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From waste to wealth: exploring recent trends in tropical fruit waste utilization

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Abstract

The escalating demand for food due to a burgeoning global population has heightened the strain on natural resources, leading to significant challenges in sustainable food production and waste management. Tropical regions, abundant in fruit trees, contribute significantly to this challenge, generating substantial fruit waste during production and consumption processes. This review paper examines the current trends in the utilization of tropical fruit waste, drawing insights from recent research and developments. Through an exploration of bioactive compounds extracted from fruit waste and their potential applications, this paper aims to inspire further innovation in this burgeoning field. Various valorization methods are discussed, highlighting their potential for converting fruit waste into valuable resources. Additionally, the paper explores emerging extraction techniques such as Microwave-Assisted Extraction (MAE), Supercritical Fluid Extraction (SFE), Ultrasonic-Assisted Extraction (UAE), Pressurized Liquid Extraction (PLE), and High Hydrostatic Pressure Technique (HHP), offering promising avenues for maximizing the utilization of tropical fruit waste. Furthermore, case studies on the utilization of specific tropical fruits showcase the diverse applications and value-creation opportunities in this field. This review underscores the importance of sustainable resource management and the potential of fruit waste utilization to address both environmental and food security challenges.

Keywords: Waste management, tropical fruits, current trends and food security

Introduction

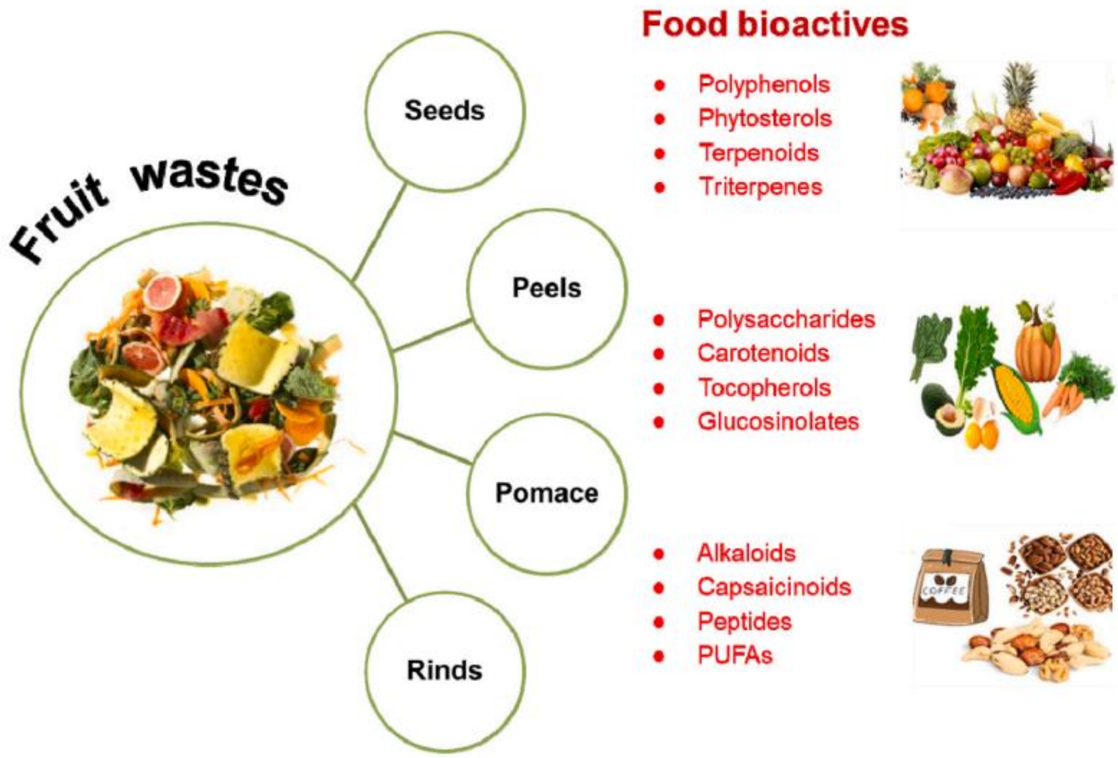
With the world population projected to reach 9.7 billion by 2050, the demand for food is escalating, particularly in developing countries (Matharu *et al.,* 2016). This surge in demand exacerbates the strain on already limited natural resources, leading to significant challenges in sustainable food production and waste management. According to the Food and Agriculture Organization of the United Nations (FAO), approximately 14% of the world's food production was lost or wasted post-harvest in 2019, resulting in staggering economic losses (FAO, 2019). Furthermore, more than 50% of food waste comprises fruits and vegetables, underscoring the global magnitude of the issue (De Laurentiis *et al.,* 2018).

