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Extraction of Pectin from Passion Fruit Peel

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Abstract
The addition of pectin to fluid systems alters its gelling, consistency, and texture characteristics. Thus, the use of this acid polysaccharide in product development can generate materials with different technological properties, capable of industrial use. For this, low-cost pectin sources are required. Among these is passion fruit, whose peel is an industrial byproduct that is rich in pectin. It is noteworthy that passion fruit peel is a byproduct generated in large quantities during fruit processing for the production of passion fruit pulp and juice, and that Brazil is the world's largest fruit producer. In this context, this review presents the characteristics of several methods (conventional extraction, enzyme-assisted extraction, extraction with subcritical fluids, UAE, MAE, UAME, S-MAE, HHP, DESs, and NADESs) used for pectin extraction and explains the effect of the studied variables, with emphasis on the extraction from passion fruit peel. The application of pectins in different industrial systems is also addressed. Pectins are featured as functional food ingredients of high commercial value due to their technological properties. It also has applications in different areas, such as the pharmaceutical and biotechnology industries.

Keywords Degree of esterification · Methods · Polysaccharide · Studies · Use · Yield

Introduction

Pectin, a polysaccharide discovered in 1790, is native to the cell wall of many plants, mostly fruits and vegetables [1, 2]. It is known for its extensive use in the food industry because of its ability to gel and give viscosity and consistency to food products. It also has applications in different areas, such as the pharmaceutical and biotechnology industries [3, 4].

Pectin is cited as an attractive investment and has therefore been industrialized by companies such as CP Kelco, Calleva, FMC Biopolymers, and Herbstreith & Fox, contributing significantly to the global hydrocolloid market.

Most commercial pectins are extracted from citrus peels such as lemon and orange. However, with the growth of pectin applications, alternative sources have been presented, such as guava pulp [5], mango peel [6, 7], passion fruit peel [8, 9], and fig seed [10].

It is noteworthy that passion fruit peel is a byproduct generated in large quantities during fruit processing for the production of passion fruit pulp and juice, and that Brazil is one the world's largest fruit producer. In 2018, 602,651 tons of passion fruit were harvested in Brazil (Fig. 1), which generated approximately 319,405 tons of peel in that year [11]. It is emphasized that the peel represents about 53% of the total mass [12].

The large quantity of passion fruit peel justifies the need to study the methodologies that can be used to extract pectin from the passion fruit peel, the influence of the extraction conditions, and the results obtained so that propositions of productive pectin arrangements are efficient.

Pectin Chemical Structure

Pectin naturally exhibits remarkable diversity in its molecular structure, in which there is a variety of functional groups that can assign different functionalities to this biomolecule, depending on the environmental conditions. Selective changes in the molecular structure of pectin and its characteristics can make such polysaccharide suitable for numerous applications. Properties, like size and solubility, associated with chemical

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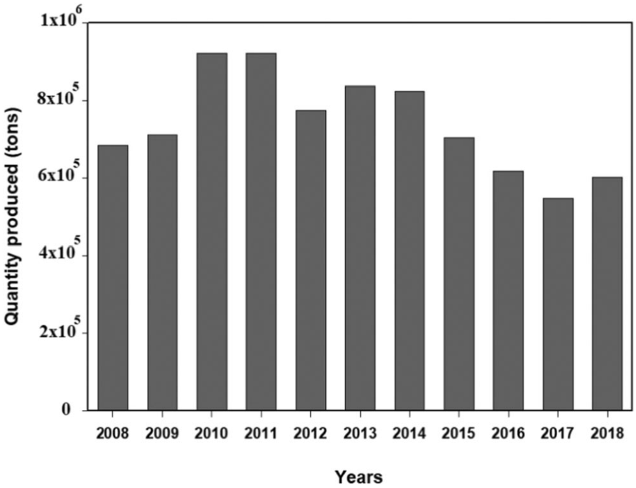

Fig. 1 Amount of passion fruit produced in recent years in Brazil. Source FAOSTAT [11]

and enzymatic reactions during the isolation process of pectin can affect its composition [13–17]. Thus, the functional properties of pectin are dependent on their structural characteristics.

Pectin is a vegetable macromolecule with one of the most complex and diverse molecular structure that varies according to the physiological state of the plant and between its tissues. The structure of the polysaccharide mainly includes the homogalacturonan (HG), xylogalacturonan (XGA), rhamnogalacturonan I (RGI), and rhamnogalacturonan II (RGII) [8, 15, 18, 19].

