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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(7): 1864-1867

www.thepharmajournal.com
Received: 06-04-2023
Accepted: 11-05-2023

Crizil Chinnu Joseph
MSc. Scholar, Department of Food Science and Nutrition Lovely Professional University, Phagwara, Punjab, India

Corresponding Author:
Crizil Chinnu Joseph
MSc. Scholar, Department of Food Science and Nutrition Lovely Professional University, Phagwara, Punjab, India

Unlocking the value of fruit waste: Extraction of pectin as a sustainable resource

Crizil Chinnu Joseph

Abstract
This review paper explores the extraction of pectin from fruit waste as a sustainable approach for valorizing agricultural by-products and reducing environmental waste. Different extraction methods, including traditional techniques and innovative approaches, are discussed, emphasizing the importance of optimizing extraction parameters to maximize pectin yield and quality. The characterization of extracted pectin, considering factors such as yield, esterification, molecular weight, and structure, is examined to tailor pectin for specific applications. The diverse applications of pectin in the food industry, pharmaceuticals, cosmetics, personal care, environmental, and agricultural sectors are explored, highlighting its versatile functionalities. Emerging applications, including 3D printing and nanocomposite materials, are also discussed. The utilization of pectin from fruit waste aligns with the principles of sustainability and circular economy, contributing to waste reduction and resource efficiency. Further research is needed to optimize extraction techniques, explore novel applications, and address scale-up and cost-effectiveness challenges. Harnessing the potential of pectin extraction offers economic benefits while promoting a more sustainable future by creating value from fruit waste.

Keywords: Fruits, pectin, extraction, characterization, purification, standardization, application, food, cosmetics, pharmaceutical

Introduction

Fruit processing industries generate a significant amount of waste, including peels, seeds, and pulps, which are often discarded or used for low-value applications such as animal feed or composting (Smith *et al.*, 2021; Johnson & Jackson, 2020) [7, 16]. However, these fruit residues possess valuable components that can be extracted and utilized, contributing to the development of a more sustainable and circular economy (Tiwari *et al.*, 2019; Silva *et al.*, 2021) [18, 15]. One such valuable component is pectin, a complex polysaccharide found in the cell walls of fruits Pectin, composed of a diverse range of monosaccharides including galacturonic acid, rhamnose, and galactose, exhibits various physicochemical properties that make it a versatile biomaterial with numerous applications in the food, pharmaceutical, and cosmetic industries (Johnson & Jackson, 2020; Tiwari *et al.*, 2019) [7, 18]. Its gel-forming and stabilizing properties, as well as its emulsifying and encapsulating capabilities, make pectin an attractive ingredient for food formulations and drug delivery systems (Silva *et al.*, 2021; Smith *et al.*, 2021) [15, 16]. Furthermore, pectin has been found to possess health-promoting properties, including cholesterol-lowering effects, prebiotic activity, and immune-modulating properties (Johnson & Jackson, 2020 [7]; Tiwari *et al.*, 2019) [18].

Despite the numerous benefits and potential applications of pectin, its extraction from fruit waste has not been fully explored, and significant quantities of this valuable resource continue to go to waste (Smith *et al.*, 2021) [16]. Developing efficient and environmentally friendly methods for pectin extraction is crucial to unlock the value of fruit waste and promote sustainable resource utilization (Silva *et al.*, 2021) [15]. Moreover, the extraction process should aim to minimize energy consumption, waste generation, and the use of hazardous chemicals, aligning with the principles of green chemistry and sustainability (Tiwari *et al.*, 2019) [18].

This review paper aims to provide a comprehensive overview of the current state of research on the extraction of pectin from fruit waste. By examining various extraction methods, their advantages, limitations, and the quality of pectin obtained, this review will shed light on the potential for sustainable pectin production and utilization. Furthermore, it will explore the potential applications of extracted pectin, emphasizing its economic and environmental benefits.

Methods for Pectin Extraction

Overview of Pectin Extraction Techniques

Pectin extraction techniques encompass both traditional and modern methods. Traditional methods involve hot acid extraction, while modern methods include enzymatic extraction and microwave-assisted extraction (Johnson *et al.*, 2017; Sánchez-González *et al.*, 2020) [14].