In tropical regions across the globe, verdant landscapes foster the growth of a diverse array of evergreen fruit trees, yielding an abundant supply of tropical fruits. Mangoes, pineapples, papayas, and jackfruits are among the prominent fruits dominating the global market, with mangoes leading in annual production exceeding 30 million tonnes, largely driven by agricultural powerhouses like India, China, and Thailand (Pedraza-Chaverri *et al.,* 2008). However, this bountiful harvest is accompanied by a significant challenge – the management of substantial waste generated during both production and consumption processes.

Fruits like durian, mangosteen, and jackfruit yield considerable waste due to their large seeds and thick rinds, often constituting more than half of the fruit's total weight [Table- 1]. These fruit wastes, characterized by high moisture content and rich organic composition, pose pressing environmental concerns. They emit greenhouse gases during decomposition and create fertile breeding grounds for pests and bacteria, exacerbating environmental degradation (Dhillon *et al.,* 2013).

The disposal of tropical fruit waste presents not only an environmental challenge but also a missed opportunity for resource optimization and value addition. Fruit waste holds potential for conversion into various valuable products such as vermiculture, compost, enzymes, pectin, essential oils, dietary fibers, carotenoids, flavonoids, edible fungi, bioethanol, and biogas (Ding *et al.,* 2023). The variation in the composition of bioactive compounds across different fruit wastes is illustrated in Figure 1 (Ritika *et al.,* 2024). Additionally, these waste products have the capacity to enhance the nutritional content of food items. Extracting valuable bioactive compounds from fruit waste not only mitigates environmental harm but also meets the growing demand for natural health supplements and additives. However, many parts of tropical fruits, including rinds, seeds, and peels, are often discarded despite containing valuable bioactive compounds essential for various applications, including food additives, dietary supplements, and pharmaceuticals.

In this review paper, we aim to provide an in-depth exploration of the current trends in tropical fruit waste utilization, drawing insights from recent research and developments. By analyzing the recovery and utilization of bioactive compounds from tropical fruit wastes, we seek to inspire further innovation in this burgeoning field. Through a comprehensive examination of bioactive compounds found in various parts of tropical fruits and the analytical methodologies employed for their quantification, we endeavour to shed light on the diverse opportunities and challenges in tropical fruit waste utilization.



(Fig-1 Variation in the composition of bioactive compounds across different fruit wastes)

Table 1: Percent of flesh, rind/skin, and seed in tropical fruits. (Cheok *et al., 2016)*

Fruit	Flesh (%)	Rind/Skin (%)	Seed (%)	References
Durian	20–35	55–66	5–15	Siriphanich, 2011
Mangosteen	25–29	60–65	6–11	Chen *et al.*, 2011; Ketsa and Paull, 2011
Rambutan	34–54	37–62	4–9	Sirisompong *et al.*, 2011.
Mango	60–75	11–18	14–22	Mitra *et al.*, 2013
Jackfruit	30–35	55–62	8–10	Saxena *et al.*, 2011
Papaya	80–90	10–20	10–20	Lee *et al.*, 2011; Parni and

				Verma, 2014
Passion fruit	44–54	45–52	1–4	Arjona *et al.*, 1991; Almeida *et al.*, 2014
Dragon fruit	54–74	22–44	2–4	Esquivel *et al.*, 2007; Liaotrakoon *et al.*, 2013b
Pineapple	60–71	29–40	—	Ketnawa *et al.*, 2012

Bioactive substances present in tropical fruit waste.

