

From Waste to Wealth: Unlocking the Potential of Dragon Fruit By-Products

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Dragon fruit by-products are valuable sources of bioactive compounds with immense potential for value addition. Green postharvest technologies enable their conversion into functional foods, nutraceuticals, biodegradable packaging, and bioenergy. Transforming agricultural waste into sustainable, high-value products while promoting a circular bioeconomy and environmental sustainability.

Introduction

The rapid growth of the food processing industry has led to a significant increase in agricultural and food waste, posing serious environmental and economic challenges. According to the Food and Agriculture Organization (FAO), nearly one-third of the food produced globally is lost or wasted every year. Instead of treating these residues as waste, they can be transformed into valuable products through waste valorisation, supporting sustainable agriculture and a circular bioeconomy. Dragon fruit (*Selenicereus* spp.), popularly known as pitaya, is an emerging tropical fruit valued for its attractive appearance, pleasant flavour, and rich nutritional composition. It is widely cultivated in countries such as Vietnam, Thailand, Indonesia, Malaysia, and India. The fruit is an excellent source of dietary fibre, vitamin C, polyphenols, flavonoids, and betalains, which are known for their antioxidant and health-promoting properties. Besides fresh consumption, dragon fruit is processed into juices, jams, beverages, and other value-added products.

Processing of dragon fruit generates a considerable amount of by-products, mainly peels, seeds, and pulp residues. The peel alone constitutes nearly one-third of the total fruit weight and is often discarded, contributing to environmental pollution. However, these by-products are rich in pectin, dietary fibre, natural pigments, phenolic compounds, and healthy seed oils, making them valuable raw materials for developing functional foods, nutraceuticals, cosmetics, biodegradable packaging, animal feed, compost, and biofuels. Converting dragon fruit by-products into high-value products not only reduces waste and environmental pollution but also creates additional income opportunities for farmers and food industries. This "waste-to-wealth" approach promotes sustainable resource utilisation.



Figure 1. Value addition of dragon fruit by-products through postharvest processing

Biochemical compounds Hidden in Dragon Fruit Waste

Although dragon fruit is mainly consumed for its sweet and colourful pulp, a significant portion of the fruit about 30–40% is discarded as peel, seeds, and pulp residues. These by-products, once considered waste, are now recognised as valuable sources of nutrients and bioactive compounds with immense industrial and commercial potential. The peel, which forms the largest fraction of the waste, is particularly rich in dietary fibre, pectin, polyphenols, flavonoids, vitamin C, and natural pigments. Among these, pectin is an important polysaccharide widely used in the food industry as a gelling, thickening, and stabilising agent in products such as jams, jellies, and confectioneries. Dragon fruit peel has emerged as an alternative and sustainable source of high-quality pectin, reducing dependence on conventional sources (Chua et al., 2020). Betalains, the natural pigments that give dragon fruit peel its vibrant red and purple hues, are another significant bioactive component. These water-soluble pigments are increasingly being used as natural food colourants in beverages, dairy products, bakery items, and confectioneries. Besides imparting colour, betalains possess strong antioxidant, anti-inflammatory, antimicrobial, and potential anticancer properties, making them attractive ingredients for functional foods and nutraceuticals.

Dragon fruit peel is also abundant in phenolic compounds and flavonoids, which help neutralise harmful free radicals and protect the body from oxidative stress. These bioactive compounds have gained attention for their potential role in promoting human health and extending the shelf life of food products through their natural antioxidant activity (Le, 2022). Dragon fruit seeds contain significant amounts of healthy oils enriched with linoleic and linolenic acids, as well as vitamin E compounds. Owing to their nutritional and functional properties, these seed oils are increasingly being explored for use in food products, pharmaceuticals, and cosmetic formulations. The rich profile of bioactive and biochemical compounds in dragon fruit by-products demonstrates their considerable potential as value-added resources rather than waste materials. By recovering valuable compounds such as pectin, betalains, phenolics, flavonoids, dietary fibre, and seed oil, these by-products can be transformed into a wide range of value-added products. Such utilisation not only reduces environmental pollution but also promotes sustainable resource management and creates new economic opportunities under the "From Waste to Wealth" concept.



Figure 2. Bioactive rich powder prepared from dragon fruit peel

Health-Promoting Properties of Dragon Fruit By-products

Dragon fruit by-products, especially the peel and seeds, are not merely processing waste but are rich sources of bioactive compounds that offer numerous health benefits. These valuable components, including betalains, polyphenols, flavonoids, pectin, dietary fibre, vitamins, and

essential fatty acids, have attracted considerable interest for their potential applications in the food, pharmaceutical, and cosmetic industries. One of the most important properties of dragon fruit by-products is their strong antioxidant activity. Natural antioxidants such as betalains and phenolic compounds help neutralise harmful free radicals, reducing oxidative stress and protecting cells from damage. These compounds also contribute to the prevention of chronic diseases and improve the shelf life of food products. Dragon fruit peel also exhibits antimicrobial activity, helping to inhibit the growth of certain harmful bacteria and fungi. This makes it a promising natural ingredient for food preservation and the development of antimicrobial products.

The dietary fibre and oligosaccharides present in dragon fruit act as prebiotics, promoting the growth of beneficial gut bacteria and supporting digestive health. Maintaining a healthy intestinal microbiota promotes efficient digestion, facilitates nutrient uptake, and contributes to general well-being. The bioactive constituents present in dragon fruit by-products, including betalains, flavonoids, and phenolic compounds, exhibit potential anti-inflammatory and anticancer activities. These compounds may help alleviate inflammation and inhibit the growth of cancer cells. Further clinical studies are required to validate these beneficial effects in humans. The diverse biological properties of dragon fruit by-products demonstrate that these materials are far more valuable than ordinary agricultural waste. Their incorporation into functional foods, nutraceuticals, natural preservatives, and healthcare products offers a sustainable way to improve human health while reducing environmental waste.

