Chapter

# New Sources of Pectin: Extraction, Processing, and Industrial Applications

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## Abstract

One of the most important polysaccharides in the vegetal kingdom is pectin. This class of natural polysaccharide is found primarily in citrus fruits and apple pomace. Pectin has been used in different sectors of the industry, among which the food, pharmaceutical, cosmetic, and paper industries stand out. Today, there is a growing demand for this type of hydrocolloid, where both the scientific and industrial fields have focused on using new sources of pectin and developing novel extraction methods. This chapter describes the chemical structure of pectin and its main chemical characteristics. Then, the conventional sources from which pectin is obtained are exposed as well as its main industrial applications. Subsequently, the physicochemical and functional properties of pectins obtained from unconventional sources are described and analyzed as well as the main technologies used for their extraction. Finally, the most recent advances in the role played by pectin in the industrial sector are described.

**Keywords:** pectin, extraction, functional properties, husks, hulls, Cactaceae, new applications

## 1. Introduction

Pectin is considered one of the main polysaccharides found in plant sources; it participates in the constitution of cell walls of higher plants, impacting the physical and nutritional contribution of products of plant origin. Pectin is a globally recognized polysaccharide with great relevance in the global biopolymer market due to its inherent functional properties and vast applications in the food, pharmaceutical, and biomedical industries [1]. It is a macromolecule capable of forming flexible polymer chains that lead to forming hydrogel-type structures [2]. Its functional properties are associated with the extraction conditions and influenced by the source used. The primary sources of commercial pectin are citric fruits and apples; however, non-conventional sources have been investigated, such as agro-industrial sub-products and residues, pulps, husks, hulls, peels, Cactaceae, and vegetables, among others [3]. Furthermore, pectin has been functionalized

through chemical or enzyme reactions that lead to changes and improvements in its physicochemical properties, such as molecular weight, degree of esterification (DE), and surface charge, which in turn contributes to the development of new functional or improved properties, along with new approaches and applications [4].

## 2. Pectin structure

Pectin is a negatively charged branched heteropolysaccharide, composed of up to 17 different monosaccharides with more than 20 types of linkages [5, 6]. This polysaccharide was first reported in 1825 by Braconnot and defined as a biopolymer rich in galacturonic acid (GalA; up to 65%) [7]. Although the precise structure of pectin has not yet been fully elucidated due to its complexity, three major polysaccharide domains are recognized; as shown in **Figure 1**, the most abundant is based on a linear homopolymer of α-(1–4)-linked-D-galacturonic acid (GalpA, GalA) residues that can be methyl esterified at the C-6 position and to a lesser extent O-acetylated in C-2 and C-3; this domain is defined as homogalacturonan (HG) [5, 7]. In the rhamnogalacturonan I (RG-I) domain, the rhamnose (Rhap, Rha) residues disrupt the HG structure to form a preferably ramified structure of pectin (20–35%) due to the presence of the repeating disaccharide [→4)-α-D-GalpA-(1→2)- α-L-Rhap-(1-]. Here, the GalA residues are not methyl esterified, and attachment of neutral sugar side chains [α-L-arabinose (Araf, Ara) and β-D-galactose (Galp, Gal)] to the C-4 positions of Rha residues can be suitable, leading to linear side chains (LC-A) when α(1→5)-L-Araf or linear type I (β(1→4)-L- Galp) or branched side chains (LC-B) when α(1→2,3)-L-Araf or branched

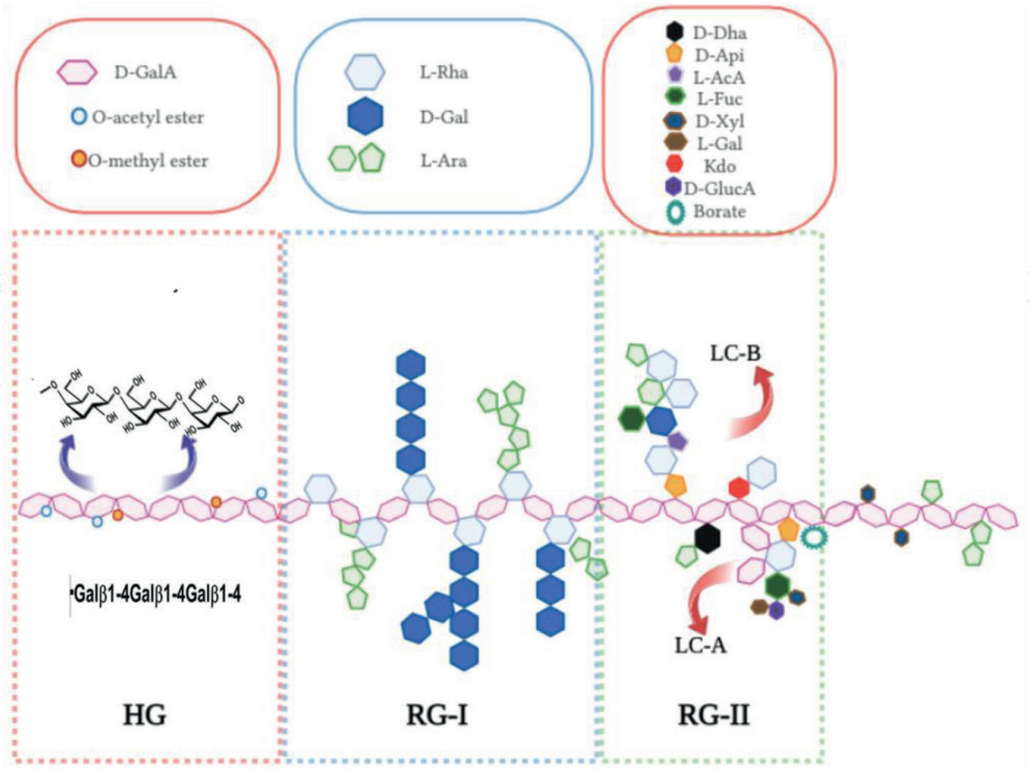


**Figure 1.**
*The schematic representation of the pectin structure contains the HG, RG-I, and RG-II domains. L-AcA: L-Aceric acid. Adapted from [8].*