The ratio between HG, XGA, RGI, and RGII may vary. However, HG generally constitutes, on average, 65% of pectin, standing out as the most abundant polysaccharide, while RGI constitutes 20 to 35%. XGA and RGII are smaller components, making up less than 10% [20, 21]. It is worth mentioning that the different pectic polysaccharides are not separate molecules, but domains covalently linked [19].

Through enzymatic and non-enzymatic reactions, depolymerization and de-esterification can occur in HG. Due to depolymerization, there is a decrease in the molar mass of pectin [22]. By de-esterification, polymers are produced with non-esterified galacturonic acid residues [23, 24]. RGI is mainly exposed to enzyme-catalyzed depolymerization reactions. The main and side chains of RGI can be degraded with ease and affect the average molar mass of pectin [25–27].

Regarding the basic structure, pectin is formed by at least 17 different monosaccharides, of which galacturonic acid is the most abundant, followed by L-arabinose, D-galactose, L-rhamnose, and others, presenting as part of the chain, main, linked as a side chain or as isolated contaminants [28, 29]. According to the Food and Agriculture Organization (FAO), at least 65% of the structure of pectin corresponds to galacturonic acid (Fig. 2) [30].

The physicochemical properties of pectin are influenced by molecular characteristics, such as protein fraction, acetyl

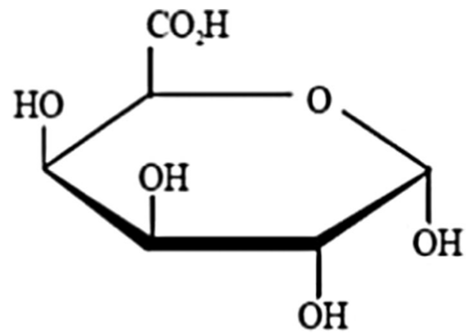

Fig. 2 Structure of the galacturonic acid

group content, and molecular mass. Generally, the chemical composition of pectin extracts reveals the presence of proteins (mainly bound to neutral sugar side chains), which are considered as contaminants or a non extracted component of the polymer. The presence of these proteins can be explained because due to its growth mechanism the primary cell wall of plants contains both polysaccharides and structural proteins [15]. Changes in the pectin structure, and thus in its molecular properties, have an impact on its quality and physicochemical properties such as size and solubility which are associated with chemical and enzymatic reactions during the pectin isolation process affecting the composition of the extracts [16].

The emulsifying properties of pectin are related to the presence of proteins and their molecular characteristics such as degree of acetylation and average molecular weight and extrinsic characteristics such as pectin concentration and pH of solution [15, 31, 32]. The emulsifying activity is greater for pectins with a high content of acetyl-esterified. The literature reported that acetyl groups, like ferulic groups, can promote the increase of the interfacial activity of pectin, which is also associated with the presence of methyl groups [32–35]. The influence of the methyl ester groups on the surface activity of the pectin molecule is because they are more hydrophobic than the carboxyl groups [36]. Regarding the molecular mass, this is a fundamental parameter that determines the ability to guarantee the stabilization of emulsions [15, 32, 37]. The reduction of the length of the pectin chain, through acid hydrolysis, decreases the interfacial tension and, consequently, decreases the size of the emulsion droplets [32, 33]. Siew et al. [38] and Funami et al. [39] studied the influence of neutral sugar chains on the emulsifying capacity of pectin and observed the preferential adsorption of pectin chains rich in neutral sugars in oil droplets.

Modifications in Pectin for Different Applications

Given the different demands for industrial applications of pectins, physical, chemical, and enzymatic changes are made in the pectin structure to improve its functionality. As a result, these modifications promote changes in the pectin physicochemical properties, such as molecular change, degree of esterification, molecular mass, and basic chemical structure [40]. These changes ultimately result in changes in the pectin biological activities like for example antioxidant [41], anticancer [42], prostate carcinoma, colon carcinoma, and breast carcinoma [43] activities. Modification of pectin can be achieved using techniques such as substitution (alkylation, amidation, thiolation, and sulfation, etc.), chain elongation (crosslinking and grafting), and depolymerization (acidic or enzymatic hydrolysis, elimination of β and mechanical degradation) [44].

Regarding the carboxylate alkylation technique, the alkylating carboxyl group of the COO-alkyl ester group is used to increase the hydrophobicity of the pectin. If the pectin is alkylated with the methyl group, it is called methoxylation. The esterification of pectin with methanol, in the presence of sulfuric acid or hydrochloric acid as a catalyst, is a usual method used for the methoxylation [45]. Opposite to pectin methoxylation, demethoxylation is a reaction that eliminates the methyl esters of the esterified galacturonic acid residues and converts the C-6 carbon into the carboxylic acid. A relevant issue is the methoxylation pattern, as it can largely affect the pectin properties, influencing depolymerization rates [44, 46].

