Chapter

Pectin - Extraction, Purification, Characterization and Applications

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Abstract

Fruits, vegetables, and other plant-based foods are particularly important as they are source of dietary carbohydrates, and therefore much of the energy in the adult diet. Plant food also contains a wide range of dietary components rich in bioactive phytochemicals and is essential to the human body that may provide desirable health benefits beyond basic nutrition. Pectin is one of the nonstarch polysaccharides (NSPs), which constitutes the major fraction of the plant cell wall in association and/or substituted with other polysaccharides, and they cover a great variety of biological functions and chemical structures. Generally, pectin is isolated from by-products of agro-foods using extraction technologies with the emergence of novel and effective techniques that inclined toward a cleaner process. Pectin is widely used both in food sector (as gelling, thickening, and stabilizer agent) and in pharmaceutical industries (bioactive components) including biomedical application (drug delivery, tissue engineering, and wound healing) as innovative applications.

Keywords: new sources, pectin isolations, innovative application, food sector, tissue engineering, drug delivery

1. Introduction

Pectins represent a group of structurally heteropolysaccharides, composed mainly by covalently α-1,4-linked D-galacturonic acid (GalA) units, found in primary cell walls and middle lamella of higher plants [1, 2]. Pectin contributes to the firmness and structure of plant tissue, being involved in the intercellular adhesion and mechanical resistance of the cell wall. They also have an important role in the development of plant cells providing turgidity and resistance [3] **Figure 1**. These polysaccharides have been used in the food and beverage industries for many years. The principal applications of pectin are as a gelling agent, stabilizer, emulsifier, and thickening agent [4–6].

In the food sector, this traditional usage is being complemented by the emerging utilization of pectin as a fat replacer and health-promoting functional ingredient [4, 7, 8]. Pectin also provides an important source of dietary fiber that has been identified as emerging prebiotic with improved therapeutic properties for gut microbiota modulation [9–11].

Pectin has also been used for medicine and pharmaceutical purposes as a carrier for controlled drugs or bioactive release [12], for example, in drug delivery [13, 14].

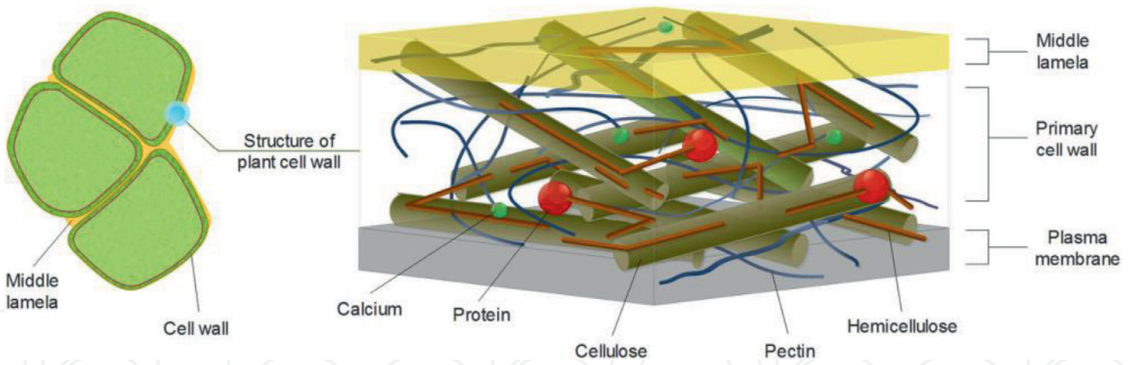

Figure 1.
Structure of primary plant cell wall (Copyright Figure 1, [56]).

2. Pectin chemical structure

Nowadays, there are a consensual classification of pectin based on three main structural domains: homogalacturonan (HGA), alternating with two types of highly branched rhamnogalacturonan regions designated as RG-I and RG-II [2]. Other structural classes of pectic polysaccharides also comprise xylogalacturonan, apiogalacturonan, arabinan, galactan, and arabinogalactan I [15, 16]. The pectin structure largely governs its physicochemical properties and its applications for several purposes. In this context, it is important to note that the carboxylic groups or hydroxyls may be methyl-esterified and/or O-acetyl-esterified [16]. The O-acetyl-esterification occurs predominantly at the O-3 position and occasionally at the O-2 position. However, not only these chemical variables are important but also the composition of neutral sugars, the degree of branching, and the degree of polymerization (molar weight), which can also modify the structure of this complex polysaccharide [17, 18]. The pectin gelation process is strongly influenced by the pectin esterification degree (DM). So, depending on the DM of pectin (defined as percentage of carboxyl groups esterified) [19], two different procedures of pectin gelation can be distinguished. High-methoxylated pectins (DM > 50%) are pectin formed in the presence of cosolutes as sucrose, at a concentration > 55%, and under pH < 3.5 [20]. Low-methoxylated pectins (DM < 50%) are gels created with the presence of divalent cations, mainly Ca^{2+}. Gelation process is due to the formation of junction zones between HGA regions of different pectin chains through calcium bridges between dissociated carboxyl groups [21].