type II β(1→3,6)-D-Galp and arabinogalactans. The branching design of the structure in RG-I depends on the pectin source, the extraction conditions, and the presence of other sugars such as xylose (D-Xyl), fucose (L-Fuc), and glucuronic acid (D-GlucA), among others [9]. The RG-II domain (1–8%) is constituted of around nine α(1→4)-linked GalpA units partially methyl esterified with four heteropolymer side chains attached, mainly composed of 11 monosaccharide residues, including apiose (D-Api), 2-O-methyl-L-fucose, 2-O-methyl-D-xylose. 3-C-carxy-5deoxy-L-xylose, 3-deoxy-D-manno-octulosonic acid (Kdo), and 3-deoxy-D-lyxoheptulosaric acid (D-Dha), which are linked with up to 22 glycoside bonds [10, 11].

Some investigations about the basic structure of pectin establish that although the pectin source may influence the structure diversity by partially modifying the chain conformation of the macromolecule, the RG-II region seemed to be well preserved among the different sources [12]. Moreover, pectins contain functional groups besides carbohydrate type, such as phenolic acids, methanol, acetic acid, and some amide groups. Methanol and acetic acid are relevant in the esterification of galacturonic acid residues for developing the inherent structure functionalities of pectin. The degree of methylation (DM) is a helpful tool for describing the structure of pectin and potential applications; high methoxy pectins (HM) contain more than 50% of carboxyl groups in methylated form, while those with lower content are defined as low methoxy pectins (LM). Most common native pectins are characterized by being methyl esterified. Likewise, acetylation in pectins rarely occurs in native pectins. The degree of acetylation (DA) in pectins is defined as the percentage of galacturonosyl residues that can be acetylated per unit of monosaccharide. DA can be larger than 100% and is usually found in the branched RG regions. In pectins from citrus and apple, the acetyl groups in the HG region are present in low content, rather than in pectins from sugar beet and potato, where higher amounts have been found [13, 14]. Amidation of pectins does not occur naturally; instead, it is induced chemically or enzymatically to improve the functional properties such as solubility in water, gelling, and rheological properties through modifying some non-esterified carboxyl groups into amide groups by using various amino compounds [15–17].

## 3. Conventional sources of pectin and their applications

Commercial pectin is generally obtained from citrus peels (25% dry matter) and apple pomace (15–18% dry matter), their processing subproducts, and sugar beet pulp (25% dry matter) [18]. The most significant part of commercial pectins includes 85.5% from citrus peels, 14% from apple pomace, and ~ 0.5% from sugar beet pulp [19]. Industrial processes for the extraction of pectin are based on the thermal hydrolysis of the citric peels (mainly from orange, lemon, and lime), apple pomace, and sugar beet pulp by using hot mineral acids like HCl, $H_2SO_4$, or $HNO_3$ (~pH 1.5) at ~85°C [20], where the control of the extraction conditions is of great relevance for minimizing the de-esterification and depolymerization of the polysaccharide and improving the functional properties of pectins as gelling, fiber enrichment, stabilizer, texture, and rheology control agent [21]. Notably, these pectin extraction processes generate large amounts of acidic industrial wastes and high energy consumption [22]. Hence, recent investigations have explored the use of more green technologies to overcome these environmental issues and enhance yield extraction [23]. **Table 1** shows some physicochemical properties of pectins obtained from conventional sources using different extraction procedures.

| Source | | Extraction conditions and yield | Functional Properties | References |
|---|---|---|---|---|
| Citrus peel | Lime | HHP extraction<br>Enzyme treatment<br>pH: 4.5; 50°C, 4 h.<br>Yield: 26.1% | DE: 75.7%; GalA: 82.8%<br>MW:308.4 kDa; $\eta_{int}$ 5.0 dL/g<br>Enhanced solubilization<br>Shorter gel setting time | [23] |
| | | Enzyme treatment<br>pH 3.5; 50 °C, 4 h.<br>Yield: 23% | DE: > 82%; GalA:81–84%<br>MW: 69 kDa; Gelling properties | [24] |
| | Orange | USE: 150 W, 20 kHz, 10 min, 50 °C<br>Citric acid pH 1.5<br>Yields: 28.1% | GalA: 72%; DE: 37.5%<br>Surface tension: 42.1–46.6 mN/m (0.1–0.5% wt.)<br>WHC: 3.10 gwater/gpectin<br>OHC:1.32 goil/gpectin | [25] |
| | Pomelo | Conventional extraction<br>Nitric acid pH 2.0; 90 °C; 1.5 h<br>Yield: 23.19% | DE: 57.9%; MW: 353 kDa<br>Viscoelastic solution (<1% wt.)<br>Weak gelation (<1% wt.)<br>Newtonian behavior (<0.4% wt.)<br>Pseudoplastic behavior (>0.4% wt.) | [26] |
| | Mandarin | HHP: 500 MPa, 10 min<br>Citric acid pH 1.4<br>Yield: 21.95% | GalA: 75.4–84.4%; DE: 67.7–70.4%<br>MW:1201–2626 kDa<br>Pseudoplastic behavior (3% wt.) | [27, 28] |
| | Grapefruit | USE:800 W;20 kHz; 58% amplitude<br>67.8 °C; 30 min<br>Yield: 27.3% | DE: 65.5%; GalA: 50%<br>$\eta_{int}$: 3.26 dL/g; MW: 109.5 kDa | [29, 30] |
| | | Conventional extraction<br>H2SO4 pH; 80 °C 1 h.<br>Yield:33.6% | DE: 71.7%; $\eta_{int}$: 18.36 dL/g<br>MW 2.3x105 kDa | [31] |
| Apple pomace | Granny Smith; Royal; and Golden varieties Pomace used for commercial pectin | Chemical or enzyme treatment<br>Yield:4.2–19.8%* | GalA:18.0–67.9%*; DE:52.5–76.4% *<br>DM:58–88%; MW:68–790 kDa * | [32–34] |
| Sugar beet pulp | | Conventional extraction<br>HCl, pH 1.2, 90 °C, 3 h. | DE: 38.6–40.8%<br>Pseudoplastic behavior (2%wt.)<br>Emulsifying activity | [35, 36] |