Research examining the bioactive compounds found in different parts of tropical fruits provides valuable insights for both scientists and food manufacturers, offering a basis for further exploration of their potential applications. Notably, studies have shown significant variations in the composition of bioactive compounds across different fruit components, highlighting the importance of recovering fruit waste for food applications while also mitigating environmental impacts.

These findings highlight the diverse array of bioactive compounds present in different parts of tropical fruits and underscore the potential nutritional and functional benefits of utilizing fruit waste in various food applications.

Table 2. Bioactive substance ingredients from tropical fruit wastes.

Bioactive compound	**Fruit**	**Function**	**Reference**
Carotenoids	Orange (peels, pulp)	Pigment, Radical scavenger	Casarotti *et al.*, 2018
	Guava, orange, and passion fruit by-products		
Flavonoids	Satsuma (Peels)	Antibacterial, Antioxidant	Anosa *et al.*, 2011
	Orange/Lemon (Peels, Pulp)	Anti-parasitic, Antioxidant	Bleve *et al.*, 2008
	Banana (Peels, Roots)	Food color additives	Rebello *et al.*, 2014m
Pectins	Citrus (peels)	Thickening agent and emulsification, Food additives	Wang *et al.*, 2018
Dietary Fiber	Tamarind seeds	Binders, Texturizers	Al-sayed *et al.*, 2013
	Grapfruit peels	Low-calorie bulking ingredient	Wedamulla *et al.*, 2022
Amino acids and proteins	Kinnow mandarin waste, pineapple peels, papaya peels	Protein supplementation	El-safy *et al.*, 2012

Glycosides	Banana stem	Anti-cancer, Antioxidant	Milner *et al.*, 2010
Polyphenols	Banana Peels	Antimicrobial activity	Rebello *et al.*, 2014
	Mango Kernel		Matua *et al.*, 2017
	Orange (Peels, Pulp)		Adiamo *et al.*, 2018

Valorization of tropical fruit wastes: exploring bioactive compounds and potential applications:

Tropical fruits like mango, jackfruit, papaya, passion fruit, and dragon fruit are indeed preferred for their delightful taste and rich nutritional profiles. However, despite their popularity, a significant portion of these fruits, including their peels and seeds, often goes underutilized, leading to substantial waste. The valorization process involves extracting the bioactive compounds from the fruit wastes (table 2) through methods like solvent extraction, supercritical fluid extraction, or enzymatic extraction. Once extracted, these compounds can be incorporated into various products to enhance their nutritional value or functionality.

For example, fruit peel extracts rich in antioxidants can be used as natural preservatives in food products to extend their shelf life. Seed extracts with antimicrobial properties can be used in the development of antimicrobial films for food packaging, reducing food spoilage and increasing food safety. Additionally, bioactive compounds from tropical fruit wastes can be formulated into dietary supplements or skincare products to promote health and wellness.

Anaerobic digestion: harnessing energy from tropical fruit waste

Anaerobic digestion (AD) emerges as a promising technology for converting tropical fruit waste into biogas and bio-methane. The process involves biochemical reactions by anaerobic microorganisms, resulting in the production of organic acids, ethanol, hydrogen, carbon dioxide, and methane. With its high moisture content and biodegradability, tropical fruit waste is well-suited for AD, offering a renewable energy source for various applications.

Fermentation: bioethanol production from tropical fruit waste

Fermentation processes offer an alternative route for utilizing tropical fruit waste in energy production. By converting fruit and vegetable waste into bioethanol, fermentation reduces reliance on conventional feedstocks like corn or wheat. Pre-treatment methods enhance the digestibility of lignocellulosic materials, improving the efficiency of bioethanol production from tropical fruit waste.

Incineration: converting tropical fruit waste into heat and energy

Incineration represents a mature technology for converting tropical fruit waste into heat and energy through combustion. While effective in waste volume reduction, incineration raises concerns about emissions of harmful substances such as dioxins and heavy metals. Nonetheless, advancements in emission control systems and waste heat recovery have contributed to mitigating environmental impacts.

