published by Ural Federal University
eISSN 2411-1414
chimicatechnoacta.ru

REVIEW
2024, vol. 11(2), No. 202411213
DOI: 10.15826/chimtech.2024.11.2.13

Reviewing twenty years of patents on ultrasonic-assisted pectin extraction from food and food waste

Aleksandr A. Drannikov [ab] *, Marina E. Trusova [a], Antonio Di Martino [a]

a: Research School of Chemistry and Applied Biomedical Science, National Research Tomsk Polytechnic University, Tomsk 634050, Russia
b: Faculty of Physical Engineering, Novosibirsk State Technical University, Novosibirsk 630073, Russia
* Corresponding author: aad12@tpu.ru

This paper belongs to a Regular Issue.

Abstract

A growing number of alternative agro-industrial waste sources are being considered as possible sources of pectin because of the growing market demand. Pectin's multifunctionality stems from the nature of its molecule, which varies in its chemical structures, physicochemical characteristics, and possible uses based on the extraction methods and sources used. Green methods utilizing microwaves and ultrasound are becoming more popular, in addition to the traditional extraction of pectin, which relies on the use of acids and/or chelators. As a result, this review focuses on patents related to the extraction of pectin from food and food waste using ultrasound assisted technologies. The following patent databases were searched using International Patent Classification (IPC) codes and relevant keywords: PatFT-AppFT, Espace Patent Search, Information Retrieval System, Eurasian Patent Office Search, and Patentscope. Based on the analysis findings, which cover the years 2003 to 2023, 54 pertinent documents—the majority of which were issued in China—were chosen and categorized into multiple groups based on their objectives, methods for extraction intensification, and raw materials. According to the data, 2017 had the greatest number of patent registrations in the industry.

Keywords

pectin
ultrasound
extraction
food waste
patent

Received: 01.05.24
Revised: 24.05.24
Accepted: 24.05.24
Available online: 04.06.24

Key findings

- A total of 54 patent documents emerged between 2003 and 2023, with the greatest number occurring between 2016 and 2017.
- Five methods were implemented to intensify the extraction process: surfactant, enzyme, microwave, vibration, and supercritical solvents application.
- There is a growing interest in combining or replacing conventional extraction techniques with ultrasound assisted extraction.
- Using food waste as the main pectin source correlates with the current need for reducing its environmental impact.

1. Introduction

Pectins are a class of complex carbohydrates that are mostly present in plants and consist of galactose and rhamnose connected to β-(1-4)-linked D-galacturonic acid [1]. The sugar moiety's carboxyl group in the pectin structure can be partially esterified with a methyl group and partially or completely neutralized with one or more bases. Pectinic acid is a polygalacturonic acid that contains many methyl ester groups. In turn, pectic acid is the result of polygalacturonic acid's lack of methyl ester groups.

Therefore, the term "pectin" refers to water-soluble pectic acids that, in the right circumstances, can form gels with sugars and acids and have different degrees of neutralization and methyl ester concentration [2]. A high methoxyl pectin content makes it difficult for it to gel on its own; instead, it needs a high concentration of both sugar and acid to do so. Conversely, in the presence of specific metal ions, low-methoxyl pectin readily forms a gel without the need for sugar [3]. Pectins can be categorized as low methoxyl pectin (<50 % esterification) or high methoxyl pectin (>50 % esterification) based on the amount of methoxyl present [4,5]. Methoxyl content is a crucial factor that influences pectin's commercial properties and its use in industry [6, 7].

Pectin is primarily used as a gelling, thickening, and stabilizing ingredient in the food companies [8]. The traditional use is to prepare jams or marmalades. Pectin also makes low-calorie jams gel stronger and decreases syneresis in jams and marmalades [9]. It is approved as fat and sugar replacer [10]. Besides, recent results demonstrate high potential of pectin for the formation of biopolymer films that are widely used in food coatings [11].

The second largest market for pectin is the health care sector. Since it was discovered that pectin can remove a variety of harmful substances from the human body, including heavy metals [12], long-lived radioactive elements like cesium, strontium, yttrium, and other nuclides with decades-long disintegration times, the interest towards it has increased significantly over the past three decades [13]. Nitrates, free radicals, metabolic products, xenobiotics, biogenic toxins, anabolic steroids, and other hazardous chemicals as well as compounds stored in the body, such as cholesterol, bile acids, urea, mast cell products, and many other toxins, are expelled from the body using pectin's absorbent quality [13 – 15].