High and low methoxyl pectins have diverse physicochemical properties and therefore have varied applications. High methoxyl pectin can be used as a gelling agent, emulsifier, stabilizer, and thickener in the food industry for the production of jams and jellies. Low methoxyl pectin can be used like a fat replacer, ice cream, yoghurt, bakery glazing, emulsified meat products, and low calorie products [22]. The diversity of pectin structures influences the physicochemical properties and also in its different technological applications, biological activities, biofunctionality, and therapeutic properties.

2.1 Homogalacturonan (HGA)

HGA is a linear homopolymer of α-1,4-linked GalA and is known as the "smooth region." It is an abundant and widespread domain of pectin, accounting for approximately 60–65% of total pectin amount [23]. The carboxyl groups present at C-6 in the GalA units can be partially methyl-esterified. Around 70–80% of GalA units, methyl-esterified could also be O-acetyl-esterified at O-2 or O-3 positions,

depending on its provenance [2]. The amount of GalA units present in a HGA chain is estimated to be around 100–200 units [24]. The smooth region can sometimes be joined by one or two α-1,2-linked L-rhamnopyranose units and most of the pectins have this structure. In addition, GalA units may be substituted at the C-2 or C-3 positions with residues of xylose or apiose, producing domains known as xylogalacturonan or apiogalacturonan, respectively [25].

Regarding other structural classes of pectin polysaccharides, xylogalacturonans (XGAs) are HGA substituted with β-linked-D-xylose-(1-3) at O-3 single unit side chains [26]. The degree of xylosidation can vary between 25 and 75% for instance in watermelon and apple, respectively [27]. Part of the GalA residues in XGA is methyl-esterified independently of the xylose substitutions [28].

2.2 Rhamnogalacturonan I (RG-I)

RG-I comprises a backbone of repeating disaccharide units of [-α-L-Rhap-1,4-α-D-GalpA-1,2-]$_n$ [29, 30]. The RG-I backbone may enclose up to 300 rhamnosyl and 300 galactosyluronic acid residues. The composition of neutral sugar side chains can be a glycosyl residue up to 50, resulting in a large and highly variable family of polysaccharides with a range of glycosidic linkages [23]. The highly branched nature of RG-I has led to the name "hairy region." The GalA residues of RG-I could be O-acetyl-esterified but they are not methyl-esterified [31]. In most cases, rhamnose residues are preferably substituted at the C-4 position with neutral sugar side chains, like arabinose and galactose forming arabinan, galactan, and arabinogalactans [2, 32].

Regarding to arabinogalactans, RG-I with galactose and arabinose side chains possess two structural different forms designed as arabinogalactans I (AGI) and arabinogalactans II (AGII). The AGI consist in a linear chain of 1,4-linked β-D-galactose, containing up to 25% α-L-arabinose residues 1,5-linked in short side chains, connected predominantly to O-4 of the rhamnosyl residues [1]. This type of arabinogalactan has been widely spread in citrus, apple, potatoes, soybean, lupin, cabbage, onion, tomato, and kiwi. It is know that HG and RGI are covalently linked and cannot be separated without a chain-cleavage using, for example, enzymes such as endopolygalacturonase or chromatographic fractionation methods [33]. AGII similarly contains chains of β-D-galactopyranosyl units, but glycosidic linkages occur at C-1, C-3, and C-6 in galactose molecules [34]. This type of arabinogalactan is highly ramified, and it may also include an L-arabinopyranosyl residue at the end of the chain of β-1,6-D-galactopyranosyl units.