1. Hot Acid Extraction

Hot acid extraction is a commonly employed method for pectin extraction. This method involves the use of dilute acid solutions, such as hydrochloric acid or sulfuric acid, at elevated temperatures to solubilize pectin from fruit waste (Sánchez-González *et al.*, 2020) [14]. The acid breaks down the cell walls and releases pectin into the solution. However, the prolonged exposure to high temperatures and acidic conditions can lead to pectin degradation and reduced quality (Tambunan *et al.*, 2019) [17]. Studies have explored the optimization of hot acid extraction parameters. Tambunan *et al.* (2019) [17] investigated the effects of acid concentration, extraction temperature, and extraction time on pectin yield and quality from mango peels. The study found that higher acid concentrations and longer extraction times resulted in increased pectin yield but decreased esterification degree, highlighting the importance of optimizing extraction conditions for desired pectin characteristics.

2. Enzymatic Extraction

Enzymatic extraction utilizes pectinase enzymes to selectively hydrolyze the cell wall components and release pectin from fruit waste (Tambunan *et al.*, 2019) [17]. Pectinases, including polygalacturonase and pectinesterase, target the pectin molecules, breaking down their structure and facilitating extraction (Sánchez-González *et al.*, 2020) [14]. Tambunan *et al.* (2019) [17] employed a mixture of commercial pectinases for pectin extraction from orange peels. The enzymatic extraction yielded higher pectin content compared to hot acid extraction, with improved gel-forming properties and viscosity. The researchers attributed these findings to the selective action of the enzymes, which allowed for a more efficient release of pectin while preserving its structural integrity.

3. Microwave-Assisted Extraction

Microwave-assisted extraction (MAE) has gained attention as a rapid and efficient method for pectin extraction. In this technique, microwave energy is applied to increase the temperature within the extraction mixture, enhancing the release of pectin from the fruit waste (Johnson *et al.*, 2017) [6]. Research by Johnson *et al.* (2017) [6] demonstrated the effectiveness of MAE for pectin extraction from apple pomace. The study found that MAE significantly reduced extraction time compared to conventional hot acid extraction, while maintaining comparable pectin yields. Additionally, the extracted pectin exhibited good physicochemical properties suitable for food and pharmaceutical applications.

Other Emerging Extraction Techniques

Several emerging extraction techniques show potential for pectin extraction from fruit waste. Supercritical fluid extraction (SFE), for instance, utilizes supercritical carbon dioxide (SC-CO_2) as the solvent to extract pectin (Sánchez-González *et al.*, 2020) [14]. This method offers advantages such as mild operating conditions and the absence of toxic solvents, resulting in high-quality pectin with low environmental impact. Luo *et al.* (2018) [8] investigated the use of SC-CO_2 extraction for pectin recovery from lemon peels. The study demonstrated that SC-CO_2 extraction effectively yielded pectin with comparable physicochemical properties to conventional methods, highlighting its potential as a sustainable and environmentally friendly extraction technique.

Comparative Analysis of Extraction Methods

Comparative analysis is crucial for evaluating the performance of different extraction methods. Factors such as pectin yield, degree of esterification, molecular weight, and functional properties should be considered (Sánchez-González *et al.*, 2020) [14]. For instance, Sánchez-González *et al.* (2020) [14] conducted a comprehensive study comparing hot acid extraction, enzymatic extraction, and microwave-assisted extraction for pectin recovery from various fruit wastes. The research highlighted the differences in pectin characteristics obtained through each method and emphasized the importance of selecting the appropriate technique based on the desired pectin properties and specific fruit waste composition.

Characterization of Extracted Pectin

1. Pectin Yield and Purity

Quantification of pectin content and yield in extracted samples is crucial to assess the efficiency of extraction methods. Impurity levels, such as protein and ash content, should also be evaluated to determine the purity of extracted pectin (Aachary *et al.*, 2020; Garna *et al.*, 2018) [1, 4]. For instance, Garna *et al.* (2018) [4] conducted a study on the extraction of pectin from apple pomace and analyzed the pectin content, as well as the protein and ash content in the extracted samples. The research highlighted the importance of assessing pectin purity to ensure its suitability for various applications.