Pyrolysis and gasification: thermal conversion of tropical fruit waste

Pyrolysis and gasification offer thermal conversion pathways for tropical fruit waste, yielding bio-oil, syngas, and char. Operating at high temperatures in the absence of oxygen, these processes enable the conversion of carbon-based waste into valuable energy products. Nutshells and other fruit residues have shown promise as feedstocks for pyrolysis and gasification.

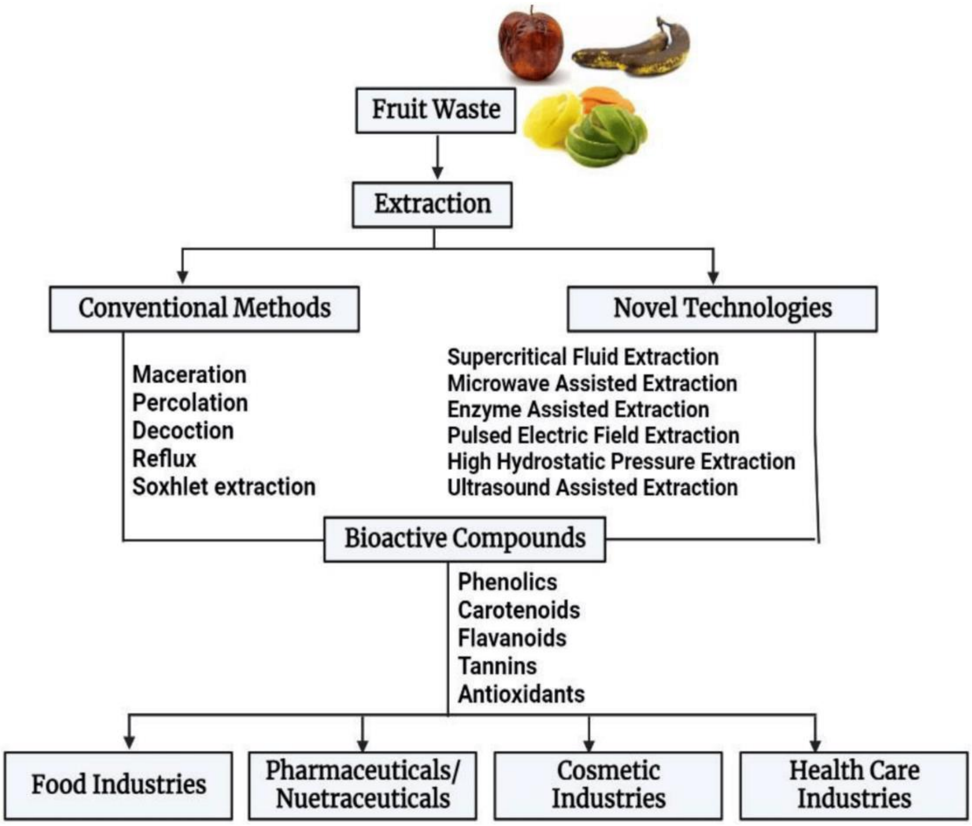
Hydrothermal carbonization (HTC): sustainable treatment of tropical fruit waste

Hydrothermal carbonization (HTC) provides a sustainable treatment option for high-moisture content tropical fruit waste. Operating at relatively low temperatures and pressures, HTC converts fruit and vegetable residues into bioenergy and hydrochar. This process offers several advantages, including odour reduction, nutrient recovery, and carbon sequestration, making it an attractive option for tropical fruit waste management.

Exploring biorefinery technologies for the detection and measurement of bioactive compounds in tropical fruit wastes:

Recent scientific inquiries have delved into the bioactive compounds present in these fruit by-products, uncovering their immense potential for various applications across diverse industries. Utilizing waste from tropical fruits presents a promising avenue for harnessing bioactive compounds. The extraction of these compounds often requires specific processing techniques, with some innovative methods coming to the fore. These techniques play a pivotal role in efficiently extracting bioactive compounds from fruit and vegetable waste.