2.3 Rhamnogalacturonan-II (RG-II)

RG-II is a homopolymer composed of a backbone that consists of 7–11 galacturonic acid residues branched with 4 side chains, preferably at C-2 and C-3, which may include apiose, 2-O-methyl-L-fucose, 2-O-methyl-D-xylose, 3-C-carboxy-5-deoxy-L-xylose (aceric acid), 3-deoxy-D-manno-octulosonic acid, and 3-deoxy-D-lyxoheptulosaric acid [15, 35]. The side chains of RGII consist of 12 different types of sugars with over 20 different linkages [2]. The RGII, the most structurally complex pectin domain, is highly conserved across many plant sources. In addition, RG-II has the ability to form borate esters dimers [36].

3. Food sources

Nowadays, fruit and some food by-products can be considered as raw materials to produce value-added products enriched with pectin. Pectin is not only a gelling

agent but also a thickening, stabilizing, and emulsifying agent [37], and even it has been used as a fat replacer and health-promoting functional ingredient [4, 8]. Thus, pectin must be taken into account within the set of new opportunities for the development of innovative products.

3.1 Conventional sources

Historically, commercial pectin is mostly extracted from citrus peel (85.5%), followed by apple pomace (14.0%) and, to a smaller extent, of the sugar industry (0.5%) [7, 38–42]. In the cases of apple, citrus, and sugar beet, where the backbone of HG is formed by at least 72–100 D-galacturonic acid residues, the degree of methylation is one of the key parameters related to gelling aptitude. The gelation process is affected by factors including the number and distribution of free carboxyl groups and the molecular weight, but also by other factors as calcium concentration, pH, ionic strength, and temperature [1, 43].

Regarding to citrus fruit, the amount of pectin has been estimated to account for as much as 13.4–29.1% of the dry weight [44]. The yield of pectin recovery from lime, orange, lemon and, lime peels using enzymatic extraction showed no significant effect compared with the extraction yields obtained using acid isolation technique [45].

The second most used source of pectin is apple pulp and apple pomace containing among 4.2–19% of pectin rich in neutral sugars as arabinose, galactose, rhamnose, glucose, and xylose [42]. Apple pectin displays a more elastic-viscous gel; however, citrus pectin produces a more elastic-brittle gel [46, 47].

Sugar beet pulp is also considered as an outstanding low cost source for commercial pectin coming from the sugar industry activity [32]. The combined effect of reduced pH, increased temperature, extraction time, and solvent-solid relation of the extraction process have been related with higher recovery rates of sugar beet pectin ranged between 6.5 and 24.8% [48]. Sugar beet pectin are characterized by showing a diminished gelling properties that have been attributed to its higher acetyl group content, lower molecular weight, higher amount of proteins bound covalently in the lateral chains and greater neutral sugar level [49–51]. Nevertheless, sugar beet pectin processes remarkable emulsifying properties, greater to pectin extracted from other conventional sources, as consequence of the ferulic acid residues on the arabinan side chains of RG-I, which allow to create covalently cross-linked hydrogels increasing its industrial potential [52, 53].

3.2 Nonconventional sources

Currently, other vegetable wastes constitute a new source of pectin with interesting food applications as valorizing new products and as functional ingredient with health-promoting benefits [54–56]. Nowadays, there are several unconventional feasible sources of pectin coming from food, vegetable residues, and plant species, which have different pectin contents and physicochemical properties. In this sense, sunflower head residues possess a very interesting gelling properties based on its high molecular weight and high GalA content. This kind of pectin contains around 3.5–5.0% water soluble high-methoxyl pectin and between 12 and 14% of insoluble low-methoxyl pectin [57].

Pectin from olive pomace, a semi-solid by-product from the olive oil industry has low molecular weight and high content of neutral sugars (as beet pectin) and a high percentage of acetylation, which facilitate the formation of gel by ionic interactions with calcium [58, 59]. Among 5–8% of pectin from olive pomace have