Acetylation is one of the most relevant alkylations of hydroxyl groups in pectin, because pectin extracted from some plants, for example, potato and sunflower, can be naturally acetylated in O-2 and/or O-3 of galacturonic acid units, which makes gelation difficult. Complete gelation inhibition occurs when one in eight D-galacturonic acids is acetylated in O-2 or O-3 [44, 47]. Acetylated pectin can be utilized as a stabilizer and emulsifier. Besides, acetylating agent-modified pectin has shown promise in modifying the release pattern of ibuprofen, a weakly acidic drug, throughout the gastrointestinal tract, due to the reduced polarity and solubility of pectin. Generally, acetylation is performed in types of solvent catalyst systems with acetic anhydride [32, 48].

Amidated pectin can form stronger gels, mainly at low pH, due to the establishment of hydrogen bonds between the amide groups [49, 50]. However, the simplest amidated pectin most applied industrially contains the primary amino groups $–CO–NH_2$ that is particularly useful for the food segment due to its excellent gelling properties. The amidated pectin gels are thermoreversible. Thermoreversibility indicates when the heating is transitioning to a liquid and a solid after cooling. In addition, it is allowed to be prepared in hydrogel spheres that can be used in the administration of specific drugs in the colon and also retain insulin in order to make it oral [44]. The common method of pectin amidation is ammonolysis of methyl ester groups with ammonia in anhydrous methanol. It can be classified as a type of alkaline demethoxylation by the action of ammonia in the ester groups, in which amino groups replace some of the methyl ester groups. Amidation can also be prepared by reacting pectin with amino acids [24, 44].

Quaternization is reported as an efficient method for assigning new functional properties to polysaccharides, which can transform ionic hydrocolloids into their cationic derivatives [44]. Fan et al. [51] prepared quaternized pectin by reacting pectin with 3-chloro-2-hydroxypropyltrimethylammonium chloride in the presence of sodium hydroxide obtaining pectin with exceptional absorption capability, moisture retention ability, and pronounced antimicrobial activity. This type of pectin derivative can also be used in pharmaceutical, packaging, preservatives, and cosmetics fields.

The thiolation technique also encloses the interest for the development of the “second generation” of mucoadhesives, since the mucoadhesive properties of natural polysaccharides, which belong to the “first generation,” can be improved by their thiolation [52]. Sharma, Ahuja, and Kaur [53] prepared nanoparticles of thiolated pectin using timolol maleate as a model medicine and magnesium chloride as an ionic crosslinker and verified that thiolated pectin is a promising mucoadhesive polymer for the ocular distribution of timolol maleate.

Sulfation is the method in which sulfate groups replace the hydroxyl groups of the polymeric structure. Through sulfation, significant effects are obtained on the physiological functions of polysaccharides, such as anticoagulant, antithrombotic, contraceptive, antioxidant, and anti-inflammatory infection [54, 55]. Sulfuric acid, chlorosulfonic acid, monomethyl sulfate, or sulfamic acid is generally utilized in the presence of formamide, trimethylamine, or pyridine [44]. However, the use of these agents can degrade the polysaccharide chain during the reaction; besides, it can promote pollution problems. Therefore, other sulfating agents were developed. For example, Fan et al. [56] synthesized apple pectin sulfates in aqueous solution with trisulfonated sodium amine $[N(SO_3Na)_3]$ as a sulfating agent.

Oxidation of pectin has also received attention in recent years since oxidized pectin has more reactive groups and faster degradation than non-oxidized when used in supports for controlled drug delivery [57]. The reactions take place in the –OH groups at the C-2 and C-3 positions of the galacturonic acid units and can be carried out by the use of sodium periodate, with the formation of two aldehyde groups in each oxidized monomer, by breaking the carbon- linkage carbon [44].

Pectin is used in several industrial applications. Therefore, for a given application, different characteristics are required. Such characteristics can be obtained through modifications in the molecule structure to obtain knowledge of the physical and chemical properties and to assign adequate conditions to meet the necessary functions.

Degree of Pectin Esterification

Pectins have part of the esterified galacturonic acid main chain carboxyl groups, the most common substituent being the methyl group. Other substituents include ethyl and acetyl groups. Therefore, this substitution is expressed as the degree of methylation (DM) or degree of esterification (DE). DM corresponds to the total percentage of esterified galacturonic acids with methyl groups, while DE corresponds to the ratio of esterified galacturonic acid clusters to total galacturonic acid clusters [58].