Traditional extraction methods, while time-tested, often suffer from drawbacks such as high solvent consumption and lengthy extraction times, leading to increased energy usage. To mitigate these limitations, emerging technologies have been developed, offering advantages such as enhanced extraction capacity and reduced treatment times. These technologies can be classified into two main categories: traditional methods and novel techniques.



(**Fig-2**: Flowchart of methods of fruit waste extraction)

Microwave-Assisted Extraction (MAE) utilizes magnetic and electric fields, along with microwave heating, to directly impact polar materials. It's known for its ability to achieve high extraction yields in relatively short timeframes. For instance, studies have demonstrated that MAE can significantly enhance the extraction yield of antioxidants from mango peel compared to traditional methods (Dorta *et al.*, 2013).

Supercritical Fluid Extraction (SFE) employs carbon dioxide as the main solvent, leveraging its lower viscosity and higher diffusivity to improve extraction yields. This method has been successful in extracting various compounds from fruit and vegetable waste, including lycopene and β-carotene from tomato peel and seeds (Sabio *et al.*, 2003).

Ultrasonic-Assisted Extraction (UAE) accelerates the release of active ingredients using high-frequency sound waves, which penetrate cell walls and enhance extraction efficiency. Studies have shown that UAE can effectively extract bioactive compounds from various by-products, such as flavanones and carotenoids (Wang *et al.*, 2019).

Pressurized Liquid Extraction (PLE) applies pressure to raise the temperature above the solvent's normal boiling point, resulting in faster extraction times and reduced solvent consumption. This method has been used successfully to extract procyanidin from red grape pomace (Monrad *et al.,* 2010).

High Hydrostatic Pressure Technique (HHP) increases cell permeability through high-pressure cavitation, promoting the release of bioactive substances. Studies have demonstrated its efficacy in extracting sulforaphane from raw broccoli and pectin from pomelo peels (Guo *et al.,* 2017).

These novel extraction techniques offer promising avenues for maximizing the utilization of tropical fruit waste, contributing to both environmental sustainability and economic viability.

The world's increasing population and the consequent demand for energy security have underscored the importance of sustainable resource management. This has led to the promotion of concepts like "reduce, re-use, recycle, and regenerate" to enhance environmental sustainability. Tropical fruit waste, abundant in many regions, represents a valuable yet underutilized resource that could contribute significantly to waste reduction and renewable energy generation.

Waste utilization of several tropical fruits:

Durian (*Durio Zibethinus*) Waste Utilization:

Durian, often hailed as the "king of fruits," is renowned for its rich, creamy pulp and pungent aroma. Beyond its culinary allure, durian contains a wealth of essential minerals such as potassium, magnesium, sodium, and calcium, along with vitamins A, β-carotene, and C (Ho and Bhat, 2015). However, a significant portion of durian comprises non-edible parts, ranging from 60% to 81% of its total weight (Siriphanich, 2011). This abundance of waste has prompted extensive research into transforming durian biomass into valuable commodities.

One notable avenue of exploration is the utilization of durian peel, which has found diverse applications across several industries. From serving as biosorbents (Foo and Hameed, 2011a). and insulators to yielding agro-pectin derivatives and polysaccharide gels, durian peel has emerged as a versatile resource. Valuable compounds like pectin, polysaccharide gel, and fiber are extracted from durian peel, offering potential applications in food additives, pharmaceuticals, and cosmetic formulations.

Through efficient extraction methods, pectin yields ranging from 0.13% to 0.71% have been achieved, as confirmed by FTIR analysis. These extracted pectins have been effectively transformed into biopolymer films with diverse characteristics, including thicknesses between 0.01 and 0.07 and transparency levels spanning from 7.40% to 40.50%. Notably, these biopolymer films exhibit considerable tensile strengths ranging from 1.26 to 2.48 MPa and display impressive biodegradability rates of up to 62% within just 14 days. (Lestari *et al.,* 2024)

Research trends reveal a significant focus on biomass transformation, with efforts concentrated on developing biosorbents, activated carbon, and biocomposites from durian peel. Additionally, studies have characterized the pasting properties of starch extracted from durian seeds, exploring its suitability for use in food, pharmaceutical, and cosmetic industries. Optimization of gum extraction from durian seeds further expands the potential applications of this tropical fruit waste (Amid and Mirhosseini, 2014).