Modern technologies for converting Dragon fruit waste into value-added products

The successful utilisation of dragon fruit by-products depends on efficient and environmentally friendly processing technologies. Traditionally, valuable compounds were extracted using chemical solvents and conventional extraction methods. Although effective, these techniques are often time-consuming, require large quantities of solvents, and may have negative environmental impacts. Today, the focus has shifted towards green extraction technologies, which are safer, faster, and more sustainable. Among these, microwave-assisted extraction (MAE) and ultrasound-assisted extraction (UAE) are widely used to recover valuable compounds such as pectin, betalains, phenolic compounds, and antioxidants from dragon fruit peel. These techniques improve extraction efficiency, reduce processing time, minimise solvent consumption, and help preserve the quality of sensitive bioactive compounds (Boyapati et al., 2023).

Another promising technique is supercritical fluid extraction (SFE), which uses environmentally friendly fluids, such as carbon dioxide, to obtain high-quality pigments, antioxidants, and essential oils without leaving harmful solvent residues. Likewise, the use of green solvents such as water, ethanol, and other biodegradable solvents is gaining popularity because they are safe, eco-friendly, and suitable for food and pharmaceutical applications. In addition to extraction technologies, biological processes using beneficial microorganisms play an important role in waste valorisation. Through microbial fermentation, dragon fruit waste can be converted into bioethanol, biogas, organic acids, enzymes, and other bio-based products, contributing to renewable energy production and sustainable waste management. The adoption of these advanced technologies not only improves the recovery of valuable bioactive compounds but also supports green chemistry, sustainable processing, and the circular economy. By transforming agricultural waste into useful products, these innovations create new business opportunities while reducing environmental pollution and promoting resource-efficient agriculture.

Industrial applications of Dragon fruit by-products

The growing demand for sustainable and eco-friendly products has created new opportunities for the utilisation of dragon fruit by-products. Rich in bioactive compounds and natural

polymers, these residues are now being transformed into a wide range of value-added products across the food, energy, packaging, pharmaceutical, and cosmetic industries.

Food Industry

Dragon fruit peel is an excellent source of dietary fibre, pectin, betalains, and antioxidants, making it a valuable ingredient for developing functional foods. Peel powder and extracts have been successfully incorporated into cookies, bread, noodles, dairy products, ice cream, meat products, and beverages to improve nutritional quality, natural colour, antioxidant capacity, and shelf life. The use of peel as a natural food colourant also offers a healthier alternative to synthetic additives.

Renewable Bioenergy

Instead of being discarded, dragon fruit processing waste can be converted into renewable biofuels through microbial fermentation and anaerobic digestion. The by-products can be utilised to produce bioethanol, biogas, biohydrogen, and even bioelectricity, providing sustainable energy while reducing dependence on fossil fuels. This approach also helps minimise waste disposal problems and greenhouse gas emissions.

Biodegradable Packaging

With increasing concerns over plastic pollution, dragon fruit peel has emerged as a promising raw material for producing biodegradable packaging materials. The pectin and other natural polysaccharides present in the peel can be used to manufacture bioplastics and biodegradable films, offering an environmentally friendly alternative to conventional plastics (Taharuddin et al., 2023).

Pharmaceutical and Cosmetic Applications

The abundance of betalains, polyphenols, flavonoids, vitamin C, and essential fatty acids makes dragon fruit by-products valuable ingredients for the pharmaceutical and cosmetic industries. These bioactive compounds are being explored for use in nutraceuticals, dietary supplements, skin-care products, natural antioxidants, and herbal formulations due to their antioxidant, antimicrobial, and anti-inflammatory properties. The diverse industrial applications of dragon fruit by-products demonstrate that agricultural waste can be transformed into valuable commercial products. By converting waste into food ingredients, renewable energy, biodegradable materials, and health-promoting products, the dragon fruit industry can support sustainability, resource efficiency, and the circular economy, truly reflecting the concept of "From Waste to Wealth."

Future Perspectives

As the demand for sustainable agriculture and eco-friendly products continues to grow, the effective utilisation of dragon fruit by-products offers immense opportunities for the future. Instead of treating peels, seeds, and other residues as waste, they can be transformed into valuable products using green technologies and biological processing methods. This approach not only reduces environmental pollution but also supports the principles of a circular economy, where waste is converted into useful resources. Future research should focus on developing cost-effective and large-scale technologies for extracting valuable compounds such as pectin, betalains, antioxidants, and seed oils. Greater collaboration among researchers, industries, entrepreneurs, and policymakers will help commercialise these innovations and promote zero-waste processing in the dragon fruit industry. By embracing the "Waste to Wealth" concept, dragon fruit by-products can create new income opportunities for farmers, support sustainable industries, and contribute to a greener and more resource-efficient future.

Conclusion

Dragon fruit by-products, once considered agricultural waste, are now recognised as valuable resources rich in pectin, betalains, dietary fibre, antioxidants, and essential oils. Their utilisation in the production of functional foods, natural colourants, nutraceuticals, biofuels, biodegradable packaging, and other value-added products demonstrates their immense economic and environmental potential. Adopting green extraction technologies and

sustainable bioconversion approaches can transform these by-products into commercially valuable products while reducing waste and environmental pollution. This "Waste to Wealth" approach not only supports a circular economy but also creates additional income opportunities for farmers, processors, and entrepreneurs. With continued research, technological innovation, and industry participation, dragon fruit by-products can play a significant role in sustainable agriculture, resource conservation, and the development of eco-friendly industries, proving that today's waste can become tomorrow's wealth.

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