Extraction technique	Plant source	Operating conditions	Pectin content (%)	Effect on yield and quality	Ref.
Solvent extraction (SE)	Cocoa husks	Solvent: water, citric acid or hydrochloric acid; pH: 2.5 or 4.0; temperature: 50 or 95°C; time: 1.5 or 3.0 h	3.38–12.60	The highest pectin yield (7.62%) was obtained using citric acid (pH 2.5, 95°C, 3.0 h), while the highest uronic acid content in pectin (65.20%) resulted by using water (95°C, 3.0 h). Extraction with citric acid produced pectin with a wider DM range.	[86]
	Sour orange peel	Solvent: water; liquid/solid ratio: 20:1, 30:1, or 40:1 (v/w); temperature: 75, 85, or 95°C; time: 30, 60, or 90 min	17.95	The yield of pectin extracted at the optimal condition (95°C, 90 min, and liquid/solid ratio of 25:1) was 18.35%. GalA content and DE of the extracted pectin ranged from 57 to 83%, and 17–30.5%, respectively.	[87]
	Durian rinds	Solvent: water; solid/liquid ratio: 1:5–1:15 (g/mL); pH: 2–3; temperature: 75–95°C; time: 20–60 min	9.10	Under optimal conditions (solid/liquid ratio of 1:10 g/mL, pH of 2.8, 43 min, 86°C)	[88]
	Lime peel	Solvent: water: nitric acid; pH: 1.5, 2.3, or 3.1; temperature: 60, 70, or 80°C	15.7	Higher pectin solution concentrations were obtained at the lower pH values. Increased temperature and especially acidity caused a faster decrease of DE, effect that was particularly significant during extractions at pH = 1.5.	[89]
	Apple pomace	Enzymes: endo-xylanase and endo-cellulaseb; solid/liquid ratio: 1 g/15 mL; enzyme dose: 50 U/g; pH: 5.0; temperature: 40°C; time: 10 h	6.85	Treatment with endo-xylanase resulted in the highest pectin yield (19.8%) and very high DM (73.4%). Pectin extracted by endo-cellulase treatment was characterized by the high GalA content (70.5%). Simultaneous use of both enzymatic preparations resulted in a 10.2% extraction yield and a pectin rich in galacturonic acid (74.7%).	[90]
	Rapeseed cake	Commercial enzymes: celluclast and alcalase; enzyme/rapeseed cake ratio: 1:50–1:65 (v/w); celluclast/alcalase ratio: 0:5, 1:4, 2:3, 3:2, 4:1, or 5:0 (v/v); time: 90, 180, 270, 360, or 450 min	6.85	Pectin yield (6.85%) without significant loss of GalA was a 1:50 enzyme/RSC ratio with a celluclast/alcalase ratio of 1:4 for a 270 min hydrolysis time. Enzymes indicated different functions: alcalase led to the destruction of protein-carbohydrate complexes, while celluclast slightly cleaved some linkages of carbohydrate.	[91]
	Lime peel	Enzymes: Laminex C2K, Multifect B, GC220, and GC880; pH: 3.5–6.5; temperature: 40–70°C	23	Laminex C2K preparation proved to the most effective, as in optimum conditions (4 h treatment at pH 3.5, 50°C) gave a high yield (23%) and a pectin with good composition and properties (gelling, stabilization).	[92]

Extraction technique	Plant source	Operating conditions	Pectin content (%)	Effect on yield and quality	Ref.
Ultrasound-assisted extraction (UAE)	Passion fruit peel	Extraction solvent: 1.0 mol/L HNO3; pH 2.0, peel/solvent ratio of 1:30 (g/mL); temperature: 45–85°C; power intensity: 132.8–664.0 W/cm^2; time and frequency (constant): 10 min, 20 kHz	10.0–30.30	The highest pectin yield (12.67%) was obtained at 85°C and a power intensity of 664 W/cm^2. Despite the fact that pectin isolation reached the highest level, the isolate did not display the best composition, as the GalA content and DE showed minimum values.	[63]
	Mango peel	Extraction solvent: citric acid, pH 2.5, peel-solvent ratio of 1:40 (g/mL), time and frequency (constant): 15 min, 20 kHz; temperature: 20 or 85°C	9.20–31.80	Extraction yield of pectins varied greatly with the increase in temperature, from 2.09% (at 20°C) to 17.15% (at 85°C). A significant influence of temperature was also observed for GalA content (increase from 29.35 to 53.35%) and molecular weight (increase from 378.4 to 2320 kDa).	[93, 94]
	Jack fruit peel	Extraction solvent: distilled water); liquid-solid ratio: 10:1–20:1 (mL/g) pH: 1–2; sonication time: 15–30 min; extraction temperature: 50–70°C	8.94–14.5	Optimal conditions for the extraction were: liquid-solid ratio of 15:1 mL/g, pH of 1.6, sonication time of 24 min, and temperature of 60°C.	[95]
	Grapefruit peel	Emitter surface: 13 mm or 25 mm; power density: 0.20–0.53 W/mL; duty cycle: 33–80%; temperature: 30–80°C; solid-liquid ratio: 1/30–1/70 (g/mL); sonication time: 10–60 min	21.5	Heating significantly improved the extractability and extraction rate of pectin, leading to higher yield (26.74%) in shorter extraction time (52 min). The optimized parameters were: ultrasound power density 0.40 W/mL, duty cycle 50%, temperature 60°C, S/L 1/50 g/mL.	[8]
Subcritical water extraction (SWE)	Apple pomace and citrus peel	Solid to liquid ratio of 1:30 g/mL, extraction time of 5 min (constant); extraction temperature: 130, 150, or 170°C for apple pomace; 100, 120, or 140°C for citrus peel	14.0–21.9	The highest yield (21.95%) of citrus pectin (68.88% GalA content) was obtained at 120°C, and the highest yield of apple pectin (16.68%) was gained at 150°C.	[96]
	Sugar beet pulp	Temperature: 110, 120, or 130°C; extraction time: 20, 30, or 40 min; liquid/solid ratio: 30, 40, or 50 (w/w); extraction pressure: 8, 10, or 12 MPa	6.5–24.8	Increase in all parameters enhanced the extraction up to a certain level past which a decrease of pectin recovery was recorded. The optimum extraction conditions to obtain a maximum yield of 24.63% (with 59.12% GalA and 21.66% arabinose content) were as follows: L/S ratio of 44.03, 120.72°C extraction temperature, extraction time of 30.49 min and extraction pressure of 10.70 MPa.	[48, 97]