Mangosteen (*Garcinia Mangostana* L.)

Mangosteen, often referred to as the "queen of fruit," is esteemed for its sweet, tangy flavour and vibrant purple hue. However, the fruit's peel constitutes a significant portion of its weight, ranging from 60% to 65%, leading to substantial waste generation (suvarnakuta *et al.,* 2011).

Despite this, mangosteen peel harbors valuable bioactive compounds with notable medicinal properties. Extracts from mangosteen peel have demonstrated antioxidant and antitumor capabilities against various types of cancers (Krajarng *et al.,* 2011), sparking interest in its utilization for therapeutic purposes. Research endeavors have explored the potential of mangosteen peel in diverse applications, including as activated carbon for dye removal (Chen *et al.,* 2011), biosorbents for toxic metal removal, and sensitizer for dye-sensitized solar cells. Although the focus has primarily been on its medicinal properties, efforts have been made to derive pectin from both mangosteen peel and seed, with potential applications in food formulations (Chairat *et al.,* 2007).

Rambutan (*Nephelium Lappaceum*)

Rambutan, characterized by its hairy exterior and juicy, translucent flesh, is a tropical fruit that contributes to the growing issue of fruit waste. The peel and seed of rambutan account for a significant portion of its total weight, ranging from 37% to 62% for the peel and 4% to 9% for the seed (Lestari *et al.,* 2014).

Despite being non-edible, these parts have garnered attention for their potential pharmaceutical properties. Research has revealed that rambutan peel possesses antioxidant properties (Okonogi *et al.,* 2007) and antiproliferative activities against human cell lines (Khonkarn *et al.,* 2010), suggesting its utility in therapeutic applications. Investigations into rambutan peel have explored its potential as biosorbents for toxic metal removal and as sensitizers for dye-sensitized solar cells. Similarly, rambutan seed has been studied for its pharmaceutical properties, particularly its antioxidant and antiproliferative activities (Bhat and Al-daihan, 2014). Overall, rambutan peel and seed represent untapped resources with promising applications in pharmaceutical and biotechnological fields.

Mango (*Mangifera indica* L.)

Mango is often referred to as the "king of fruits" due to its deliciously sweet and juicy flesh, coupled with a tropical aroma that is unmistakable. The fruit is rich in essential nutrients, including vitamins A, C, and E, as well as minerals like potassium and magnesium.

Mango waste, primarily consisting of peels and kernels, contains valuable bioactive compounds (Mitra *et al.,* 2013). Mango peel, for instance, is a rich source of mangiferin, a polyphenolic compound with antioxidant and anti-inflammatory properties. Numerous research works have associated mangiferin with pharmaceutical properties that enhance the migration of endothelial cells (Berardini *et al.,* 2005). Mango kernel extract has shown promise in exhibiting anticancer properties against breast cancer cells (Luo *et al.,* 2014). Additionally, gallotannins derived from mango kernels exhibit antimicrobial activity (Engels *et al.,* 2012).

Pectin, enzymes, and fiber are primarily derived from mango peels for food applications, while their utilization in non-food applications, particularly as biosorbents, is limited (Lestari *et al.,* 2023). The extraction of pectin from mango peels has shown promising yields ranging from 12.2% to 21.2%, with degrees of esterification between 56.3% and 65.6%, indicating mango peels as a valuable source of high-quality pectin (Berardini *et al.,* 2005). This has led to increased research interest in this area (Kermani *et al.,* 2014). Additionally, mango peels contain important enzymes such as protease and pectinase (Amid *et al.,* 2011), while their high dietary fiber content suggests their potential as functional food ingredients (Ajila & Prasada Rao, 2013; Garcia-Magana *et al.,* 2013). In non-food applications, mango peels are utilized as biosorbents for removing heavy metals from water (Iqbal *et al.,* 2009).