The degree of esterification (DE) plays an essential role in the gelling capacity of pectin, being a parameter to indicate the physical, functional, and technological properties. Pectins are commercially classified into high esterification pectins (when they contain over 50% of their esterified carboxylic groups) and low esterification pectins (when 50% or less of these groups are esterified) [59].

Both pectin classifications have industrial applications. However, high DE pectins are employed in products with sugar presence, usually at pH below 3.6. Regarding the time required for gelation, as the DE increases, the time decreases [30, 60–62]. Low DE pectins are used in the presence of calcium, with a pH range of 2.6–6.0. They are chemically more stable to moisture and heat than high DE pectins. High DE pectins stored in powder lose their ability to form gels when stored in hot, humid conditions [63].

Pectin Extraction Sources

Pectin is one of the polysaccharides present in the plant's cell wall along with cellulose, hemicellulose, and lignin and can be extracted from various natural sources. It is present in abundance in the walls surrounding the growing and dividing cells and in the junction zone between the cells with secondary walls. It is a component of all superior plant walls and the walls of gymnosperms, pteridophytes, bryophytes, and Chara, a carophyllous algae believed to be the closest relative of terrestrial plants [64].

Different plant species may have different pectin contents. Physicochemical properties vary according to the source, degree of fruit maturity, harvest time, storage time, the process used during extraction, and subsequent treatments [65].

Literature over the last few years has shown that there is a significant difference in pectin content according to fruit varieties. Considering the source from which pectin is extracted, pectin may vary in gel-forming capacity due to differences in the size of the polygalacturonic acid chain and the degree of esterification of its carboxylic groups [66].

Many sources are currently employed to obtain pectin; the main ones are listed in Table 1.

Table 1 Main sources used for pectin extraction

Source	Yield (mg pectin/g dry peel)	Reference
Banana peel	142.3	[67]
Jackfruit peel	151.9	[68]
Orange peel	248.0	[69]
Grapefruit peel	280.0	[69]
Lemon peel	306.0	[69]
Passion fruit peel	303.0	[70]
Cocoa peel	70.0	[71]
Fig seed	60.7	[10]
Mangosteen peel	121.0	[72]
Guava pulp	136.6	[5]
Mango peel	185.0	[6]
Beet pulp	162.0	[29]
Apple pomace	209.2	[73]

Factors Affecting Pectin Extraction

During the extraction of pectin from the passion fruit peel, some factors must be taken into account, as they can alter the process yield. These factors are discussed below:

- pH: It is evaluated as one of the most critical parameters. As shown in the literature, extraction yield increases with decreasing pH, because the acid condition favors pectin extraction [3].
- Time: It should be enough for the solvent to dissolve a sufficient amount of the product since the mass transfer occurs until equilibrium is reached. Thus, the longer the time, the higher the yield. However, once equilibrium is attained, time should not be extended, as very long times can cause pectin degradation [74].
- Temperature: The higher the temperature, the higher the rate at which the solvent dissolves a solute, hence the higher the extraction yield. On the other hand, studies that evaluated the influence of temperature on the degree of esterification proved that high temperatures have a reducing effect on the degree of esterification [8].
- Solvent: A low-viscosity solvent must be used to be able to easily enter the bed of dry substances [75]. Research on the type of solvent seeks to favor extraction, ease of purchase, and economic and environmental benefits, mainly due to problems with the use of strong acids, such as toxicity and difficulty in treating the effluents generated during the process, which causes impacts [3]. In this sense, studies have been carried out to replace mineral acids with organic acids [76]. With the increasing application of green chemistry, attention is focused on solvents called ecologically correct. With unique characteristics, biodegradable deep eutectic solvents (DES) are suitable for

pectin extraction due to their low volatility at room temperature, non-flammability, and miscibility in water [77].

- Agitation: Pectin yield tends to increase significantly with increasing agitation rate as agitation causes increased mass transfer rate and decreases diffusion layer thickness, which consequently improves extraction [3].
- Surface area: It is proportional to the mass transfer rate, i.e., the smaller the granulometry of the raw material, the better the mass transfer in the extraction step [75].
- Solid-Liquid Ratio: According to published studies [8, 9, 61, 74, 75, 78, 79], dry peel and solvent ratios are generally maintained at the ratio 1:10 and 1:50 m/v. Based on the results obtained, when using a proportion lower than 1:10 m/v, a low extraction was extracted, this can be justified by the fact that the amount of solvent is insufficient for the solubilization of pectin. An increase is found in the solid-liquid relation (up to 1:30 m/v) increments in the pectin yield due to the rise of dissolution capacity. However, an additional increase does not conduce to significant effects [8].

