et al.*, 2024) [15]. These findings support the potential of dragon fruit

3.2 Packaging and Nanomaterials

Studies are exploring the use of peel-derived components in bio-nanocomposites and edible films for active packaging (Homthawornchoo *et al.*, 2023) [26]. Several researchers have explored the development of biodegradable packaging materials from dragon fruit (*Hylocereus* spp.) peel. Homthawornchoo *et al.* (2023) [26] developed rice starch-based films enriched with 2% dragon fruit peel extract, enhancing antioxidant properties suitable for wrapping coconut-milk candy. Soy protein isolate films incorporated with betalain-rich red dragon fruit peel extract formulation, resulting in improved compact, dense, UV-blocking, antioxidant capacity, tensile strength, and reduced water vapor permeability (Prajapati and Jadeja, 2024) [49]. Pectin extracted from dragon fruit peel (yield ~11%) is suitable for biodegradable film formation. Addition of ethylene glycol reduced moisture content from 12-5.71% to 5.71-2.86% and improved flexibility and ease of film handling (Listyarini *et al.*, 2020). Biodegradable intelligent films using a chitosan-xyloglucan matrix enriched with betalains from dragon fruit peel. The film containing a 1:5 ratio of betalain extract to polymer blend (w/v) demonstrated the best performance, featuring strong mechanical integrity, visible pH-sensitive color change for spoilage indication, and antimicrobial activity against E. coli and S. aureus. These findings support its potential use as eco-friendly active packaging for preserving perishable foods (Permana *et al.*, 2025) [48]. A bioplastic prototype (Hylopoly-Bag) made from dragon fruit peel and polyvinyl acetate showed ~ 6.3% cellulose content, 17% water absorption, and ~92% bio-degradation within 28 days. The material also demonstrated suitable elasticity for bag applications (Agung *et al.*, 2024) [1]. Dragon fruit peel powder contains around 34.35% cellulose, indicating its promise as a renewable biopolymer. Additionally, the material exhibited thermal stability up to 204°C, supporting its suitability for bioplastic applications (Taharuddin *et al.*, 2022) [66]. Optimized pectin extraction methods and characterized the peel's cellulose content, highlighting its suitability for edible films and as a reinforcing agent in biocomposites. These multidisciplinary efforts illustrate the growing potential of dragon fruit peel valorization for sustainable packaging innovations.

4. Toxiological study on dragon fruit peel

Research studies were supported to the dragon fruit peel and their extract was safe to consume.Toxicological assessments of red dragon fruit (*Hylocereus polyrhizus*) peel extract indicate its general safety and potential protective effects against oxidative stress. Rizkifani *et al.* (2024) [57] conducted an acute oral toxicity test in Wistar rats and found no mortality or organ damage at doses up to 5,000 mg/kg, suggesting the extract is practically non-toxic. Similarly, Hor *et al.* (2012) [28] reported no adverse effects in rats following 28 day subchronic administration of methanol extract at the same dosage, establishing a NOAEL (No-Observed-Adverse-Effect Level) of 5,000 mg/kg/day. Ardhianditto *et al.* (2023) [5] demonstrated the extract's antioxidant capacity by showing significantly reduced malondialdehyde (MDA) levels in rats exposed to cigarette smoke, indicating a mitigation of oxidative stress. Thaiudom *et al.* (2021) [71] developed a natural colorant powder from the peel and confirmed its safety through heavy metal screening and antimutagenicity assays, supporting its potential for food applications. Additionally, Patel *et al.* (2024) [47] showed that combined aqueous extracts of Nigella sativa seeds and H. *polyrhizus* fruit caused no histopathological changes in rats at high doses, further confirming the extract's non-toxic nature. Collectively, these studies suggest that dragon fruit peel is not only safe for consumption but also exhibits promising antioxidant and protective properties, supporting its valorization in food, nutraceutical, and pharmaceutical applications.

5. Conclusion

Dragon fruit peel, a typically discarded by-product of the fruit processing industry, holds significant potential as a valuable source of bioactive compounds, particularly betacyanins, flavonoids, phenolic acids, dietary fiber, and pectin. The growing body of research underscores its antioxidant, antimicrobial, anti-inflammatory, and functional properties, which can be harnessed for applications in food, nutraceuticals, cosmetics, and sustainable packaging. Emerging green extraction techniques such as ultrasound- and enzyme-assisted extraction have demonstrated effectiveness in maximizing yield, purity, and functional stability of these compounds, aligning with circular bio-economy principles and sustainable development goals.

Despite its promise, the large-scale valorization of dragon fruit peel faces challenges including extraction scalability, compositional variability, regulatory hurdles, and limited consumer awareness. Addressing these issues through standardization of processing methods, interdisciplinary research, and industry collaboration is critical to fully unlock its potential. Overall, dragon fruit peel represents a sustainable, multifunctional resource with wide-ranging applications, encouraging a shift toward zero-waste utilization and added-value innovation in agri-food systems.

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