Extraction technique	Plant source	Operating conditions	Pectin content (%)	Effect on yield and quality	Ref.
Microwave-assisted extraction (MAE)	Waste papaya peel	Microwave power: 320, 480, or 640 W pH: 1, 2, or 3; time: 20, 100, or 180 s; solid-liquid ratio: 1:5, 1:15, or 1:25 g/mL	11.11–49.83	All the process variables had significant effect on pectin yield. The optimal conditions for reaching a maximum pectin yield (25.41%) were: microwave power of 512 W, pH of 1.8, time of 140 s, and solid-liquid ratio of 1:15 g/mL.	[98, 99]
	Waste mango peel	Microwave power: 160, 320, or 480 W; pH: 2, 3, or 4; time: 60, 120, or 180 s; solid-liquid ratio: 1:10, 1:20, or 1:30 g/mL	9.20–31.80	For all process parameters, a similar influence was observed: the increase in their level was positively correlated with the pectin yield up to a certain point, beyond which their effect on pectin extraction was negative. The maximum pectin yield (28.86%) could be obtained at a microwave power of 413 W, pH of 2.7, time of 134 s, and solid-liquid ratio of 1:18 g/mL	[88]
	Tangerine peels	Microwave power: 600, 700, or 800 W; temperature: 40, 50, or 60°C; time: 30, 40 or 50 s	19.9	The optimal extraction parameters were: microwave power 704 W, 52.2°C, extraction temperature, and extraction time of 41.8 min	[47]
	Opuntia ficus-indica cladodes	Microwave power: 200, 400, or 600 W pH: 1.5, 2.25, or 3; time: 1, 2, or 3 min; solid-liquid ratio: 2:20, 2:35, or 2:50 g/mL	12.56	The optimum conditions to obtain a maximum pectin recovery of 12.56% were 2.16 min, pH 2.26, 517 W microwave power and 2 g/30.66 mL of solid-liquid ratio. FTIR analysis indicated a GalA content of 34.4% and no alterations in the chemical structure of pectin following microwave treatment.	[100]

Extraction techniques and their effects on pectin yield. Adapted from [56].

Table 1.
Main sources of commercial pectin.

suitable emulsifying properties for commercial uses and also possess antioxidant and functional properties for its high dietary fiber levels. Carrot pomace and carrot peel, resulting from juice production, are vegetable wastes that possess approximately 22–25% of the total dietary fiber (29.6%) [60]. Pectin from carrot peels displays a very high level of linearity, a lower DM, and a better solubility than pectin extracted from carrot pomace [54] what makes it especially interesting for gelling mechanisms.

Pumpkin pulp and peel showed 7.46% of pectin under extraction at pH 4 with EDTA as chelating agent [61]. Moreover, the pumpkin cake is suggested to have a positive effect on gut bacteria [62]. In the same way, pectin from banana peels comprises around 1/4 of total fruit weight and contains a low amount of water-soluble pectin for gelling, thickening, or stabilizing purposes [63].