Conventional Pectin Extraction

Conventional pectin extraction can be performed by acidic or basic aqueous medium. Alkaline extraction results in pectins with a low degree of esterification due to the saponification of the ester group. The acid extraction generally results in pectins with a high esterification degree, close to the naturally occurring esterification degree. Another advantage of acid extraction is that as a result, pectin is commonly enriched with galacturonic acid units [10, 80].

On an industrial scale, acid extraction is generally performed in which strong acid solutions such as nitric, phosphoric, sulfuric, and hydrochloric acid are used, under heating. However, mineral acids have some disadvantages, such as equipment corrosion and difficulty in treating process waste. For these reasons, many studies are currently seeking to replace strong acids with organic acids such as citric, lactic, malic, acetic, or tartaric [81]. Organic acids cause less pectin depolymerization due to the low dissociation capacity [67] and, therefore, have been used by some researchers, such as Liew, Chin, and Yusof [74], Yapo [82] and Pinheiro et al. [61]. A study with citric, nitric, and sulfuric acids showed that the type of acid strongly influences the macromolecular and gelling properties of the extracted pectin [82].

In the specific case of passion fruit, the process begins with the preparation of the raw material, that is, the obtaining of the flour of the passion fruit peel through the drying and grinding operations, being used in the extraction step. The other steps employed to obtain pectin involve purification of liquid extract and isolation of pectin by precipitation and drying [83]. Extraction from the passion fruit peel flour in an acidified solution occurs for a set time and temperature. Purification of the liquid extract containing soluble pectins is generally accomplished by filtration and/or centrifugation. Subsequently, the filtrate is cooled to a temperature of ± 4 °C. The cooled solution proceeds to precipitation by the addition of two to four volumes of alcohol (ethanol, methanol, isopropanol), followed by washing with alcohol successively to remove alcohol-soluble compounds such as salts and free sugars. These solvents can be used due to their polarity [5, 61, 78]. If pectin should be addressed to the food industry, the use of toxic solvents should be avoided, and green solvents, such as ethanol, are indicated. For extractions of food products using toxic solvents for human beings, it is necessary the complete removal of the solvent to guarantee its absence in the final product. Evaporation is one unit operation that could be used to reach such purpose. Drying is performed at temperatures below 50 °C [81]. The general process for obtaining pectin from passion fruit peel flour is shown in Fig. 3.

Given the various methodologies used in the conventional extraction of passion fruit peel pectin, it is clear that there is a need to gather information on the studies performed in order to verify the influence of changes in the variables and methods used.

Based on this, information summarizing the studies found in the literature involving conventional extraction of passion fruit peel pectin is presented in Table 2.

Given the above, it is confirmed that pectin can be efficiently extracted from the passion fruit peel, with an average yield of 143.5 mg of pectin/1 g of the dry peel. Besides, the importance of performing statistical planning when conducting a survey is highlighted, since there is a strong influence of variables, both on yield and the quality of the extracted product.

Alternative Methods for Pectin Extraction

Due to the prolonged warming duration of conventional pectin extraction, the need to study faster alternatives for extraction has emerged. Some alternatives include enzyme-assisted extraction, use of subcritical fluids, ultrasound-assisted extraction, microwave-assisted extraction, the combination of these methods [84], high hydrostatic pressure, deep eutectic solvents, and natural deep eutectic solvents.

The extraction with enzymes is noteworthy due to the ability of enzymes to catalyze reactions, reduce the extraction time and the volume of alcohol used in the precipitation step, and increase the yield. One of the prominent enzymatic methods for pectin extraction is enhanced in protopectinases, which are microbial enzymes capable of solubilizing protopectin pectin. Although many advantages, the application of this technique on an industrial scale is linked to several factors, especially the cost of enzymes. As large volumes of raw materials are used

