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Pectin Recovery Based on the Exploitation of Kiwi By-Products and the Application of Green Extraction Techniques †

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Abstract: The *Actinidia* genus comprises 54 species and 21 varieties of which *A. chinensis* var. *chinensis* and *A. chinensis* var. *deliciosa* are the most commercialized ones. The nutritional properties of kiwifruit have prompted their global production to nearly reach the value of 4.5 million tons per year, with Asia being one of the top producers. This increment in their production has raised a parallel augment of associated organic wastes, especially when kiwifruits are used for processed products. The most abundant by-products obtained include skins, seeds and discarded fruits. This biomass has a huge potential for its high content of bioactive compounds, such as dietary fiber or polyphenols. Therefore, it has been targeted by the food industry as a sustainable and cost-effective source of natural ingredients, highly demanded by consumers. Indeed, kiwi skins and seeds have been pointed out as a relevant source of pectin followed by the kiwi pulp. Pectin is a recognized ingredient due to the organoleptic properties it may confer but also for its prebiotic capacities. The recovery of pectin has been mainly performed via the application of extraction techniques that implied the use of chemical reagents such as acids. Nowadays, the use of chemicals is negatively regarded for their associated side effects. Indeed, customers' claims for chemical-free food ingredients have triggered the development and application of green extraction techniques: ultrasonic, microwave, enzyme, supercritical fluid or electrical pulse. Pectin has been successfully extracted with these green techniques both in terms of yield and quality, improving results obtained with traditional extraction techniques. Therefore, the main objective of this work is to review the wide variability of green techniques applied to extract pectin along with the comparison of the optimal parameters as a basis for the future development of an optimized extraction method. In addition, this work also aims to disclose the potential of kiwifruit by-products as a source of pectin and their industrial applications for the development of functional foods, nutraceuticals, food additives or cosmetics.

Keywords: agro-industrial by-products; biomass; kiwi; bioactive compounds; pectin; *Actinidia*

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1. Introduction

Kiwi, originally from China, is the best-known fruit of the *Actinidia* genus (Actinidiaceae family). In fact, it has become a widely consumed product worldwide due to its innumerable nutritional properties and health benefits [1,2]. It has been reported that global kiwi production reached 4 million tons per year [3]. Generally, this fruit is consumed raw, but it is also employed in the food industry in the production of wines, ice creams, jams and juices [1,2]. These applications produce different waste derived from processing, mainly skins, bagasse and discarded fruits [4]. The food industry is interested in these wastes because they contain a high content of bioactive compounds, such as polyphenols, vitamins, minerals, pigments and polysaccharides, including dietary fibers and pectin [5]. These wastes constitute a source of biomolecules beneficial to health, which can be used in food, cosmetic and/or pharmaceutical applications [5]. Currently, research has focused on the use of these residues to obtain mainly phenolic compounds and some pigments such as carotenoids, paying less importance to obtaining functional polysaccharides such as pectin [5,6].

Traditionally, pectin is extracted by chemical methods, using acidified or alkali hot water (HWE) [7]. However, the high consumer demand for more natural products has favored the development of innovative and environmentally friendly extraction methods called green extraction methods. Among these methods, the following stand out: ultrasound-assisted extraction (UAE), high-pressure-assisted extraction (HPAE), microwave-assisted extraction (MAE), enzyme-assisted extraction (EAE), supercritical fluid extraction (SFE), pulse electrified field extraction (PEF) and pressurized liquid-assisted extraction (PLE) [8]. In fact, several studies report greater benefits in the use of green extraction techniques compared to traditional pectin extraction [6,9–13]. Firstly, a higher yield of pectin is achieved and also better functional properties, which translates into better quality pectin. On the other hand, the use of chemical solvents is reduced and shorter extraction times are achieved, which require less energy [6,9–13]. In this sense, the main objective of this work is to review the wide variability of the green techniques applied to extract pectin, together with the comparison of the optimal parameters as a basis for the future development of an optimized extraction method (Figure 1). In addition, this work also aims to raise awareness of the potential of kiwi by-products as a source of pectin and their industrial applications for the development of functional foods, nutraceuticals, food additives or cosmetics.

