

Valorization of Dragon Fruit Peel Waste Extraction, Functional Properties and Food Applications

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Dragon fruit (*Hylocereus spp.*) is widely appreciated for its distinctive appearance and health benefits. However, its thick outer peels are generally thrown away as trash, which ends up creating a huge environmental burden. To tackle this problem, this study explores how we can recycle these discarded peels and extract the valuable nutrients hidden inside them. We tested several modern, eco-friendly extraction methods—specifically looking at microwave-assisted, ultrasound-assisted, and supercritical fluid techniques—to see which ones give the best results and highest yield. After extracting the raw material, we used advanced filtration and chromatography to clean and concentrate the beneficial compounds. The final analysis shows that these peel extracts have incredibly strong antioxidant, germ-fighting, and swelling-reducing properties, along with potential cancer-fighting benefits. Because of these qualities, they can easily replace artificial chemicals as natural food dyes, healthy ingredients in drinks, or safe mixes for skincare and medicines. In short, reusing dragon fruit peels does two great things at once, it cuts down waste and helps factories move away from harsh synthetic chemicals toward a cleaner, eco-friendly future.

Keywords: Dragon fruit peel waste, betacyanins, green extraction, bioactive compounds, natural compounds and functional food applications.

Introduction and Waste Generation

Dragon fruit, commonly known as pitaya, is a fruit that comes from the *Hylocereus cactus* family. There are three main types of this fruit that farmers grow. The first one is *Hylocereus undatus*, which has a pink skin and white pulp inside. The second one is *Hylocereus costaricensis*, which has deep red flesh. The third one is *Hylocereus megalanthus*, which has a yellow peel and white flesh. At first, dragon fruit only grew in Central America. But now, because many people want to eat it for its health benefits and unique taste, farmers grow it on a very large scale. You can find large dragon fruit farms in Southeast Asia, Australia, and South America. In the food processing industry, factories use the inner edible pulp of the fruit to make many different food items. They use the pulp to manufacture commercial products like fruit juices, sweet jams, jellies, ready-to-serve beverages, dried fruit powder, chips, and yogurt. Because the popularity of these processed food products is growing rapidly every year, factories have to process thousands of tons of fresh dragon fruits.

During this industrial processing of dragon fruit, a major problem arises. To extract the inner pulp for making food products, factories must peel the fruit. The thick outer peel represents about 30% to 35% of the total weight of the fruit. This means that for every ton of fruit processed, more than 300 kilograms of peel becomes waste. Right now, most food processing factories just throw this peel away. It is treated as agro-industrial waste. Industries usually dump this massive amount of organic waste directly into open landfills. Some factories give a very small amount of it to animals as cheap feed or mix it with soil to make compost. Dumping raw dragon fruit peels in landfills creates severe environmental pollution. High

moisture and sugar content leads to rapid microbial degradation. This rotting waste creates a terrible smell and attracts harmful insects, flies, rats, and bacteria. To solve this waste problem, scientists are working on valorization. Valorization simply means taking a waste material and turning it into something valuable. Studies show that dragon fruit peel waste is not useless. It contains high amounts of dietary fibers, polyphenols, and betacyanins, which are natural red pigments (Andrade *et al.*, 2024). Food factories can extract these useful components from the peel waste using simple machines. Then, they can use them back in the food line as natural food colors, thickeners, and stabilizers. This reduces landfill pollution and helps factories save money.

Extraction of Bioactive Compounds from Dragon Fruit Peel

Dragon fruit peel is a highly valuable agricultural byproduct that contains a dense concentration of phytochemicals/bioactive compounds. To isolate these high-valuable compounds, specialized extraction techniques are required from the tough plant structure using specific extraction techniques. The primary goal of this process is to maximize the amount of nutrients recovered—known as the extraction yield—while ensuring that the natural colors and health benefits are not destroyed by high heat or harsh processing conditions. Because these compounds are sensitive to their environment, choosing the right method is critical to keeping them active and useful.

Traditionally, scientists use conventional solvent extraction, which involves soaking the dragon fruit peel in liquids like water, ethanol, or a mixture of both. For example, research demonstrates that soaking the peel in a 50:50 mixture of ethanol and water yields a reliable number of red-violet pigments. Acidified water extraction can also be employed under controlled pH conditions maintaining a low pH of 3.6 at a warm temperature of 30°C for just 10 minutes can efficiently draw out these pigments into the liquid. However, conventional methods can sometimes take hours, prompting the development and use of much faster, advanced technologies.

To enhance extraction yield and efficiency, advanced methods such as Ultrasound-Assisted Extraction are implemented. This technique uses high-frequency sound waves to create tiny acoustic cavitation, which disrupt cell wall of the peel, allowing the trapped nutrients to dissolve rapidly into the solvent. Studies show that using this ultrasound method with a 50% ethanol solvent system for 25 minutes provides the most optimal balance, resulting in highly concentrated yields of antioxidants and plant pigments. Another advanced method is Supercritical Fluid Extraction, which uses pressurized gases like carbon dioxide mixed with ethanol. While this is a clean and eco-friendly technology, data indicates that standard ultrasound and liquid mixtures still tend to pull out a higher overall volume of pure pigments. Once these sensitive compounds are successfully extracted into a liquid form, they face a new challenge because they degrade quickly when exposed to light, air, and room temperatures. To prevent this, scientists use stabilization methods like micro-encapsulation, where the liquid extract is blended with a food-safe starch like maltodextrin. This starch acts as a protective shield, locking in the nutrients and preserving up to 80% of the active antioxidants. Finally, the choice of drying technique determines the ultimate quality of the product. While traditional tray drying or vacuum drying uses heat that can fade the natural colors and destroy vitamins, freeze-drying is the superior method. By freezing the extract and removing moisture through a vacuum at ultra-low temperatures, freeze-drying perfectly locks in the vibrant red color and retains the absolute highest levels of raw antioxidant power, ensuring the final powder remains potent for a very long time.