*HHP: High hydrostatic pressure; MW: Molecular weight; $\eta_{int}$: Intrinsic viscosity; USE: Ultrasound-assisted extraction; WHC: Water holding capacity; OHC: Oil holding capacity. *Depending on the variety of pomace.*

**Table 1.**
*Physicochemical properties of some pectin extracted from conventional sources.*

Pectin is widely used in the food industry as an excellent thickener agent for producing jellies and jams, a pH stabilizer in dairy products and low-calorie products, and an emulsifier in pharmaceutics for the design of drugs to treat gastrointestinal disorders, blood cholesterol reduction, and cancer treatment as well as good former of edible films and coatings, foams, and paper substitutes [17, 24]. Because of the

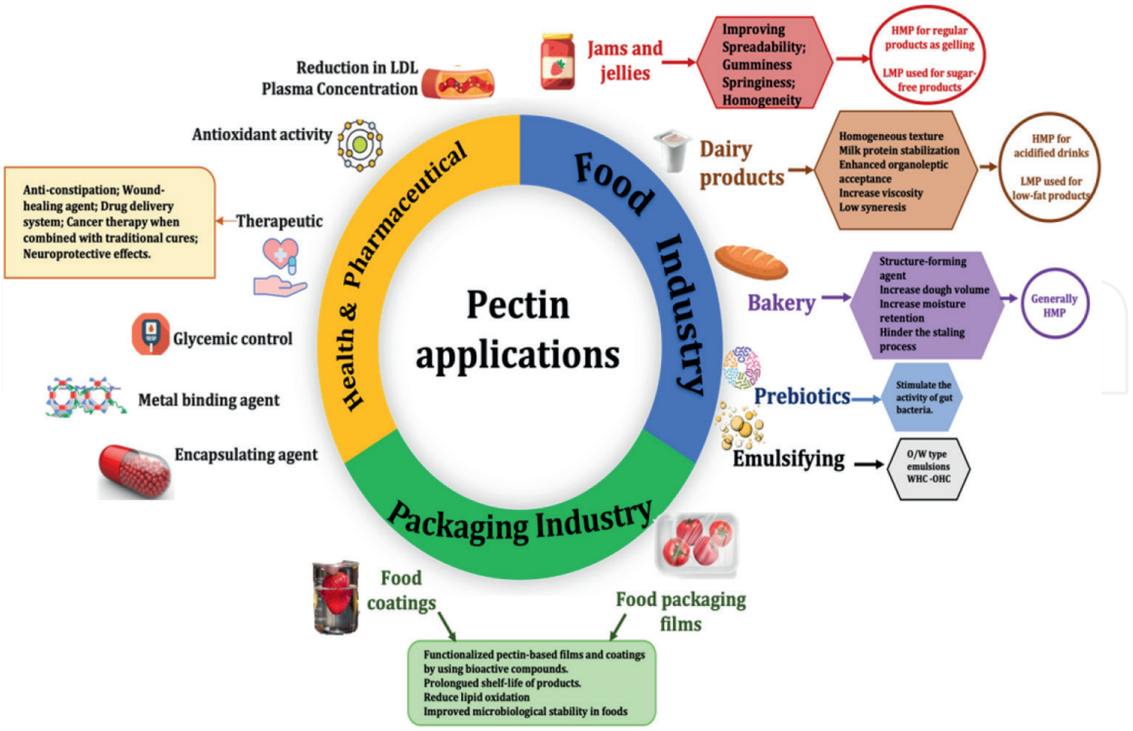


**Figure 2.**
*Principal applications of commercial pectin in food, packaging, and pharmaceutical industries [17].*

functional properties of pectins, both LM and HM, many applications in food, industrial, and pharmaceutic sectors can be considered (**Figure 2**).

Most commercial pectins are facilitated to dissolution when a dextrose content is present. An additional pectin classification is based on its gelling capacity, which is relevant in product processing and preservation. Pectins are classified as rapid-set pectin, when gels are formed, preferably at high temperatures, generally used for jams because it reduces the possibility that the fruit rises to the surface before the pectin gel is set, and slow-set pectin, which is preferred in jellies because it allows handling the product before the gel setting without damaging the texture and firmness of the product [25].

Despite the presence of extensive contents of pectin polysaccharide in fruit subproducts, like citrus peels, apple pomace, or sugar beet pulp, it is not the most critical parameter to define a lucrative extraction and the best functional properties for this functional agent [17]; the exploration of novel sources of pectins is raising the attention of scientists and technologists.