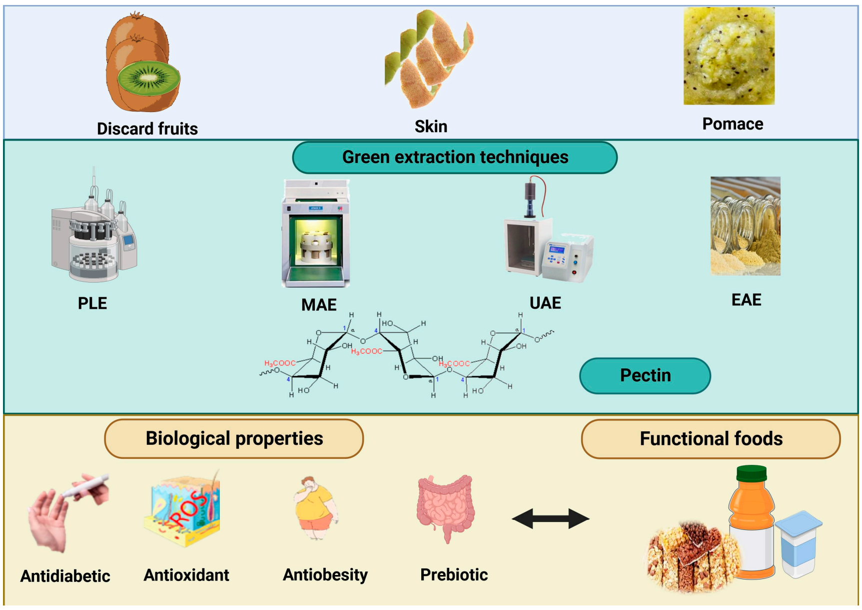

Figure 1. Kiwi by-products as a source of pectin, for the formulation of functional foods.

2. Kiwi By-Products as A Source of Pectin

Several studies related to kiwi residues and the application of green extraction techniques to obtain pectin have been compiled in Table 1.

Table 1. Pectin recovery from kiwi by-products, using green extraction methods.

Source	Technique	Experimental Conditions	Functional Properties	Bioactivity	Ref
Skin	MAE	Solv: H_2O:HCl; S/L 1:30 (g/mL); 3 min 360 W;	Yield: 17.97%; DE: 50.95%	-	[14]
	UAE	Solv: H_2O:HCl; S/L 1:30 (g/mL); 75 ◦C; 45 min 200 W	Yield: 17.30%; DE: 50.75%	-	[14]
Pomace	EAE	Celluclast 25 °C for 30 min	Yield: 4.5% Ash: 6.33% Protein: 9.82% GalA: 22.85%	-	[15]
Discard fruits	EAE	Celluclast 25 °C for 30 min	Early-harvested: Yield: 4.39% Ash: 7.09% Protein: 13.85% DE: 85% GalA: 29%	-	[7]
			Main-harvested: Yield: 4.39% Ash: 12.87 Protein: 29.62 DE: 90% GalA: 52%		
	UAEE	PCPR: 1:2:1 g/kg, S/L: 1:6.68, Ph: 5.23, UAE: 300 W	Yield: 4.25%; KS: 873.23mg/g; V: 7933 Cp; DE: 87%	DPPH: 1.93 µM TE/g	[16]
	MAE	H20:EtOH 80:20; S/L: 50 ml/g; 8 min; 480 W	Yield: 2.92%; Protein: 3.50%; GalA: 43.88%; DE: 43.33%	DPPH 2,33 mg/mL; ABTS 2.3 mg/mL	[6]
	UAE	H20:EtOH 80:20; S/L: 30 ml/g; 8 min; A: 70%	Yield: 2.82; Protein: 6.8%; GalA: 43.32%; DE: 48.38%	DPPH: 2,78 mg/mL; ABTS: 2.5 mg/mL	[6]
	UAE	H20: 100%; 12 min; A: 50%	Yield 25.7%	-	[13]

Abbreviations: MAE: microwave-assisted extraction; Solv: solvent; H_2O: water; HCl: hydrochloric acid S/L: solid/liquid ratio; min: minutes; W: Wat; DE: degree of esterification; UAE: ultrasound-assisted extraction; EAE: enzyme-assisted extraction; Ash: ashes; GalA: galacturonic acid; UAEE: ultrasound-assisted enzymatic extraction; PCPR: pectinase/cellulase/papain ratio; KS: starch content; V: viscosity; DPPH: 2,2-diphenyl-1-picrylhydrazyl; µM TE/g: milliequivalents of Trolox; ABTS: 2,2′-azinobis 3-ethylbenzothiazoline-6-sulfonic acid; EtOH: ethanol; A: amplitude. Yield, ash, protein, DE and GalA (expressed in % dry weight DW).

2.1. Skin

Kiwi skin is an important waste product from the industrialization of the fruit, representing about 10–15% of its total weight [4]. Regarding its macronutrient composition, it is known that it has 49–70% carbohydrates, 0.6–2.5% lipids and 3.6–7% proteins based on their dry weight (DW) [4]. It has been reported that kiwi skin has greater biological activity compared to the pulp, which may be due to a higher content of bioactive compounds, such as phenolic compounds, among others [5]. In addition, some authors claim that its rich contribution of fiber dietary and pectins (50% of the total fruit) can contribute to this effect [5,6,17]. Kiwi skin comprises mixtures of pectingalactan (40–50%) and hemicellulose (15–25), mainly xyloglucans [7]. On the other hand, it is reported that pectin extracted from citrus peel can reduce serum levels of triglycerides and total cholesterol in mice [18]. Additionally, it is reported that it can increase the activities of enzymes involved in the inhibition of free radicals (ROS), such as total hepatic superoxide dismutase (T-SOD) and glutathione peroxidase (GSH-Px), giving it antioxidant effects [5,19–21]. Kiwi peel pectins are reported to have protective effect on liver damage, hepatic steatosis, insulin resistance, disorders of fatty acid metabolism and dyslipidemias in mice on a high-fructose diet [6]. Thus, kiwi skin and its peptic substances should be further investigated with the aim of developing food supplements for industrial potential.