Pectin is an effective antioxidant as well. Beyond treating digestive issues [16], wound healing [17], preventing colon cancer [18, 19], antibacterial therapy [20] and many other ailments, its use in healthcare extends far beyond these boundaries. Keeping diabetic patients' glycemic index stable is one of pectin's most crucial uses [21].

Indeed, a few of countries have put laws into place requiring the use of pectin to treat employers who work in dangerous environments.

Pectin is used by the pharmaceutical industry to make children's granules [22], suspensions [23], wound treatments [17], nutrient media [24], and as a viscosity agent in emulsions for absorbing heavy metallic ions [25].

Pectin is also used in cosmetology to make a variety of gels [26] and face masks [27], among other products. Pectin is employed in a number of technical processes, including the synthesis of D-galacturonic acid.

Overall, pectin is a valuable ingredient that is in high demand in the aforementioned industries as well as in the dairy, bread, fragrance, cosmetics, canning, pharmaceutical, textile, typography, and other sectors.

Commercial pectin is currently extracted primarily from citrus peels (85.5%) and apple pomace (14.0 %), with a small fraction extracted from sugar beet pulp (0.5 %) [28]. Pectin obtained from various sources and extracted via various techniques may have distinct molecular configurations. Furthermore, the maturity and growth stages of the fruit and parent plant, respectively, might affect the pectin structure [29].

Pectin is coded E440a for Low Molecular Pectin (LMP) and High Molecular Pectin (HMP), and E440b for amidated pectin. However, due to rising interest in food byproduct valuation and strong worldwide demand, the global pectin market is expected to reach a valuation of USD 1.0 billion by 2019 and is expected to rise by 50 % over the next six years [30]. This encouraged researchers to investigate new pectin sources. Several studies have focused on the extraction and characterization of pectin from different agro-industrial wastes, such as mango and banana peels [31, 32], pumpkin and melon peels [33, 34], cocoa pod husks [35], eggplants [36], tomatoes [37], and potato peels [38].

Pectin extraction is a multi-step physico-chemical process where temperature, pH, solvent characteristics, source characteristics, and extraction duration affect the solubilization, hydrolysis, and extraction of pectin from plant tissues [39].

The following are the primary obstacles in the pectin extraction process: blanching and drying raw materials, a large amount of water, gathering and using the pectin source (typically the leftovers from fruit and vegetable processing industries), chemicals essential to creating the right conditions for pectin extraction, large amounts of precipitating agents such as various kinds of alcohol (up to 10 L for the production of 10 g of pectin), and high energy consumption by machinery for mechanical grinding, freeze-drying, and heating are all required during the extraction process [40].

In the last decades, conventional acid extraction of pectin has been adopted. It is carried out at elevated temperatures (50–100 °C) for up to 2 h [41]. The choice of solvent for extraction is determined by several factors, including its ability to dissolve pectin, selectivity, stability, renewability, and viscosity [4]. However, degradation of pectin in acid extraction leading to loss of its quality, and potential impacts of effluents of acid extraction on environment have encouraged use of alternative sustainable extraction methods such as microwave, ultrasonication, high pressure and pulsed electric field assisted extractions [42].

These green extraction protocols and new techniques like applying ultrasound or microwaves demand less energy and fewer reagents, have shorter extraction times, and are less hazardous. They also reduce processing time and enhance the use of environmentally friendly extractants. Further investigations are still needed to develop novel extraction techniques that will extract pectin in a way that is economical, reliable, safe for the environment, and efficient.

Herein we report a patent analysis described in Global patent literature in the period 2003–2023 focused on the ultrasound assisted extraction (UAE) of pectin from food and food waste. Additionally, the influence of the extraction on the pectin properties, in particular molecular weight and esterification degree, is reported, as they strongly influence the industrial application of the pectin.

2. Methodologies

The databases used for the patent search related to the pectin ultrasonic extraction from different food waste were:

- Patentscope [43];
- Espace Patent Search [44];

 DOI: 10.15826/chimtech.2024.11.2.13

- Information Retrieval System [45];
- Eurasian patent Office Search [46];
- PatFT-AppFT database [47].

The search period set was for the last twenty years, between 2003 and 2023, to cover the most updated patent registered worldwide.

2.1. Search Equation

In this database, the search query was developed with keywords relating extraction methods to different sources of pectin. The following keywords in combination with the boolean operators were used: (TITLE -KEY (pectin*) AND TITLE-ABS-KEY (ulras*ound) AND TITLE-ABS-KEY ("extraction* method*) AND TITLE-ABS-KEY (food* waste).