## 4. Vegetable sources of pectin

New sources of pectin that are receiving significant interest in the scientific field are those obtained from different kinds of vegetables, such as pumpkin, eggplant, chayote, and *Opuntia ficus* indica cladodes.

Several studies have been conducted on the extraction of pumpkin pectin using different extraction methods, such as the chemical acid treatment (0.1 M HCl) or enzymatic extraction, where the last has given much higher yields than the acid extraction [26]. Pumpkin pectin fraction **A** was obtained from raw pumpkin with an enzyme preparation of cellulase and α-amylase. Pumpkin pectin fraction **B** was

obtained by treating the solution of fraction **A** with pronase to reduce the protein content. The pumpkin pectin fractions **A** and **B** yielded 10.03 and 8.08 g/100 g, respectively.

The DE values of about 47% for pumpkin pectin fractions **A** and **B** were not significantly different, while the GalA contents represent 75.02 and 78.22 g/100 g, respectively. This finding indicated that both fractions are mainly composed of HG [27]. Small amounts (about 10 g/100 g) of six different neutral sugars were found in both pectin fractions, including rhamnose, arabinose, galactose, glucose, xylose, and mannose.

FT-IR and 1D NMR analyses revealed that the pumpkin pectin backbone is mainly composed of 1,4-D galacturonic acid, in which a considerable portion of galacturonic acid residues is present as methyl esters, and L-rhamnose is involved in the linear region of the backbone through α-1,2 linkages. The emulsifying capacity and stability of pumpkin pectin fraction **A** were 63.7 and 58.3%, respectively. At the same time, both properties were not detected in pumpkin pectin fraction **B**. Pectin fraction **A** exhibited emulsifying properties in the water–oil mixture, evidencing the presence of hydrophobic protein components in the pectin structure. In contrast, protein removal in fraction **B** resulted in a loss of emulsifying properties [26]. Therefore, pumpkin pectin could be used as an emulsifying agent in the preparation of oil-in-water emulsions for the beverage industry as long as residual hydrophobic protein components are not removed.

Eggplant fruit (*Solanum melongena* L.), a popular vegetable with an elongated oval shape and dark purple peels, grows worldwide, especially in tropical and subtropic regions. Under optimal extraction conditions by the ultrasound-assisted extraction method (UAE) (ultrasound power of 50 W, irradiation time of 30 min, and pH of 1.5), the pectin extracted from the peels of this vegetable (EPP) indicated that the EPP had a high GalA content (66.08 g/100 g) [28]. Considering the Food and Agriculture Organization (FAO) and European Union recommendations, the GalA content of pectin used as a food additive or pharmaceutical purpose should not be lower than 65 g/100 g pectin. This pectin had a high DE (61.22%) and was categorized as HM pectin (DE > 50%). EPP had a protein content of 2.53 g/100 g, which can be attributed to the difference in raw materials and extraction techniques. However, FAO suggests that the protein content of pectin should not be higher than 15.6 g/100 g [24]. In addition, EPP showed good values in functional features such as water-holding capacity (WHC) and oil-holding capacity (OHC). Under the optimal extraction conditions, EPP exhibited a WHC of 6.22 ± 0.21 g water per g EPP, while the OHC was 2.12 ± 0.15 g oil per g EPP. The emulsifying activity (EA) and emulsifying stability (ES) of EPP were evaluated, EA was about 56.16%, and the highest emulsion stability was 96.36 ± 0.80 at 4°C. EPP also exhibited antioxidant activity, determined by the DPPH radical scavenging method, reaching a highest antioxidant activity at a concentration of 50 mg/mL (94%), which was still lower than the antioxidant activity performed by the ascorbic acid, with an $IC_{50}$ value of 1.39 mg/mL; this activity is due to the higher total phenolic content (TPC = 96.81 ± 2.18 mg GAEa/g pectin) associated to the EPP. The GalA content of the extracted pectin can be also effective in the antioxidant activity due to active portions in its structure [29].

Chayote is one of the most cultivated vegetables in the world. The major producing countries are Mexico, Brazil, and China [30]. The UAE method has been used to extract chayote pectin (PEUO) [31]. Using a liquid/solid ratio of 50 mL/g, a temperature of 70°C, and an ultrasonic time of 40 min as optimal extraction conditions. The yield was around 6.19%. Under these extraction conditions, PEUO exhibited a low DE (17.6%), indicating that the chayote pectin could be considered as LM pectin.

This property could be attributed to the harsh extraction conditions that would promote the de-esterification of polygalacturonic chains. The GalA content in PEUO accounted for 57.25%. To our knowledge, the ripeness, blanching, ultrasound, and other effects may influence the GalA content in the extracted pectin [31], besides the contribution to improve the depolymerization of polysaccharides, releasing the water-soluble pectin from the plant tissue [32]. The molecular weight in pectins significantly affects the emulsification, rheology, and their colloid stability. In this sense, the weight-average molecular weight and number-average molecular weight of PEUO were $2.47 \times 10^6$ g/mol and $1.29 \times 10^6$ g/mol, respectively, and the polydispersity index was 1.91. Polydispersity index higher than 1 suggests that PEUO extracted by UAE represents a heterogeneous natural polysaccharide with a broad range of polymer size distribution [31]. The monosaccharide composition of PEUO indicated the presence of five monosaccharides, where glucose (Glu) represents the most abundant monosaccharide (90.6%), followed by Gal (8%), D-Xyl (0.6%), Ara (0.6%), and Rha (0.2%). Besides, the content of Gal was significantly higher than that of Ara, indicating that the RG-I region may have been highly branched with galactan or arabinogalactan. Rheological properties of PEUO aqueous dispersions (<5%wt.) exhibited a non-Newtonian behavior [31]. Other functional properties like WHC and OHC for PEUO showed suitable values for both WHC (3.14 ± 0.42 g water/g PEUO) and OHC (3.73 ± 0.30 g oil/g PEUO). High WHC in PEUO makes it suitable as a food industry thickener. EA and ES were determined at 4°C and 25°C. The ES for PEUO emulsions were 88.36 ± 5.63% and 81.28 ± 4.82% after 1 day, and these values changed after 30 days to 85.33 ± 4.16% and 77.59 ± 5.19%, respectively. The lower temperature (4°C) was presumably more suitable for storing the PEUO emulsion. These results provide further evidence that chayote pectin may have great potential to be applied as an emulsifier and stabilizer in the food industry [31, 33]. Regarding the antioxidant activity of PEUO, it was higher when compared to pectin extracted from apples. Due to its techno-functional properties, PEUO may be used as a gelling agent and preservative in jam production or as a viscosity enhancer in beverages.