Mango seeds have various applications, including as a source of cocoa butter, antioxidants, and antimicrobial compounds, as well as starch and activated carbon (Kittiphoom, 2012). They contain approximately 4.76% to 6.70% protein and 71.90% to 76.28% carbohydrate, making them suitable for flour production and as ingredients in bread making (Muchiri *et al.,* 2012). The fat extracted from mango seed kernels, processed with supercritical carbon dioxide, is considered premium grade cocoa butter analogue fats (Jahurul *et al.,* 2014). Mango seeds are also a source of vegetable oil, with a crude lipid content of 8.5% to 10.4%, primarily composed of 9-(z)-octadecenoic acid and octadecanoic acid (Muchiri *et al.,* 2012). Their high carbohydrate content also makes them suitable for poultry feed (Diarra, 2014).

Papaya (*Carica papaya* L.)

Papaya is a tropical fruit known for its vibrant orange flesh, sweet flavor, and numerous health benefits. It contains enzymes like papain and chymopapain, which aid in digestion and possess medicinal properties.

Papaya waste, including peels and seeds, contains bioactive compounds with diverse applications. Papaya peels and seeds are rich sources of antioxidants and have been studied for their antimicrobial and wound-healing properties (Nayak *et al.,* 2012). Papaya seeds have found various applications in both food and non-food sectors. Researchers have explored different methods to extract oil from papaya seeds, including ultrasound-assisted extraction (Samaran *et al.,* 2015), extrusion-expelling processes (Lee *et al.,* 2011), as well as solvent and aqueous enzymatic extraction (Puangsri *et al.,* 2005). Moreover, papaya seed flour has been noted for its exceptional foaming and emulsifying properties (Alobo, 2003) and is rich in protein and dietary fiber content, making it a recommended ingredient for food product formulations. Additionally, papaya peel contains pectin, a polysaccharide used in food formulations and enzyme production substrates.

Research on papaya waste valorization has focused on exploring the bioactive compounds present in peels and seeds for pharmaceutical and cosmetic applications. Studies have investigated the efficacy of papaya extracts in wound healing, skincare formulations, and as natural preservatives in food products. Efforts are ongoing to develop sustainable extraction methods that maximize the yield of bioactive compounds from papaya waste.

Jackfruit (*Artocarpus heterophyllus* Lam.)

Jackfruit is a tropical fruit known for its large size, sweet flavor, and distinctive aroma. Jackfruit waste, which includes the perianths of unfertilized fruits, is commonly processed to produce syrups and jellies due to its rich pectin and cellulose content. Additionally, the rinds and other waste parts of the fruits are utilized as beneficial livestock feed, although optimizing digestibility is necessary (Feili, 2014). To enhance digestibility, cattle are fed a combination of molasses-urea cake and jackfruit waste (Haq, 2006). However, jackfruit waste comprises only about 16% of the total fruit weight. As the fruit matures, the latex content in the core increases, although it becomes denser as the fruit ripens (Moncur, 1985).

Researchers investigated the isolation of cellulose from various agro-wastes, such as the outer skin, non-edible part, and inner stick of jackfruit (*Artocarpus heterophyllus* Lam.), as well as the skins of lychee (*Litchi chinensis* Sonn.) and lotkon (B*accaurea ramiflora* Lour.). Cellulose acetate and carboxymethyl cellulose (CMC) were then prepared from these isolated cellulosic materials. The resulting cellulose derivatives were characterized using FTIR spectrum analysis and titrimetric technique analysis, indicating their potential for various commercial and industrial applications (Rahman *et al.,* 2014).

Passion Fruit (*Passiflora edulis f. flavicarpa* L.)