Watermelon rinds, which account for approximately one-third of total fruit mass and are usually discarded, were proposed as another possible source of pectin. The pectin content of wet watermelon rinds has displayed 19–21% (w/w)

[64] revealing its potential for use in the food industry. Both fresh and lyophilized watermelon pectin have showed high degree of methyl esterification and low molar mass [65]. These properties reveal its suitable application as emulsifier, stabilizing agent, and thickening agents.

Tomato residues, coming from the canning industry, lead large quantities of tomato pomace and tomato peels that contain 7.55 and 22.6% of pectin, respectively, expressed on a dry weight [66]. The structure of pectin molecules isolated from unripe tomato consist in complex biopolymer consists of HGs held together by RG-I regions [67, 68].

Another unconventional pectin sources are summarized in **Table 1**.

4. Pectin isolation process

Since pectin is a native polysaccharide that is found in the cell wall and middle lamellae of many land-growing plants, especially fruits and vegetables, an extraction process for its isolation is mandatory. The innovative applications (food and nonfood) that we will discuss in the following pages begin definitely with pectin isolation from the plant, fruit, or vegetal material.

This entire pectin production process is well documented in the literature and includes a raw material pretreatment stage, an extraction operation, and a postextraction stage (**Figure 2**). Generally, pectin is isolated by using chemical extraction process from by-products of agro-foods also called "Conventional Method." However, these methods require the disposal of, for example, acidic waste water that can cause serious environmental problems [69]. Currently, in connection with the emerging concept of "Green Chemistry," several novel or nonconventional extraction methods and more effective techniques have been developed for pectin extraction (**Table 1**).

4.1 Chemical extraction methods

Chemical extraction using acids are the most commonly employed methods in the production of pectin, and it has an impact on content and composition both of pectin monomeric as xylose, arabinose, and galacturonic acid and physicochemical properties (emulsifying activity and viscosity, among others) [70].

For example, the acid extraction from pumpkin pulp and peel using pH 4 with EDTA showed around 7.5% of pectin as chelating agent [61]. Higher yields of pectin were obtained (up to 200 mg g^{-1}) by combining the acid extraction with a microwave extraction, and those also displayed a large amount of phenolic compounds, proteins, and neutral sugars [18].

Other example for extraction yield of carrot pectin can range from 5.0 to 15.2% depending on parameters such as pH, temperature, heating time, sample provenance, and liquid/solid ratio [71].

The composition of the pectin from fabas and beans varied according to the extraction conditions: the neutral sugar galactose, arabinose, and rhamnose increased under slighter extraction conditions while glucose, mannose, and xylose sugars predominated under severe extraction. The maximum yield of extraction (15.75%) was recorded at pH 1.5 and at a temperature of 85°C for an 80-min extraction period and solid to liquid (1:25) ratio, while the highest degree of esterification (54.62%) occurred at pH 2.5 and at temperature of 90°C for a 60-min extraction period [72].