HWE is the traditional method for pectin extraction; however, it is reported to have disadvantages such as long extraction times and higher consumption of organic solvents and energy [6]. For this reason, green extraction techniques such as UAE, HPAE, MAE, EAE, SFE, PEF or PLE are being considered for pectin extraction [8]. Additionally, some authors claim that the use of these techniques positively influences their performance, quality, and functional and industrial properties [6,8,17]. The recovery of pectins from kiwi skin has been carried out using MAE and UAE (Table 1). In this sense, MAE under optimal conditions (H_2O:HCl, 3 min and 360 W) achieved a pectin yield of 17.97% DW with a degree of esterification (DE) of 50.95%. On the other hand, UAE under optimal conditions (H_2O:HCl; 75 °C; 45 min and 200 W) was able to recover 17.30% DW of pectin, with a DE of 50.75%. According to the DE and the chemical structures of the pectin obtained, it is high-methoxyl pectin, and it can be used as a gelling agent [14]. This same study reports that kiwi skin gave the highest yield of extracted pectin compared to lemon and tangerine peel [14]. Similarly, another study states that kiwi skin pectin has better physical, chemical, and structural properties and thermal properties compared to melon and pomegranate peels, making it similar to the pectins obtained from apple and orange peels, which are used for the commercial production of pectin. The authors conclude that kiwi peel could be used industrially as an alternative source of pectin [14,17]. Finally, it should be noted that the use of MAE and UAE achieves greater pectin recovery compared to HWE and EAE.

2.2. Pomace

Kiwi pomace is obtained after juice extraction for industrial uses and constitutes approximately 40% to 50% of the weight of the fresh fruit [15]. This matrix contains several bioactive compounds [22], which can become value-added products for applications in new functional and dietary foods [4]. A study evaluated the extraction of pectin from kiwi pomace using EAE (Table 1). Under optimal conditions (Celluclast 25 °C for 30 min), the authors obtained a yield of 4.5% DW of pectin, which is higher compared to the extraction with water and acids [15]. On the other hand, the authors compared the obtaining of pectin between the whole fruit including skin and seeds with the pomace. Although the extraction yields were similar, the pomace contained lower levels of protein (9.82% DW) and ash (6.33% DW). However, the authors conclude that kiwi pomace constitutes a source of pectin capable of providing unique functional properties [7,15]. Accordingly, it is reported that flour made from kiwi bagasse can be used as a promising ingredient to enrich products with dietary fiber and bioactive compounds with a powerful antioxidant action [23].

2.3. Discard Fruits

The kiwi industry generates a large amount of waste, mainly discarded products which are not suitable for commercialization. However, these fruits still contain important nutrients [4]. Different green techniques have been employed for pectin recovery from discarded fruits (Table 1). For example, EAE under optimal conditions (Celluclast 25 °C for 30 min) managed to recover 4.39% DW of high-methoxyl pectin (85% DE) [7]. In contrast, the authors report that the pectin obtained by EAE presented lower viscosity and less gel formation compared to the HWE pectin, suggesting that water extraction was less harmful to the pectin in its native state [7]. The combination of extraction techniques can result in better functional properties in the extracted pectins [9,24]. In this sense, pectin extracted using UAEE (pectinase/cellulase/papain ratio: 1:2:1 g/kg; S/L: 1:6.68; Ph: 5.23; UAE: 300 W), showed better technological and functional properties compared to the pectin extracted with EAE [16]. MAE and UAE were also investigated as techniques for the recovery of pectin in discarded fruits (Table 1). In this sense, MAE under optimal conditions (H_2O:EtOH 80:20; 8 min; 480 W) achieved a pectin yield of 2.92% DW. On the other hand, UAE, under optimal conditions (H_2O:EtOH 80:20; 8 min; A: 70%), obtained a yield of 2.82% DW of low-methoxyl pectins, highlighting its important antioxidant properties. In contrast, better yields were obtained using UAE (25.7% DW) during longer production extraction times [13].

3. Conclusions

Kiwi by-products such as skin, pomace and discarded fruits are promising raw materials for the extraction of high-quality pectin for potential applications in the food, pharmaceutical and cosmetic industries. The growing demand for natural and environmentally friendly products has led to the use of green technologies, which have demonstrated significant advantages over traditional pectin extraction, including higher pectin yield, improved functional properties, less use of chemical solvents and shorter extraction times. This not only contributes to reducing resource waste, but also promotes the production of healthier and more environmentally friendly food and personal care products.

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