Another source of pectin that has received much attention is the *Opuntia ficus* indica (OFI) cladodes. This pectin has been extracted by acid water, ultrasound, and enzyme treatments [34, 35]. The pectin obtained by ultrasound under optimal conditions (sonication time of 70 min, temperature of 70°C, pH of 1.5, and water:solid ratio of 30 mL/g) reached an extraction yield of 18.14% ± 1.41%, with a GalA content of 68.87%. This pectin had a DE of 41.42%, classifying it as an LM pectin [36]. This DE value was higher than that achieved when the OFI pectin was extracted by the chemical process, which was 30.67% [37]. WHC in OFI pectin was 4.84 g water/g OFI pectin, ultrasound-induced cavitations in the pectin structure improving the water penetration and its absorption [38]. WHC for OFI pectin extracted by the chemical process was higher (5.64 g water/g OFI pectin) [34]. OHC for OFI pectin extracted with ultrasound was 1.01 g oil/g OFI pectin, slightly lower than pectin extracted by the chemical method (1.24 g oil/g OFI pectin) [34]. EA and ES were determined at two pectin concentrations (2 and 4% w/v). EA values were 19.23% and 26.92%, respectively, showing that the emulsion stability depends on the pectin concentration. OFI pectin at 4% maintained stability of more than 57% of the emulsion after 30 min of incubation at 80°C, unlike the 2% pectin solution, which could not retain more than 40% of the emulsion. This stability of the emulsions could be attributed to the rise of viscosities in the pectin solutions caused by the formation of a layer of pectin around each oil droplet, delaying the coalescence phenomenon [39, 40]. This stability was affected by the high pectin extraction temperature (> 45°C) [41]. ES in

OFI pectin extracted with acid water at 2% displayed higher values (90.45%) [34]. Differences in the ES are due to differences in the extraction methods, which affect the average molecular weight and the GalA content in the structure of pectin and therefore influencing the long-term stability in the emulsions [42]. When enzyme treatments were used for OFI pectin extraction, the optimal conditions were cellulase/xylanase at an LS ratio of 22 mL/g, cellulase/xylanase ratio of 2 U/U, and enzymes/matter ratio of 4 U/g, reaching an extraction yield of 17.91% [35], being more effective than the chemical treatment, which resulted in an extraction yield of 6.13 ± 0.60% [34]. Enzyme-assisted extraction of pectin depends on the choice of enzymatic activities based on the strength of pectin connection with cellulose and xylan and their abundance in the cell wall of the plant source [43].

For OFI pectin, the total sugar content was 89.94%, the main monosaccharide was GalA (66.66 ± 2.46%), with a DE of 35.04%, which was higher than that reported by Lira-Ortiz et al. [44] for pectin from prickly pear fruits (*Opuntia albicarpa*; DE 30.7%). OFI pectin had a WHC of 5.42 ± 0.16 g water /g OFI pectin, slightly lower than that for pectin extracted by the chemical process (5.64 g water/g OFI pectin) [34]. Various intrinsic factors, like the chemical structure of the biomaterial, and extrinsic factors, such as the pH, temperature, and ionic strength, can affect the WHC [45]. The OHC value of pectins was 1.23 ± 0.42 g oil/g OFI pectin. It was like the OHC of the OFI pectin extracted by the acid water method [34]. Thus, the oil retention power depends essentially on the hydrophilic nature and the overall charge density of the constituents [45]. EA values for OFI pectin emulsions at 2 and 4% were 26.9% and 30.77%, respectively. These values were lower than the ones found by Bayar et al. [34] for a 2% concentration of pectin extracted by the chemical process from the OFI cladodes (35%), proving that the extraction process influences the functional properties of pectin macromolecules [46]. The ES rates were 14.31% and 87.48% for 2% and 4% of pectin hydrocolloid in the emulsions, this long-term stability when emulsions were submitted to temperature treatment at 80°C is due to the high viscosity of pectin solution and by the formation of layers around the fat globules by the pectin [39].

## 5. Unconventional sources of pectin: hulls or husks and seeds

It is well known that the primary sources of pectin extraction are those obtained from citrus fruits or apples, due to their high yield and physicochemical properties that make them useful for various applications in the food and pharmaceutical industries. However, in recent years, new extraction sources have been sought that may represent alternatives to overexploited sources and that also have the advantage of allowing the use of organic by-products, such as the case of hulls or husks and seeds, from which pectins with specific physicochemical properties of high utility for multiple applications can be obtained.