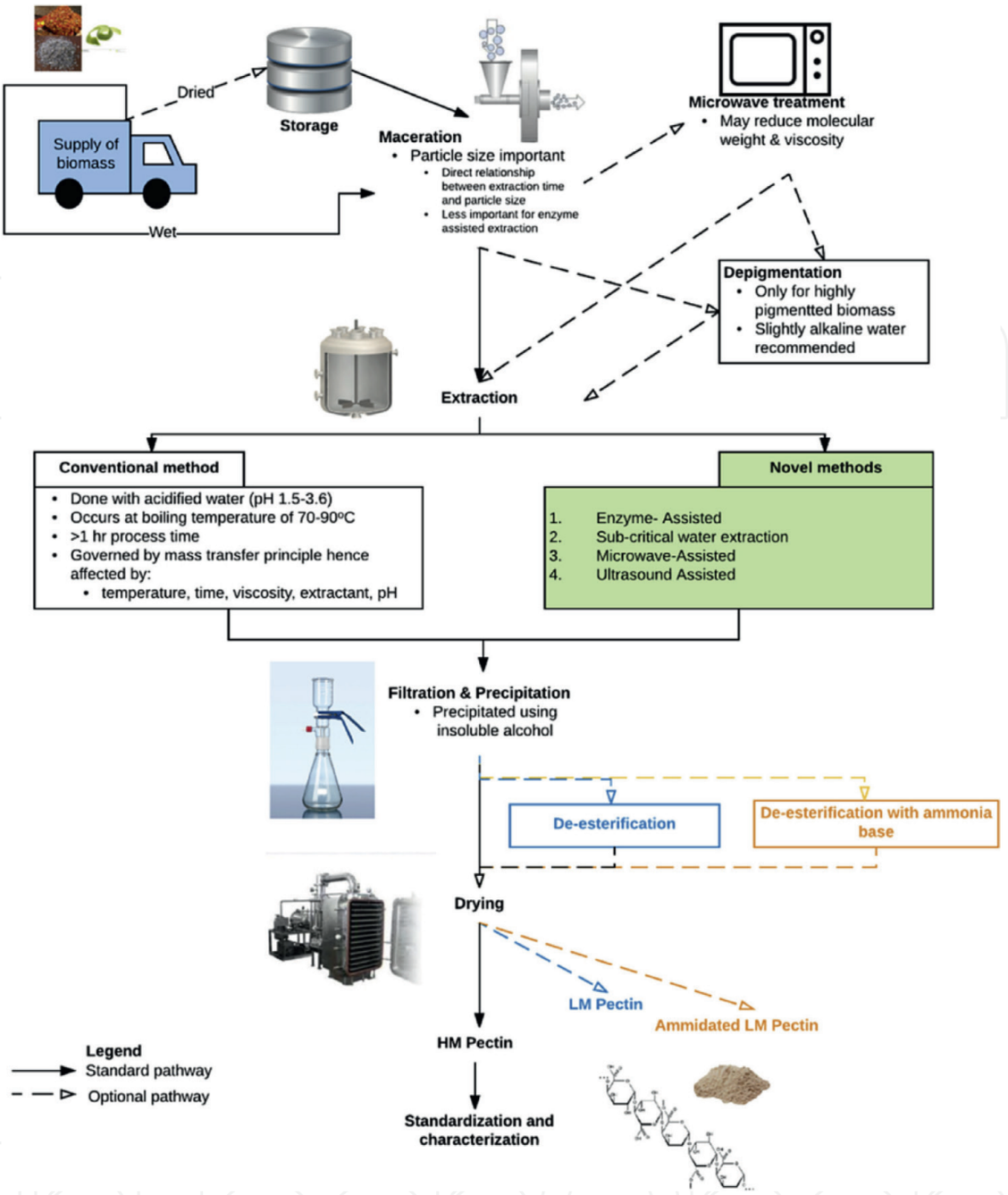

Figure 2.
The industrial pectin production process (Copyright Figure 1, [73]).

4.2 Novel technique extraction

Currently, novel and more effective techniques are inclined toward a cleaner (green or natural) extraction process. Among nonconventional extraction methods for pectin isolation are found (i) ultrasound-assisted extraction (UAE) (ii) subcritical water extraction (SWE), and (iii) microwave-assisted extraction (MAE). **Table 1** summarizes the main pectin extraction process including solvent extraction (SE).

Other relevant novel technique for pectin isolation is enzyme-assisted extraction (EAE), which among other benefits, the unavoidable presence of trace chemical solvents in products from solvent-based extraction processes [73]. The enzymes are characterized to catalyze reactions such as hydrolysis, with a high level of selectivity, which either reduces the amount of solvent/chemical needed or increase yield

for the same amount of solvent [74], in a way that is not feasible with acid-based hydrolysis. A distinction is possible between two approaches of EAE of pectin: (i) using enzymes that degrade pectin and help isolate pectin fragments, for example, galacturonic acid and (ii) using enzymes capable of deconstructing plant cell wall and isolating pectin [75].

Concretely combined enzymatic and ultrasonic treatment has been evaluated for efficient extraction of pectin in comparison with other extraction methods. The sequential treatment proposed by Yang et al. with enzyme (Celluclast 1.5 L) followed by ultrasound of sisal waste attained a much higher pectin yield of 31.1% than the ultrasound followed by enzyme, 14.6%. The pectin yield attained with the combined enzymatic/ultrasonic extraction was also higher than enzymatic extraction (9.4%), ultrasonic extraction (11.9%), and acidic extraction (5.8%) [76].

5. Innovative applications

Main pectin applications have been focused to food sector, while nonfood applications are currently presented as innovative alternative. Nonfood application includes the use in medical and pharmaceutical industries, where the health promoting benefits and bioactivities of pectin has shown potential for biomedical applications including drug delivery, tissue engineering, and wound healing [77].