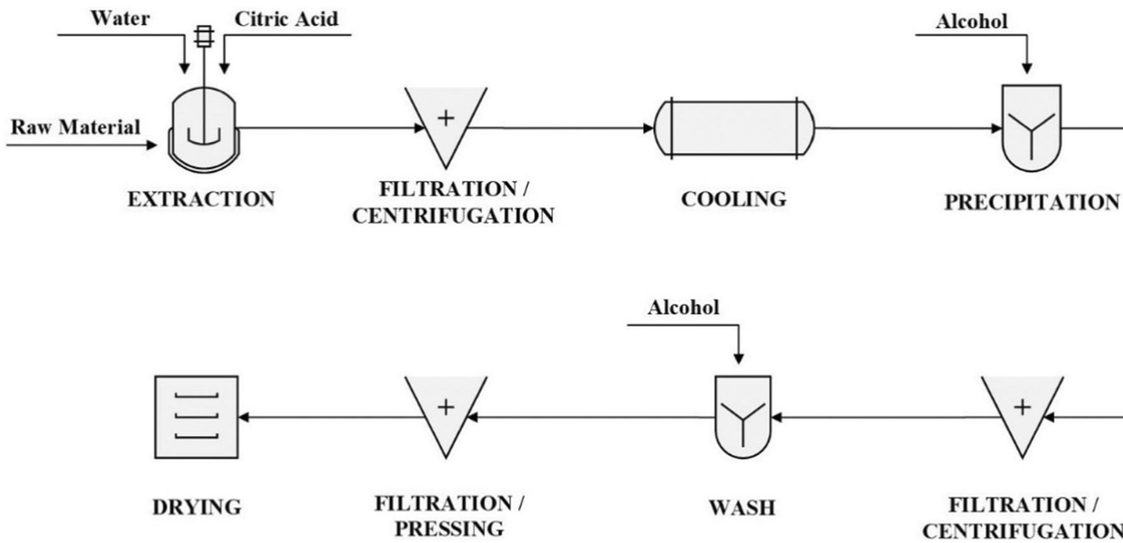

Fig. 3 The general process for obtaining pectin from passion fruit flour

in industry, enzyme extraction makes the route more expensive and less attractive. Also, scaling up this process may be hampered by changes in environmental conditions such as temperature and nutrient availability [85, 86].

Extraction with subcritical water occurs with the use of high-pressure liquid water as a solvent, being able to reach higher temperatures without phase change [87]. The process occurs with water temperature variation between the boiling point (100 °C) at 1 atm and the critical point (374 °C), under pressure necessary to keep the water in the liquid state [88]. Among the advantages presented by this process are the faster extraction process and the saving of acid solvents [87]. In this method, hydrolysis occurs without the use of acid, which eliminates the treatment of liquid waste generated and the need for corrosion-resistant equipment [87, 89, 90]. Therefore, extraction with subcritical water is known as a green method and can be successfully used to extract value-added products, such as pectin [76]. The supercritical CO_2 extraction is frequently used for extracting bioactive compounds from fruit peels [91–93] and is being utilized for polysaccharide extraction [94, 95]. However, the high cost of implementation of the two processes, extraction with subcritical water pressurized and extraction with supercritical CO_2, in the industry can be a hindrance, and the inadequate control of process conditions can lead to hydrolysis of the pectin chain [96].

Ultrasound-assisted extraction (UAE) is based on a process called cavitation, produced by sound waves (ultrasound is a special type of sound wave). These waves pass through a medium creating compression and expansion. This process leads to cavitation, that is, the production, growth and collapse of bubbles. The cavitation occurs at high temperatures and pressures. The kinetic energy of the movement is converted into heating of the medium. UAE has many advantages, such as reduced extraction time, energy consumption and equipment size, more effective mixture, and increased production,

Table 2 Results of studies involving the conventional extraction of pectin from the passion fruit peel

Levels assessed	Best results		Reference
	Yield (mg pectin/g dry peel)	DE (%)	
Citric acid concentrations (0.0002–0.0416 mo L^{-1}); 14.66–120 min; 60–96.82 °C; solute/solvent ratio = 1:30 m/v	131.8	86.76	[79]
Nitric acid (pH 0.30; 1.0; 2.0; 5.0); 10–60 min; 85 °C; solute/solvent ratio = 1:30 m/v	109	86.75	[75]
Citric acid (pH 2.0; 3.3; 4.5); 30–120 min; 70 °C; solute/ solvent ratio = 1:25 m/v	145	54.87	[74]
Nitric acid (50 nM); 25 min; 80 °C; solute/solvent ratio = 1:50 m/v	122	72.2	[78]
Hydrochloric acid (pH 1.5; 2.0; 2.5; 3.0); 30–90 min; 70–98.7 °C; solute/solvent ratio = 1:10; 1:15; 1:20; 1:30; 1:40 m/v	148	–	[8]
Precipitation (alcohol, dialysis, and metal ions); citric acid (pH 1.8); 60 min; 75 °C; solute/solvent ratio 1:25 m/v	75	–	[9]
Citric acid concentrations (0.086–2.91%); 17–102 min; 97 °C; solute/solvent ratio = 1:50 m/v	274	78.59	[61]

which is considered more environmentally friendly than the conventional method. In contrast, ultrasound-extracted polysaccharides have lower viscosity, molecular mass, and degree of esterification [97, 98].