We used International Patent Classificatory (IPC) to optimize the search. Regarding IPC the main code we applied was C08B 37/06, with all related subclasses, groups, and subgroups. This code considers inventions "Pectin; Derivatives thereof" [48].

2.2. Filtering of information

Once all the patents registered were identified, a pre-selection was made, based on the topic of pectin extraction from food and food waste by UAE reported in English language. This pre-selection was carried out by reading and analysis of each patent's information presented in the abstract. At this stage, patents dealing with the extraction of compounds different from pectin, those not mentioning extraction methods or not related to the use of ultrasound, were excluded except those in which pectin is extracted among the group of compounds.

2.3. Patents review and data relation

After the selection of the patents, a thorough analysis of each was conducted to determine the procedures and operational settings that affect the pectin's quality, yield, and physicochemical characteristics. The information was located, gathered, and arranged. The following variables were selected for analysis: UAE intensification method; the food and food waste used as biomass; the yield obtained and the quality of the extracted pectin according to the degree of esterification; the extraction parameters (pH, temperature, extraction time, mass (g) / volume (mL) ratio).

3. Results and Discussion

According to our research criteria, we selected 54 patents across the specified databases in the period between 2003–2023. These comprise 36 applications and 18 granted patents. In Figure 1 the evolution of the patent documents specific to the UAE of pectin from food and food waste is illustrated.

The first patent was filed in the depicted area in 1998 by Konovalov A.I. et al. [49], but no more applications were made until 2008.

As of now, most of patents in the field are claimed by Chinese companies (85.19 %) mainly located in south-east provinces such as Chongqing, Zhejiang, Guangxi which are among the top citrus producers [50] followed by Russian group of companies (11.11%) located in the European part of country, which is the most promising for agriculture production development [51], US and Mexican (each 1.85%).

Through the analysis of revealed patent documents, four main research directions followed by the inventors have been identified. Ultrasound-assisted extraction is an innovative and promising extraction technique that aims to enhance the yield and quality of pectin, reduce the processing time, energy, and solvent consumption as well as lower the cost of production. The UAE process uses acoustic cavitation effects that result in the damage of plant cell walls and enhanced contact between solvent and target content of the cell, which leads to an increase in mass transfer and results in high pectin yields [52]. For this reason, 1/3 of all patents claim the integration of ultrasound to increase the extraction yield and simultaneously reduce the environmental impact and lower the cost of the whole process [53–75].

Considering the research parameters, the Southwest State University (Federalnoe gosudarstvennoe byudzhetnoe obrazovatelnoe uchrezhdenie vysshego obrazovaniya "Yugo-Zapadnyj gosudarstvennyj universitet) from Russia is one of the key inventors, holding the property rights on two patents focused on the intensification of pectin extraction from the beet residues [74, 75] which are annually available due to the large production scale of beet in the Russian territory [76]. It has to be mentioned that sugar beet pectin possesses physicochemical differences to conventional pectin due to the higher proportion of neutral-sugar side chains, higher content of acetyl groups, higher content of phenolic compounds, and higher amounts of covalently bound protein moieties [77]. These outstanding properties restrict the thermally induced gelation, even in the presence of high sugar contents under acidic conditions [78].

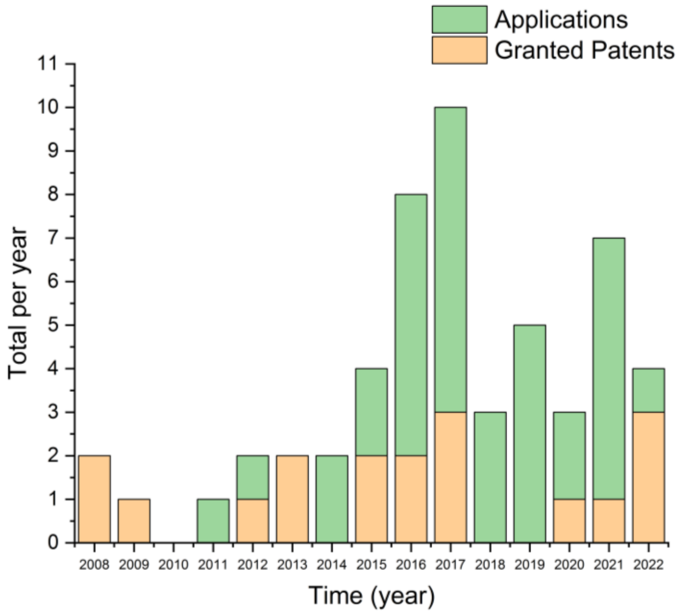

Figure 1 Evolution of the patent documents related to the UAE pectin extraction from the food waste in the period between 2008–2022.