Nutritional and Functional Properties in Food Applications

The peel is an exceptional source of dietary Fiber, containing approximately 34.35% cellulose, which provides structural and functional dietary benefits. It is heavily loaded with antioxidants, particularly betalains, which give the red dragon fruit peel its vibrant purple-red color. Betalains function both as a natural colorants and potential free-radical scavengers, reducing internal oxidative stress in the body.

In food processing, the peel powder acts as a powerful functional agent that improves food quality, shelf life, and nutritional value. When added to chicken nuggets, it significantly enhances moisture retention, emulsion stability, dietary Fiber, and cooking yield. It also naturally delays fat oxidation and stops microbial growth, keeping the meat fresh longer without changing its texture or taste. In formulated foods, it improves texture, color stability and dietary Fiber content. Furthermore, it works as an excellent fat replacer; adding the peel powder to sausages can replace pork back fat to achieve up to a 65.7% fat reduction while perfectly preserving the foods original juiciness, Flavors, and texture.

Toxicological and Safety Profile

Multiple scientific evaluations confirm that dragon fruit peel extract is completely non-toxic and safe for consumption. In acute oral toxicity tests, rats showed zero mortality or organ damage at high doses up to 5,000 mg/kg. Subchronic 28-day tests established a safe No-Observed-Adverse-Effect Level (NOAEL) at this same maximum dosage. Medically, the extract shows strong protective qualities; it significantly lowers malondialdehyde (MDA) levels in subjects exposed to cigarette smoke, meaning it actively repairs and mitigates oxidative damage. Thorough heavy metal screenings and antimutagenicity assays further prove that the peel is a clean, reliable, and completely safe functional resource.

Sustainability and Environmental Considerations

The utilization of dragon fruit peel waste for pectin extraction contributes to waste reduction and aligns with the principles of the circular economy. Extracting valuable compounds from the waste prevents the peels from being disposed of as waste, thereby reducing the environmental burden associated with waste management. Dragon fruit peel waste can have significant environmental impacts if not properly managed. When disposed of in landfills, it can contribute to the generation of greenhouse gases, such as methane, which is a potent contributor to climate change. Additionally, the decomposition of organic matter in the waste can release pollutants into soil and water, negatively impacting ecosystems. However, its environmental impacts can be minimised by valorizing dragon fruit peel waste through pectin extraction. Pectin extraction provides a beneficial use for the waste material, reducing the need for landfilling and mitigating the associated environmental issues. Moreover, the residual biomass left after pectin extraction has the potential for bioenergy production. Biomass can be converted into biofuels, such as biogas or bioethanol, through anaerobic digestion or fermentation. This bioenergy production from residual biomass can contribute to renewable energy generation, reducing reliance on fossil fuels and mitigating greenhouse gas emissions. Overall, using dragon fruit peel waste for pectin extraction contributes to sustainability by reducing waste, minimizing environmental impacts, and offering the potential for bioenergy production from residual biomass. It aligns with the principles of the circular economy and promotes a more sustainable and environmentally conscious approach to waste management.

Future Perspectives and Challenges

Peels from dragon fruit have much potential for usage in many ways, and they may be extracted and valued using eco-friendly methods. It is still difficult to realize the full potential of dragon fruit peels, and there still need to be explored. Future expansion depends critically on improving the efficacy of green extraction methods. While MAE, UAE and SFE can extract essential compounds from dragon fruit peels, further amplification and optimization are needed.

Researchers must optimize the extraction parameters to increase output, quality, and efficiency while ensuring the optimum use of the bioactive components in dragon fruit peels. A key element is the identification of novel bioactive chemicals. It is good knowledge that dragon fruit peels contain various bioactive substances, such as polyphenols, antioxidants, and dietary fibre. However, it is still unclear precisely what these substances do or whether they positively affect health.

Therefore, a comprehensive analysis and identification of the distinctive bioactive compounds in dragon fruit peels may provide crucial information about their functional features and broaden the spectrum of potential applications. It is necessary to look into innovative value-added dragon fruit peel extract products in addition to finding bioactive compounds. Conventional usages like food colourants and natural cosmetics are well known, but additional studies may provide particular functional components, nutraceuticals, medications, and environmentally friendly materials.

Dragon fruit peels will become more valuable economically, and this variety in product development will promote environmentally friendly methods and result in cutting-edge products that meet consumer demand. The scalability and regulatory compliance concerns must be resolved to enable the scaling up and commercialization of dragon fruit peel extraction processes. Moving from laboratory-scale extraction processes to industrial-scale extraction operations requires equipment optimization, cost-effectiveness analyses, and ensuring regulatory compliance. Collaboration between researchers, industry players, and policymakers is necessary to allow the development and commercialization of dragon fruit peel extraction technologies.

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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