**Table 2** shows current research work regarding unconventional sources for obtaining pectins, classified as hulls or husks that come from dry fruits (almonds, pistachios, walnuts, and cocoa), pods, and legume seeds (soy, peas, faba beans, and riang), cereal leaves (*Zea mays*) and seeds of different fruits (*Nicandra physaloides* Linn., Gaertn, papaya, jackfruit, creeping fig and sesame). In addition, its extraction methods and its most outstanding properties are also described.

The most widely used pectin extraction method for hulls or husk and seeds is the conventional one, which consists of acidifying the sample, for which different types of organic (citric and oxalic acid) and inorganic (HCl and $HNO_3$) acids are used; the

type of acid used influences the extraction conditions and the properties of the pectin obtained [30]. Subsequently, a heat treatment is carried out using a conventional hot plate, or, for more efficient extraction, it can be assisted by microwaves [49] or

| Pectin source | Extraction conditions and Yield | Functional properties | Reference |
|---|---|---|---|
| **Hulls or husks** | | | |
| Almond hull | First part: acidification with citric acid of almond hull pectin whose optimal conditions were pH = 1.4, liquid-solid ratio (LSR) 20.13, 90°C for 58.65 min followed by filtration. Second part: a mixture of pectin supernatant with 96% ethanol at a ratio of 1:1 v/v, then the precipitate obtained was dried in an oven at 50°C. Yield: 26.32% wt. | Extraction of LM pectin DE: 26.4% Forming forms gels using $Ca^{2+}$ at a pH 3–7 Do not need sugar to form gel High polydispersity due to the small chains formed during the extraction process. | [28] |
| Pistachio hull | Conventional and ultrasound-assisted, Acidification with a citric acid solution Yield: 32.3%. | Extraction of LM pectin DE = 19.29% Maximum emulsifying capacity with 6% wt. pectin, EA index: 172.85 ± 0.59 $m^2$/g ES index: 158.28 ± 3.41 min, High creaming stability Shear-thinning behavior. | [47] |
| A green husk of walnuts (*Juglans regia* L.) | Walnuts husks from different regions of cultivation. Walnut husks powder heated in an acid medium. Ethanol precipitation. The pectin was decolorized using acetone. | The soil and climate conditions where the walnut husks were obtained caused variations in the properties of the pectins obtained. DE: higher 65%. Lamellar and leaf-shaped structures, depending on the region of cultivation | [48] |
| Cocoa pod husk (*Theobroma cacao*) | Microwave-assisted extraction using an acidified medium with oxalic acid. pH 1.16 15 min. Liquid/solid ratio:25 Yield: 9.64%. | The decrease in pH during extraction produced a decrease in the esterification degree which reduced the gelling ability of pectin. This could be observed by FTIR spectroscopy. | [49] |
| **Legumes (from seeds or pods)** | | | |
| Soy hull | Thermal treatment by microwave irradiation Acidification 0.6% wt. citric acid or sodium citrate (SC). Pectin precipitation with ethanol. | The pectin extracted with SC had better stability of emulsions, smaller droplet sizes and greater emulsifying capacity. Applied into mayonnaise, achieving uniformly distributed drops and high stability. | [50] |
| Soy hull | Pectin extraction was carried out from milled soy hulls, from which galactomannan was removed. Acid medium, HCl followed by $HNO_3$. | Low uronic acid content. Low yield. Xylogalacturonan and rhamnogalacturonans as major components. Cannot form gels by adding $Ca^{2+}$. | [51] |

| Pectin source | Extraction conditions and Yield | Functional properties | Reference |
|---|---|---|---|
| Pea hull | To optimize the extraction, a central composite design was carried out where the effect of pH, temperature, and time on the yield and purity of the pectins was evaluated using two different acid media: citric acid and $HNO_3$.<br>pH 2.0<br>Yield: 3.5–9.8% with citric acid<br>Yield: 1.4–8.0% with $HNO_3$.<br>Purity: >65%, related to the high uric acid content. | LM pectin<br>Mainly composed of xylogalacturonan. | [52] |
| Faba bean hull | Microwave assisted extraction (640 W).<br>pH = 1.5 with 1 M HCl, 9 min.<br>Ethanol precipitation.<br>Yield: 14.86% | HM pectin<br>DE: 54.08%. | [53] |
| Riang (*Parkia timoriana* (DC.) Merr.) pod husk | Acid water<br>pH = 2 with $HNO_3$, heated to 90°C for 90 min.<br>Final pH adjusted to 4.5.<br>Yield: 15.0% | HM pectin<br>DE: ~66%.<br>Pseudoplastic behavior at a concentration > 2%w/v,<br>Newtonian behavior at concentrations <2% w/v.<br>High antioxidant activity and high content of phenolic compounds (mainly tannins). | [54] |
| **Cereal** | | | |
| *Zea mays* husk | Extraction with high-power ultrasound (US) application.<br>Pretreatment in a primary medium, followed by enzymatic hydrolysis with cellulase (pH = 5.2), precipitation of pectin with ethanol, and subsequent lyophilization to obtain the MP fraction.<br>Second treatment consisted of high-power ultrasound at 20 kHz, plus the steps of the first treatment to obtain the MP-US fraction. | Formation of thermo-irreversible and soft gels at pH = 6 in the presence of $Ca^{2+}$<br>Interaction with the iron (II) ion to form thermo-reversible weak gels.<br>LM pectin and high-water solubility due to the ultrasound treatment. | [55] |
| **Fruit seeds** | | | |
| Papaya seeds | Acid medium (citric acid)<br>80°C, pH 1.5, 60 min<br>Yield: 8.66% | LM: 9.22%. | [56] |
| Jackfruit seeds sheats | Pectin extraction was from the slimy sheats of the jackfruit seed (JS).<br>Water acidified with oxalic acid<br>90°C, 1 h.<br>Yield: 35.52% | Total phenolic content: 65.7 mg GAE/g<br>Antioxidant activity:<br>DPPH method: 25.29 ± 4.03%<br>FRAP: 10.4 μM | [57] |