Passion fruit is a tropical fruit known for its tart-sweet flavor and aromatic fragrance. It is rich in vitamins, minerals, and antioxidants, making it a popular choice for both culinary and medicinal purposes. Passion fruit waste, including peels and seeds, contains valuable bioactive compounds with diverse applications. Passion fruit peels are rich sources of pectin, a polysaccharide used in food formulations and enzyme production substrates. Passion fruit seeds are explored for oil extraction, as they contain high levels of crude lipids, making them suitable for food and cosmetic purposes. Additionally, passion fruit seeds can act as biosorbents for heavy metal and dye removal in wastewater treatment.

The constituent characteristics and functional properties of passion fruit seeds were summarized by Kawakami *et al.,* (2022), while possible applications of seed oil were considered by Cesar *et al.,* (2022). According to Cheok *et al.,* (2018), passion fruit peels and seeds account for about 45%-52% and 1%-4% of the total fruit, respectively. Due to the large amount of peels, they are utilized to a greater extent than the seeds (Cheok *et al.,* 2018).

Research on passion fruit waste valorization has focused on extracting bioactive compounds from peels and seeds for various applications. Studies have investigated the potential of passion fruit pectin in food products, pharmaceutical formulations, and as a substrate for enzyme production. Efforts are underway to optimize extraction methods and develop sustainable processes for passion fruit waste utilization.

Dragon Fruit (*Hylocereus sp*.)

Dragon fruit, also known as pitaya, is a tropical fruit with vibrant pink or yellow flesh speckled with black seeds. It has a mild, sweet flavor and is prized for its high antioxidant content.

Dragon fruit waste, primarily consisting of peels and seeds, contains valuable components with various applications. Dragon fruit peels are rich in pectin, a polysaccharide used in food formulations, pharmaceuticals, and cosmetics. Dragon fruit seeds yield essential fatty acids and stable oil, making them suitable for food and cosmetic purposes. Additionally, dragon fruit seeds contain antioxidants and have potential applications in functional foods and dietary supplements.

Dragon fruits are typically consumed fresh or processed into juice. However, the fruit peel, constituting 36.70% to 37.60% of the fruit, is often discarded during processing, particularly in beverage industries, leading to potential environmental issues (Jamilah *et al.,* 2011). Nevertheless, the peel is rich in valuable components such as pectin, phenols, antioxidants, betacyanin pigment, and total dietary fiber, necessitating its conversion into products with extended shelf life and enhanced functionality. Extracting pigments from the peel for utilization in other products can further enhance their functional qualities.

Research on dragon fruit waste utilization has focused on extracting bioactive compounds from peels and seeds for various applications. Studies have investigated the antioxidant properties of dragon fruit extracts and their potential health benefits. Efforts are ongoing to develop sustainable extraction methods and explore novel applications for dragon fruit waste in food, pharmaceutical, and cosmetic industries.

Citrus (*Citrus sp.*)

In recent years, researchers have explored the potential of converting citrus peel waste (CPW) into ethanol. This involves breaking down complex polysaccharides such as pectin, cellulose, and hemi-cellulose into simpler sugars, which can then be fermented into alcohol. Ethanol is an effective fuel that can improve octane content and replace lead as an anti-knocking agent. While conventional cars can accommodate up to 20% ethanol blended with petrol, there is a risk of oxidative corrosion in the engine's iron components. Therefore, blending ethanol with petrol requires the use of anhydrous ethanol to mitigate this issue (Kimball 2012)

Each of these tropical fruits offers unique characteristics and opportunities for waste valorization, contributing to sustainable resource utilization and the development of value-added products across diverse industries. Continued research and innovation in this field hold the potential to uncover new applications and foster a more environmentally conscious approach to fruit processing and utilization.

Conclusion

In conclusion, the utilization of tropical fruit waste holds significant promise for sustainable resource management and the creation of value-added products. Advanced extraction techniques and innovative processing technologies have revealed opportunities for waste valorization across various sectors. To drive future progress, it's essential to prioritize technological advancements, embrace circular economy initiatives, foster cross-sector collaboration, establish sustainable supply chains, and educate consumers about the environmental and nutritional benefits of fruit waste utilization. By embracing these approaches, the field can contribute to a more sustainable food system while addressing global challenges related to food security and waste management.

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