Microwave-assisted extraction (MAE) is a green method in which a polar solvent absorbs microwave energy and consists of two oscillating perpendicular fields: electric and magnetic fields. Among the advantages of this form of extraction, it is worth mentioning that during heating, there is no temperature gradient, as is the case with conventional thermal processing [99]. The control inside the oven makes the system safer since inadequate closed system control can result in user and equipment risks and extraction time becomes reduced, as well as solvent requirements and equipment size can be considerably reduced. On the other hand, despite the reduced volume of acidified water used in the process, the fact that this acidic solvent is used and needs to be discarded creates the corrosion problem and subsequent wear of the equipment [84].

A new technology involving the combination of the UAE and MAE resulted in the method of ultrasound-assisted microwave extraction (UAME), for which ultrasound is used as a pre-treatment step, followed by microwave treatment [100]. According to Bagherian et al. [18], this method provides a better effect on the qualitative and quantitative characteristics of the extracted pectin when compared with the individual use of UAE and MAE. The authors extracted pectin from grapefruit and obtained results of 191.6, 278.1, 179.2, and 318.8 mg pectin/g of dry peel for conventional treatments, MAE, UAE, and UAME, respectively.

Surfactant-assisted microwave extraction (S-MAE) is also an alternative extraction method [101]. Surfactants are amphiphilic molecules with a hydrophilic head and a hydrophobic tail. The nonionic surfactant had better extraction efficiency than the ionic surfactant, as reported by Hosseinzadeh, Khorsandi, and Hemmaty [102]. Su et al. [103] evaluated the extraction of pectin from the orange peel using the MAE and S-MAE methods, as surfactants were tested with Tween-80, Tween-20, polyethylene glycol (PEG) 4000, PEG 8000, sucrose fatty acid esters (SE), and sodium dodecyl sulfate (SDS). S-MAE offers advantages such as greater efficiency of extraction, reduction of time, and better quality of pectin. The yields obtained by the conventional, MAE, and S-MAE methods were 275, 280, and 328 mg pectin/g dry peel, respectively [103].

High hydrostatic pressure (HHP) is an alternative nonthermal technology to traditional heat treatment reported as a green processing technique capable of providing a higher yield compared with conventional methods [75, 104, 105]. To obtain satisfactory results from the HHP treatment, the three process parameters such as pressure, temperature, and time must be adjusted appropriately. Generally, in most pectin extraction studies, the pressures used are in the range of 100 to 600 MPa, temperatures vary from 10 to 50 °C, and the processing time from 5 to 30 min [67, 104–107]. HHP has been used for the valorization of by-products, such as orange peel, lemon, potato, and beet as unconventional resources for pectin production [104–107]. An advantage of the method is less use of solvents. Oliveira et al. [67] evaluated the potential for high pressure to extract pectin from the passion fruit peel. The results showed values of extraction yield almost doubled, indicating HHP as an effective, time-saving, and ecological method for extracting pectin from the passion fruit peel.

Bearing in mind that mineral acids have been replaced by organic acids, it should be noted that deep eutectic solvents (DESs) are interesting for pectin extraction, as they are not volatile at room temperature, non-toxic, and of low cost [75, 77, 108]. For the formation of DES, at least two compounds are used, which consist of the eutectic mixture of bases and Bronsted-Lewis acids in a particular proportion. The system is represented by a cation and an anion from organic salt and hydrogen bond–donating species (for example, choline chloride) from a hydrogen bond donor (for example, citric acid). This mixture is formed in a certain molar ratio, and then it is stirred and heat until a transparent liquid form. DES provides greater interaction with plant material and therefore can result in a significant increase in pectin extraction [76, 109], acting as an appropriate medium for extracting polar and non-polar components showing themselves as an effective means for the extraction of pectin [76, 110, 111].

Even more environmentally friendly than DESs, natural deep eutectic solvents (NADESs) are composed of natural ingredients such as amino acids, sugars, and carboxylic acid. Some studies mention the preparation of NADESs based on the molar ratio of choline chloride and hydrogen bonding donor, through heating and mixing, until obtaining a homogeneous and stable mixture without visible precipitate. It is noteworthy that the preparation based on choline chloride and organic acid is a favorable option for extraction. According to the literature, the utilization of NADESs carried out to high extraction yields when compared with the use of their separated compounds [60, 112], due to the wide range of physical characteristics and extractive abilities of NADESs. The extraction differs from the conventional method only during precipitation, in which a larger amount of ethanol is used. Also, evaporation becomes easier, allowing the reuse of NADESs, which is essential to make the process economically viable [60, 112–116]. Elgharbawy et al. [60] extracted pectin from pomelo peel using NADESs and verified both high extraction yields and an average degree of esterification.