| Pectin source | Extraction conditions and Yield | Functional properties | Reference |
|---|---|---|---|
| Creeping fig fruit seeds | Chemical extraction in acid conditions. | LM pectin<br>DE: ~20%.<br>Form gels at low pH values with the addition of glucono-δ-lactone<br>Viscous solutions are obtained at pH = 4.5 with $Na^+$ and $K^+$ ions for favoring the formation of the gel.<br>Gel strength depends on the type of salt added and its concentration. | [58] |
| *Nicandra physaloides* (Linn.) Gaertn seeds | Enzyme inactivation of the NPG seeds were inactivated with heating.<br>Aqueous extraction at 60°C.<br>Different fractions of pectin were obtained.<br>Yield: 9.17–10.56% | LM pectin<br>DE = 46.93%.<br>Spontaneous gel formation at 1.5%.<br>Gel formation at <1.5% in the presence of NaCl and KCl. | [59] |
| Sesame seed hull | Defatted seed<br>Acid medium (HCl). Fractionation with ethanol (30%, 50%, and 90%).<br>Maximum yield: 75.6% at 30% ethanol | High antioxidant activity<br>Able to stabilize emulsions. | [60] |

**Table 2.**
*Unconventional sources of pectins: Hulls or husks and seeds.*

by high-power ultrasound [61]. Finally, separation is carried out using the ethanol solvent, and the pectin obtained is dried.

Among the properties shared by pectins obtained from hulls or husks and seeds is that they are primarily LM pectins, with very varied DEs, and they also can form gels in the presence of ions such as calcium, sodium, or potassium [28]. However, the esterification degree influences the properties of the gels formed [49]. Besides, this type of pectin regularly achieves the formation of stable emulsions [24, 62], a shear-thinning rheological behavior and can even, in some cases, present antioxidant activity [14, 54, 63].

One of the main disadvantages of obtaining pectin from hulls or husks and seeds is its low yield (regularly less than 15%), since the extraction is carried out by conventional methods, where conditions such as the type of acid influence the yield obtained. However, research is currently being carried out on new methods that allow a more efficient extraction and higher yield to encourage the use of unconventional sources of pectin.

## 6. Applications of new sources of pectin

Nowadays, green chemistry leads to environmentally friendly bioproduct extraction approaches. Because bioproducts are biocompatible, they have a wide range of applications [33]. The synthesis and production of bioproducts use substantially less

energy and solvent, and they can now be scaled up with a small initial expenditure [14, 40]. Biomaterial formulations, sometimes inspired by biomimicking nature's behavior, are specifically tailored for applications involving human consumption products and innovative biobased materials [64]. In the field of biomaterials, hydrogels have gained popularity owing to their specific properties, such as biodegradability, biocompatibility, a soft-wet feel, and resemblance to organic tissue. Hydrogels with tridimensional crosslinked polymeric structures made from natural polymers have been extensively studied because of the increasing need for biomaterials with novel features for human consumption-related applications [65]. Pectin, a biopolymer found in the cell walls of fruits and vegetables, is extensively employed in the food, pharmaceutical, and textile sectors due to its ability to produce a thick gel-like solution [65]. Pectin is a gelling ingredient in the production of jams, jellies, and marmalades. Over the past decade, intense new research has yielded a new understanding of its molecular structure and physiological function, opening the gate to novel manufacturing techniques and entirely new applications, such as new advanced biomaterials, for example, calcium phosphate pectin for bone restoration and biobased construction, and building materials, for example, pectin aerogels for thermal insulation [64, 66].

According to the scientific literature, we can classify applications of pectins in two ways: first, according to their physicochemical properties, and last, according to their field of application. The specific application of each of the novel pectin sources is intimately linked to their particular physicochemical characteristics; please see **Figure 3**. For example, LM pectin is believed to be a helpful stabilizer for dairy products. This is due to low methoxyl pectin gels in the presence of divalent cations, in this specific instance, calcium ions. The capacity of HM pectin to gel at moderately lower pH values (pH 2–3.5) in the addition of soluble substances, such as sucrose, makes it suitable for use in the preparation of jams and jellies [67]. An LM pectin is an attractive option for use as a gelling agent in manufacturing low-calorie jams due to its ability to form a gel without added sugar. Unlike gums, which impart a slimy mouth feel, the use of pectin to increase the viscosity in soft drinks and beverages gives a clean mouth feel;