5.1 Food sector

In the food sector, pectin traditional usage as a gelling agent, thickening agent, and stabilizer is being complemented by the emerging utilization of pectin as a fat replacer and also as health-promoting functional ingredient [4, 7, 8, 56].

Apple pomace and citrus peel remain the main sources for the production of commercial pectins, although other sources are being considered (**Table 1**) to the rising demand and growing interest for the development of innovative products [20, 55, 56].

5.2 Nonfood pectin applications

Nonfood applications include the use of pectin in pharmaceutical industry, where pectin bioactivity has shown an outstanding potential for biomedical applications as bioactive components [12] and also includes drug and gene delivery [13, 14], tissue engineering [2], and wound healing patches [56].

Within biomedical application, drug delivery systems improve the conventional drug administration as they provide *in situ* controlled and sustained release of active biomolecules. For most drug delivery systems, natural polymers, where pectin is included, are employed as inert, biocompatible carriers. These compounds have interesting properties such as the mucoadhesiveness, the ease of dissolution in basic environments associated to its resistance to proteases and amylases, making pectin suitable to release drugs in the colon [77]. And the ability to form gels in acid environments, instead, enhances the contact time of drugs for gastric or ocular treatments [78, 79]. Furthermore, pectin has been found to recognize galectin molecules, which are involved in different stages of cancer pathologies, being particularly appealing to target tumor cells for chemiotherapic treatments [80].

Furthermore, pectin has been described as an emerging prebiotic with the ability to modulate the bacterial composition of the colon microbiota [81] being able to exert beneficial effects on health [70]. The prebiotic activity is one of the most outstanding health benefits. Pectin, indigestible food-ingredients, has

Type of dressing	Composition
Hydrocolloid sheets, uses: cavity or flat shallow wounds with low to medium exudates; absorbent; conformable; suitable for "problematic" areas: heel, elbow, sacrum	
CombiDERM® (ConvaTec Ltd.)	Cellulose, pectin, Salsorb90 (acrylic polymer)
DuoDERM® (ConvaTec Ltd.)	Carboxymethylcellulose, pectin, propylene glycol
Granuflex® (ConvaTec Ltd.)	Polyurethane foam sheet coated with pectin, gelatin and carboxymethylcellulose
Hydrocoll® (Hartmann)	Pectin, gelatin and carboxymethylcellulose
Hydrocolloid paste, uses: useful debriding agent, conformable, may be left in place for several days	
GranuGel® paste (ConvaTec Ltd.)	Pectin, carboxymethylcellulose, propylene glycol
CitruGel® (Advances medical)	Pectin, carboxymethylcellulose

Table 2.
Pectin-containing hydrocolloid wound dressing (Copyright Table 4, [77]).

considered as an emerging prebiotic that possess prebiotic effect into the colon microbiota [9–11]. The beneficial effects of the pectin-derived oligosaccharides are essentially explained by the positive effects caused into bacterial population [82]. The consumption of pectins generates increasing levels of acetate, propionate, and butyrate, derived from the intestinal fermentation of pectin. These short-chain fatty acids possess an outstanding role in the prevention and treatment of metabolic syndrome, diarrhea, and intestinal disorders mainly Crohn's disease and ulcerative colitis [83]. An example is the pumpkin cake, which is suggested to have a positive effect on gut bacteria [62].

Natural polymers have been employed as scaffolds to stimulate specific cell functions and to direct cell-cell interactions [77]. Few studies report the use of pectin for tissue regeneration; however, pectin hydrogels were found to have a great potential for bone tissue engineering applications, as they promote the nucleation of a mineral phase if immersed in adequate physiological solutions [84], with the formation of biomimetic constructs better mimicking the natural architecture of the bone [77].

Finally, other innovative applications in biomedical area are focused to wound healing patches. Hydrogel films on wounds or ulcers were aimed to prevent bacterial infection, support the autolytic debridement, and maintain a moist healing environment [77]. The natural properties of pectin impart several advantages to the wound dressings, such as hydrophilicity, which permits the removal of exudates, the retention of an acid environment, which may act as barrier against bacteria, and the ability for binding active molecules as drugs or growth factors to heal the wounds. As a wound heals, the cells around it are stimulated by growth factors to proliferate and grow into the wound [85].

A wide variety of hydrocolloid pectin-based wound dressings have been patented and are nowadays commercially available (**Table 2**).

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