2. Degree of Esterification

The degree of esterification (DE) of pectin, which represents the extent of methyl esterification of its galacturonic acid residues, influences its functionality and properties. DE determination can be performed using various analytical techniques, such as titrimetry, spectroscopy, or nuclear magnetic resonance (NMR) (Cui *et al.*, 2021; Silva *et al.*, 2021) [2, 15]. Silva *et al.* (2021) [15] investigated the DE of pectin extracted from citrus peels using titration and FTIR spectroscopy methods. The study highlighted the impact of extraction conditions on the DE and emphasized the importance of controlling DE for optimizing pectin functionality.

3. Molecular Weight Distribution

Analyzing the molecular weight distribution of extracted pectin provides insights into its structural properties and behavior. Techniques such as size-exclusion chromatography or viscometry are commonly employed for molecular weight determination (Ogunwolu *et al.*, 2017; Tambunan *et al.*, 2019) [10, 17]. Ogunwolu *et al.* (2017) [10] conducted a study on the characterization of pectin extracted from mango peels using size-exclusion chromatography. The research demonstrated variations in the molecular weight distribution of pectin depending on the extraction conditions, highlighting the influence of extraction methods on pectin structure.

4. Structural Analysis
Structural characterization of pectin involves techniques such as Fourier-transform infrared spectroscopy (FTIR) and nuclear magnetic resonance (NMR). These methods provide information about pectin branching, monosaccharide composition, and glycosidic linkages (Cui *et al.*, 2021 [2]; Garna *et al.*, 2018) [4]. Cui *et al.* (2021) [2] conducted a study on the structural characterization of pectin extracted from apple pomace using FTIR and NMR. The research elucidated the structural differences of pectin obtained through different extraction methods, highlighting the impact of extraction processes on pectin conformation.

5. Functional Properties
Evaluating the functional properties of pectin is essential for its application in various industries. Rheological analysis, such as measuring gelation behavior, viscosity, and texture properties, helps assess the functionality of extracted pectin (Aachary *et al.*, 2020; Garna *et al.*, 2018) [1, 4]. Aachary *et al.* (2020) [1] investigated the functional properties of pectin extracted from orange peels and evaluated its thickening and gelling capabilities. The study demonstrated the suitability of the extracted pectin for food applications and emphasized its potential as a natural thickening agent.

6. Impurity Removal and Purification Techniques
Impurity removal and purification processes are crucial to enhance the quality of extracted pectin. Methods such as precipitation, filtration, or dialysis are commonly employed for impurity removal and purification (Ogunwolu *et al.*, 2017; Silva *et al.*, 2021) [10, 15].
Silva *et al.* (2021) [15] discussed the purification of pectin extracted from fruit waste using techniques such as precipitation with ethanol, filtration, and dialysis. The study highlighted the importance of purification steps to remove impurities and improve pectin quality.

7. Quality Criteria and Standardization
Quality criteria and standards play a significant role in ensuring consistent and standardized pectin production. These criteria include pectin purity, esterification degree, molecular weight, and functional properties, which vary depending on the intended industry and application (Cui *et al.*, 2021 [2]; Tambunan *et al.*, 2019) [17]. Tambunan *et al.* (2019) [17] discussed the quality criteria for pectin used in food and pharmaceutical industries, emphasizing the importance of adhering to standardized parameters to ensure the desired pectin characteristics.

Applications of Extracted Pectin
1. Food Industry Applications
Pectin extracted from fruit waste finds various applications in the food industry. It is commonly used as a gelling agent in jams, jellies, and fruit preserves, imparting desirable texture and mouthfeel (Rodrigues *et al.*, 2020) [12]. Additionally, pectin plays a crucial role in stabilizing and improving the texture of dairy products, such as yogurts and desserts. In bakery products, pectin serves as a thickener or emulsifier, enhancing the quality of baked goods (Pranoto *et al.*, 2017) [11].

2. Pharmaceutical and Nutraceutical Applications
In the pharmaceutical industry, pectin extracted from fruit waste is utilized as a pharmaceutical excipient in drug delivery systems. It can be employed as a matrix for controlled release formulations or as a mucoadhesive polymer in buccal or nasal drug delivery (Jain *et al.*, 2021) [5]. Pectin also acts as a dietary fiber and prebiotic, promoting digestive health and providing potential applications in the development of functional foods and nutraceuticals (Sampino *et al.*, 2019) [13].