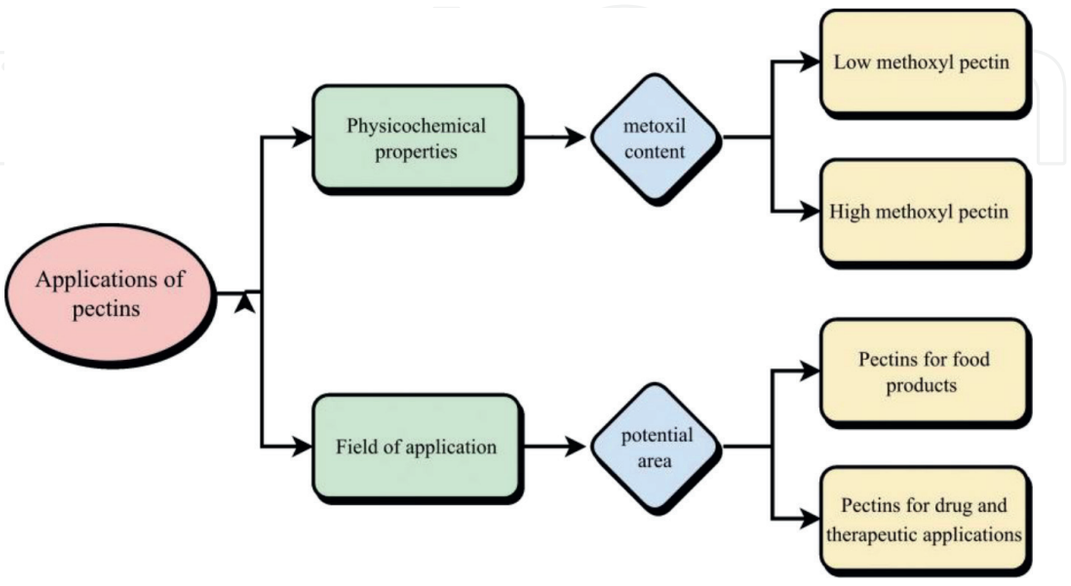


**Figure 3.**
*Different classifications for pectin.*

| Application | | Source | Extraction technique | Reference |
|---|---|---|---|---|
| Pectins for food products | Stabilizer for dairy products | Grapefruit peel | Acid hydrolysis | [68] |
| | Food films, gelling agents, and plasticizer | Lime peel | Citric acid-microwave extraction | [69] |
| | Food packaging | Lemon waste peel | Microwave extraction | [70] |
| | Films and emulsions | Citrus | — | [71] |
| | Antioxidants in food formulations | Jackfruit peel | Ultrasonic-microwave extraction | [72] |
| Pectins for drug and therapeutic applications | Drug delivery systems | Citrus | — | [73] |
| | Drug delivery systems | Fig skin | Ultrasonic-microwave extraction | [74] |
| | Tissue engineering | Lemon peels | Acid hydrolysis | [75] |
| | Bioprinting of 3D scaffolds | Citrus peels | — | [76] |
| | Wound healing | *Akebia trifoliata* fruit peel | Acid hydrolysis | [77] |
| | Accelerated wound healing | Cyclea Barbata Miers | Cold acid hydrolysis | [78] |
| | Skin wound healing | Papaya fruit | — | [79] |

**Table 3.**
*Applications of novel pectins.*

this may be due to the low viscosity of low-concentration pectin solutions at the shear rate of the mouth [67].

From the viewpoint related to their field of application, pectins may be categorized into pectins for food products and pectins for drug and therapeutic applications. Please see **Table 3**. Current research trends in food packaging promote the development of biodegradable, renewable, and environmentally friendly materials. Pectin-based edible coatings are among the most recent advancements in the world of food packaging. Including additional biopolymers, such as cellulose and natural compounds with antioxidant and antibacterial properties, has enhanced and strengthened these coatings.

Additionally, researchers have discovered the biological functions of pectin, consequently increasing its application in the pharmaceutical industry, including drug delivery systems, skin and bone tissue engineering, and wound dressings [65, 76]. Pectin is most widely used in the formulation of drugs for oral administration, such as tablets, gels, hydrogels, beads, aerogels, and coated and compression-coated doses. The ability of pectin to withstand acidic conditions and higher temperatures allows for the development of drug delivery systems able to load and release drugs at a specific location. Pectin has primarily been considered a colon-specific drug delivery vehicle that reduces systemic toxicity while increasing bioactivity and medication stability.

Pectin also has significant potential for use in tissue engineering. Pectins may promote mineral nucleation in this application if immersed in the appropriate physiological conditions, resulting in biomimetic structures that more closely resemble the

natural architecture of bone. Furthermore, pectins are responsible for wound healing treatments' gelling protection and anti-inflammatory effects [76]. By crosslinking pectins, calcium ions aid in its gelation. Solubilized pectin forms an acidic environment that acts as a bacterial or viral barrier, and pectin hydrogels allow for the loading and release of drugs such as antibiotics, analgesics, and tissue repair agents. Other physiological effects of pectin have been described, such as prebiotic, antimicrobial, antiglycation, and antioxidant. Pectin has also been used to nano-encapsulate bioactive substances, thereby increasing their shelf life and stability.

The exploration of new sources of pectin, involving the introduction of cleaner and new sustainable extraction techniques, demands more research to guarantee that an industrial application is sustainable and competitive in the current market.

## 7. Conclusions

Pectin is one of the primary polysaccharides present in plants; it contributes to the physical and nutritional value of plant-based goods. It's a macromolecule that can create flexible polymer chains. Source and extraction circumstances affect its functioning characteristics. Citric fruits and apples are the principal sources of commercial pectin, although non-conventional sources have been examined, including agro-industrial sub-products and wastes, pulps, husks, hulls, peels, Cactaceae, and vegetables. Pectin has been functionalized by chemical or enzyme processes that affect its physical characteristics, such as molecular weight, degree of esterification (DE), and surface charge, leading to new functional or enhanced qualities as well as new techniques and applications. Pumpkin, eggplant, chayote, and *Opuntia ficus* indica cladodes are new sources of pectin. Due to their high production and physicochemical qualities, citrus fruits and apples are the principal sources of pectin extraction. In recent years, new extraction sources have been sought that may represent alternatives to overexploited sources and that allow the use of organic by-products, such as hulls or husks and seeds, from which pectin with specific physicochemical properties can be obtained for multiple applications. Intense new research has yielded a new understanding of its molecular structure and physiological function, opening the door to novel manufacturing techniques and entirely new applications, such as calcium phosphate pectin for bone restoration and pectin aerogels for thermal insulation.

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## Conflict of interest

The authors declare no conflict of interest.

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