DOI: 10.15826/chimtech.2024.11.2.13

Along with the improvement of the extraction yield and reduction of the environmental and economic impact, researchers are deeply focused on the quality of pectin extracted, according to the original papers.

Generally, the molecular weight, methoxyl content, and esterification degree are the main factors used to assess the quality of pectin. Distinctive macro and microstructural variations of each pectin, which originates from a variety of plant sources, provide the basis for numerous commercial applications as a texture modifier, gel-inducing agent, colloidal stabilizer, viscosity enhancer, or health-promoting ingredient. These uses are technically connected to the pectin's behavior in solution (gels or dispersion) [78, 79]. Commercial pectin is usually utilized to customize complex food products' physicochemical, physiological, rheological, and organoleptic features [80]. Texture, mouthfeel, flavor, or digestibility are known as being specifically influenced by extrinsic (e.g., pH, overall pectin concentration, temperature, sugars, sugar type, and buffer salts) and intrinsic (e.g., degree of esterification/acetylation, surface charge density, overall surface charge, molecular weight, molecular structure, and calcium sensitivity) parameters [81]. The majority of applications for customized pectins include glazes, juices, dairy products, jams, jellies, and marmalades, among many other goods (Table 1).

Along with the type of pectin source, the temperature, duration, and type of acid employed during the extraction process have a significant impact on the quality [82, 83].

Acid extraction and alcoholic precipitation are commonly employed in industrial scale. The basis for acid extraction of pectin is the fact that protopectin hydrolyzes in an acidic environment (pH range of 1 to 3) at temperature between 70–90 °C [84, 85]. Strong acids have the main advantages of generating a high pectin yield and reducing the extraction time; however, they also come with significant environmental disadvantages, such as the need to dispose of acidic wastewater, high energy consumption and costs.

Table 1 Range of available commercial pectin for different application fields (readapted from [78]).

Degree of esterification (%)	Classification	Commercial use
>70	Rapid set	Acidified dairy drinks Jam, beverages (fruit, soy, etc.)
60–70	Slow set	Jellies, bakery, confectionery
50		"Jelly sugar" (home users)
40–50	Low-medium calcium reactivity	Reduced sugar products, Baking stable fruit preparations, Yoghurt fruit preparations, Low sugar or low acid products
30–40	High calcium reactivity	
<10	Pectate	Nonacid foods, juice fining

Rather than using HCl for extracting pectin, food-grade organic acids such citric, tartaric, and malic have been employed as an environmentally friendly alternative [86]. When compared to other organic acid treatments, the molecular weight and apparent viscosity of pectin extracted with citric acid turn out to be greater [7].

According to the analysis of the degree of methyl esterification, pectins extracted with organic acids tend to be majorly methoxylated [87]. At lower temperatures, ultrasound-assisted extraction yields high-purity product obtained in a few minutes. It is a clean, efficient, and sustainable method [87].

In relation to this, in almost thirty percent of the selected patents, the inventors developed solutions that enable extraction at ambient temperature through the use of ultrasound to provide mild extraction conditions and reducing solvent use [88–103]. The Hefei Bensheng Biotechnology Co Ltd. (China) is the leading company in the area as it filled two patent applications on pectin extraction from citrus and Premna microphylla providing a heavy metal and solvent free product [102, 103].

The trend in Figure 2 shows that starting in 2013, the aims indicated in the patents began to vary.

In 2013–2014, the inventors begin to focus on the use the ultrasound to increase the selectivity towards certain pectin fractions such as HG, RG-I, RG-II, XGA and AGA for specific commercial applications [104].

From the analysis of the found patents, we revealed that some of them are dedicated to selective isolation of metal ions and particles [105, 106]. Both methods claimed to use the enzymolysis process to decrease the degree of esterification (DE) of pectin; however, for general metal absorption, it is applied for total DE reduction, resulting in an increase in complexation ability [105], while in [106] enzymolysis is applied to remove only the polygalacturonic acid, improving the absorption selectivity of pectin towards radioactive ions.