Several studies have demonstrated the application of alternative methods for pectin extraction from passion fruit peel, some of which are shown in Table 3.

In summary, the alternative methods studied for pectin extraction are well established and feature innovative techniques. However, there is a need for process improvement, not only to maximize pectin yield and quality but for

Table 3 Studies using alternative methods for pectin extraction from the passion fruit peel

Method	Yield (mg pectin/g dry peel)	Reference
Enzymatic extraction	258.0	[117]
Pressurized process	159.5	[118]
Ultrasound-assisted extraction	149.8	[118]
Ultrasound-assisted extraction	126.7	[67]
High hydrostatic pressure	143.4	[67]
Microwave oven	302.9	[70]

industrial-scale application, which is still a hindrance due to the high cost. Besides, it is worth highlighting the importance of performing statistical planning when conducting a survey, since there is a strong influence of variables, both on yield and the quality of the extracted product.

Pectin Applications

The food applications of pectin are diverse, from drinks [119, 120], dairy products [121], meat processing [122], cosmetics, and polymers [123].

Pectins are featured as functional food ingredients of high commercial value due to their technological properties. For this reason, they are used as thickeners, gelling agents, and stabilizers in the production of many food products [4, 61, 78, 124].

Due to its hydrophilic character, due to the presence of polar groups, pectin has the property of involving a large amount of water, producing a viscous solution. Because of this capacity, it is employed in the preparation of jellies, fruit jams, fruit juices, and other branches of the food industry [125]. One of its main applications is as a thickening agent, being used in the formulation of some concentrated dairy products, such as yogurts. Pectin for home use is often sold as a complementary ingredient and is diluted with sugar and citric acid in the proper concentration to produce jelly. Its use as a food additive is usually between 0.5 and 1.0% [78].

Pectin's ability to increase viscosity and stabilize emulsions enables its use in suspensions in liquid pharmaceutical preparations. They are appreciated as a natural textured agent in creams and oils and employed as a stabilizer and thickener in hair lotions, body lotions, and shampoos. Its use can be employed in wound healing preparations, special medical patches, deodorants, toothpaste, throat lozenges, and syrups [3].

Pectin also is known to have a positive influence on cholesterol, lipoprotein, and bile acid metabolism; plasma glucose levels after a high carbohydrate meal; atherosclerosis mechanisms; and weight reduction. It has properties to be used in the treatment of disorders related to overfeeding, due to its ability to interact with water, which results in a feeling of satiety, thus reducing food consumption [61, 126].

Pectin can be used as a biosorbent because of its strong affinity for metal ions and is considered in many studies [127]. Pectin-based hydrogels have been employed in the elimination of aqueous solution pollutants [128, 129].

It is known for its relationship to colon cancer prevention as it is a soluble dietary fiber. It is reported that soluble dietary fiber cannot be digested in the gastrointestinal tract but can be degraded and fermented by the colon microbiota, which is useful for reducing the risk of colon cancer [130, 131].

It can be used to produce biodegradable films, paper substitute adhesives, foams, and plasticizers. In the tobacco industry, it is used as a natural glue for cigar and cigar manufacture [20, 132].

Besides, pectins may be used alone or in combination with other biopolymers to prepare micro- and nano-capsules containing bioactive ingredients [133, 134].

Ways to Market Pectin

Since many factors influence the extraction process, pectin rarely presents a similar composition from one batch to another. For this reason, the commercial product is usually added with sugars in order to standardize the gelation process as to application and speed. Pectin is marketed as a powder with varying colors depending on the raw material from which it is extracted and the processing and/or storage conditions. They are obtained in commercial form, mainly light brown, and may have white, beige, yellow, pink, grayish, or darkened/caramelized samples [78, 82].

Final Considerations

As presented throughout this manuscript, in the literature, it is possible to find several methodologies and variables for the pectin extraction process from passion fruit. Still, it is noted that the industrial process is commonly performed by the conventional methodology because despite the alternative methodologies have advantages such as high yield and shorter extraction time, the disadvantages are still significant, especially when it comes to the high cost for the implementation of the process.

Thus, we realize the need for further research with advances in viable, efficient, and ecological processes, so that they can be implemented in the future in the industry.

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