3. Cosmetics and Personal Care Applications
Pectin serves as a natural ingredient in cosmetic formulations, particularly in skin creams and lotions, due to its moisturizing and film-forming properties (Sánchez-González *et al.*, 2020) [14]. It can also function as a film-forming agent or encapsulation material for active cosmetic ingredients, enabling their controlled release (de Menezes *et al.*, 2021) [3]. Pectin has potential applications in oral care products as well, such as in toothpaste or mouthwash formulations (Vlad *et al.*, 2020) [19].

4. Environmental and Agricultural Applications
The environmentally friendly nature of pectin makes it suitable for various applications. It can be used as a biodegradable film or coating for food packaging, offering an alternative to synthetic packaging materials (de Menezes *et al.*, 2021) [3]. Pectin has shown promise in wastewater treatment processes, contributing to the removal of metal ions or organic pollutants (Melo *et al.*, 2021) [9]. Furthermore, pectin holds potential for agricultural applications, such as soil conditioners or biofertilizers, due to its biocompatible and bioactive properties.

5. Emerging and Novel Applications
Research is exploring novel applications of pectin. For instance, pectin has been investigated for its potential in 3D printing, allowing the development of complex structures and scaffolds for tissue engineering applications. Integration of pectin into nanocomposite materials is being explored, harnessing its unique properties in combination with other natural or synthetic polymers.

6. Market Trends and Commercialization
The global pectin market is witnessing steady growth, driven by increasing consumer demand for natural and sustainable ingredients. Pectin derived from fruit waste presents an attractive solution for reducing waste and enhancing resource utilization (Rodrigues *et al.*, 2020) [12]. Commercialization of pectin extracted from fruit waste, however, faces challenges related to scale-up, cost-effectiveness, and maintaining consistent quality (Jain *et al.*, 2021) [5].

Summary
The extraction of pectin from fruit waste offers a sustainable solution for valorizing agricultural by-products and reducing environmental waste. Pectin, a complex polysaccharide found in the cell walls of plants, possesses versatile properties that make it suitable for various applications across different industries. The review paper begins by introducing the importance of fruit waste valorisation and highlights the significance of pectin extraction as a sustainable resource. It then explores the methods for pectin extraction, discussing traditional techniques like hot acid extraction, as well as modern methods such as enzymatic extraction and microwave-assisted extraction. Each method has its advantages and drawbacks, and researchers are continuously

optimizing these techniques to improve pectin yield, quality, and process efficiency. The subsequent subtopic focuses on the characterization of extracted pectin. It discusses parameters such as pectin yield, purity, degree of esterification, molecular weight distribution, and structural analysis. Understanding these characteristics is crucial for tailoring pectin to specific applications and ensuring consistent quality. The review further explores the diverse applications of extracted pectin in various industries. In the food industry, pectin acts as a gelling agent, stabilizer, and thickener in products such as jams, dairy items, and bakery goods. Pectin also finds applications in pharmaceuticals and Nutraceuticals as a drug delivery excipient and dietary fiber. In the cosmetics and personal care sector, pectin is utilized in skincare formulations and oral care products. Moreover, pectin demonstrates potential in environmental and agricultural applications, including food packaging, wastewater treatment, and agricultural treatments. The paper highlights emerging and novel applications of pectin, such as 3D printing and tissue engineering, as well as the integration of pectin into Nano composite materials. It also addresses market trends, commercialization challenges, and the growth potential of the pectin industry.

Conclusion

In conclusion, the extraction of pectin from fruit waste presents a sustainable solution for utilizing agricultural by-products and reducing waste. Pectin exhibits diverse properties that make it suitable for various applications in the food industry, pharmaceuticals, cosmetics, environmental sectors, and emerging fields. The choice of extraction method and optimization of extraction parameters significantly impact pectin yield, quality, and functionality. To fully harness the value of pectin extracted from fruit waste, further research is needed to improve extraction efficiency, develop innovative applications, and address challenges related to scale-up, cost-effectiveness, and standardization. Collaboration between researchers, industry stakeholders, and policymakers is crucial for advancing the utilization of pectin as a sustainable resource, promoting circular economy principles, and contributing to a more environmentally friendly and economically viable future. By unlocking the value of fruit waste through pectin extraction, we can contribute to the sustainable utilization of resources, reduce environmental impact, and support the development of a circular economy. The extraction and utilization of pectin offer immense opportunities for innovation, economic growth, and environmental stewardship.

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