Another pectin composition consisting of D-mannose 5.68%, D-xylose 0.94%, L-rhamnose 18.79%, D-galacturonic acid 51.12%, D-Glucose 1.78%, D-galactolipin 16.14% and L-Arabinose 4.99% obtained from the sunflower demonstrates its antimicrobial properties. It acts in two consequent ways: firstly, the pectin oligosaccharide acts on the thallus, destroys the somatic cell wall and further inhibiting the bacterial respiration, causing their death [107].

More research groups focused on the RG-I pectin extraction with ultrasound [108–112]. RG-I pectins are of specific interest due to their higher compactness and flexibility with a random coil conformation, which make pectin more stable to the outer influence, especially the pH [94]. In this area, Zhejiang University (ZJU) is on the frontier of the RG-I rich pectin extraction process development. Those inventors applied mild extraction conditions followed by dialysis and liophyllization to prevent the degradation of the target product [111, 112].

 DOI: 10.15826/chimtech.2024.11.2.13

Over the past decade, food waste from the processing of plant and animal raw materials—which usually means eliminating or extracting nutritious components from the leftovers of low-nutrient or inedible ingredients—has also contributed to the world's environmental issues [113]. In this regard, scientist are required to develop novel strategies for valorizing food waste, such as thorough extraction of important elements despite the substantial additional costs [114–119]. Examples of food waste and potential extractives obtained by UAE extraction are summarized in Table 2.

Patent applications from the Guangxi Institute of Botany of CAS have been submitted in the greatest number; they define the complete fermentation-based production of vinegar and the subsequent UAE of pectin from mango peels, which allows for full utilization of these peel [7, 120]. Different extraction intensification techniques are often combined in modern technological pectin isolation processes to avoid hydrolysis, leading to more efficient polysaccharide extraction from exudates. The main principle of polysaccharide extraction is to break down cell walls in moderate conditions [7].

Further demand in the high yield of extraction led to the combination of ultrasound and other intensification methods, which are summarized in Figure 3.

The use of surfactants (2012 [56]), enzymes (2013 [103]), pulsed electric field application (2014 [58]), microwave (2015 [59]), vibration (2015 [74]), and supercritical conditions (2020 [71]) are some examples of these extraction-intensifying approaches. All of these components impact the pectin's quality and yield. Table 3 describes the extraction intensification strategy according to its description, advantages, and disadvantages. However, the solid-liquid UAE is mentioned in approximately 54 percent of patents without any further impact on raw material. UAE provides an already good isolation result due to its benefits, which include good scalability, low operating temperatures and process length, rapid mass and heat transfers, together with high extraction yields and selectivity. Furthermore, the UAE parameters' high degree of variability enables effective process and product quality management. Summarizing the information from the patents, the parameters of ultrasound vary as follows: frequency 4–100 kHz and 350 kHz, power 20–2000 Wt, intensity 0.35–9 Wt/cm^2, temperature 25–100 °C, power density 0.002–0.003 Wt/cm^3 and 0.2–3.5 Wt/cm^3.

The specific extraction of pectin fractions from various source materials is carried out by a variety of intensification methods. When it comes to waste materials, fruit and vegetable pieces including pulp, leaves, and pericarp are the primary sources of pectin. Figure 4 presents the primary sources of pectin recovered using ultrasound.

Wastes from citrus and apples are the primary sources of commercial pectin [7]. But when it comes to the UAE process, the utilization of apple pomace as a source accounts for only 1.75%; instead, citrus – which includes oranges (12.28%), lemons (5.26%), and pomelo (3.51%) – takes the first position, followed by other plants high in pectin.

Table 2 Food waste and extractives obtained with the UAE extraction.

Patent number	Raw material	Extractives	Ref.
CN104000138B	Potato	Pectin, dietary fiber	[114]
CN105461824A	Passion fruit pomace	Pectin, alcohol	[115]
CN112314955A	Citrus peel	Oil, flavonoid, pectin, dietary fiber	[116]
CN113425754A	Passion fruit peel	Flavone, pectin	[117]
CN109182074B, CN109337790B	Mango peel	Vinegar, pectin	[118, 119]

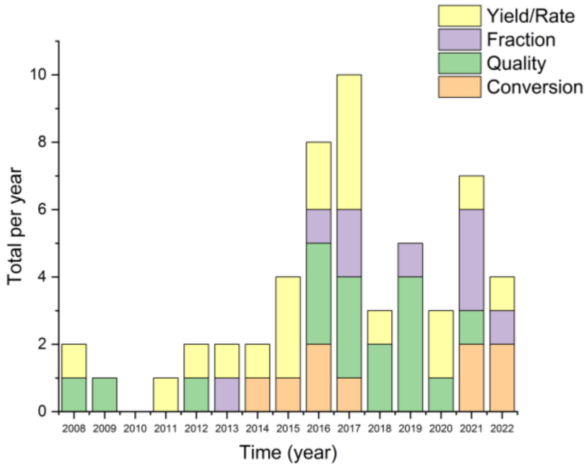

Figure 2 Aims of patent documents related to UAE in the period between 2003–2023.

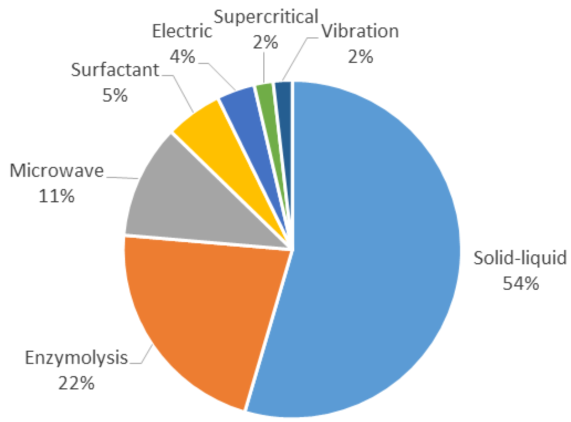

Figure 3 UAE intensification methods.

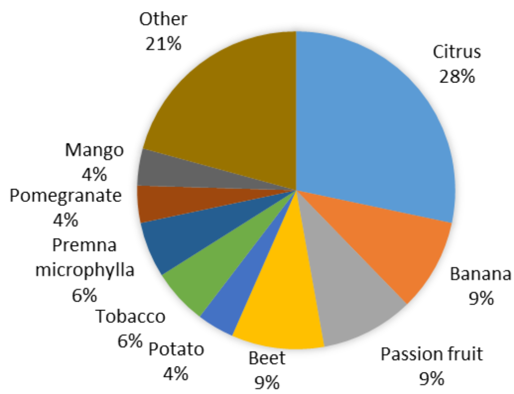

Figure 4 Source of food waste used in UAE of pectin.

DOI: 10.15826/chimtech.2024.11.2.13

Table 3 Extraction intensification approaches.

Intensification approach	Processing mechanism	Advantages	Limitations	Ref.
Detergents (surfactant)	Surface-active agents, also known as surfactants, decrease the interfacial tension thanks to their amphiphilic structure making the cell wall more permeable and the extractives more soluble	Minimized consumption of solvent Costs and risks reduction Improved yield Short processing time	Possible presence of the surfactant in the product	[130]
Enzymolysis (fermentation)	The process is based on the ability of enzymes to hydrolyze the cell wall components and to disrupt the structural complexity of the cell wall	Improved yield Improved selectivity Ability to degrade non-target components	Highly-dependent on the operation conditions (temperature, pH, enzyme concentration, particle size of substrate, time)	[131]
Pulsed electric field (PEF)	PEF extraction efficiency relies on the mechanism of electroporation	Non-thermal technology Preservation of thermolabile compounds Short processing time High mass transfer Improved yield	Not suitable with conductive materials Liquid medium is required Needs to be combined with heat to achieve higher extraction efficiency	[132]
Microwave	It consists of a non-contact energy transfer process from electromagnetic energy into thermal energy. Microwave heating of the moisture inside the treated biomaterial results in high pressure on the cell wall causing mechanical rupture and enhancing solvent penetration	Simple process Short process duration No solvent needed or moderate consumption Selective and efficient heating High extraction yields Low energy consumption Low noise levels	Extraction solvent must absorb microwave energy Filtration step required	[133, 134]
Supercritical conditions	Interest in SFE technique relies on supercritical fluid's properties. These solvents have a density close to liquids, implying that they have a solublization power close to liquids.	Fast extraction No filtration necessary Well-established technique at lab and industrial scales High extraction yields	Difficulty of extracting polar molecules without adding modifiers to CO_2	[135]

It is noteworthy that tobacco and potatoes, which are the traditional sources of starch, are common sources of pectin. This indicates that these products can be converted more efficiently, reducing environmental pollution while increase the profit.

Additionally, a relationship between the extraction source and methodologies was observed. Thus, fermentation is the main method (which is employed in 50 % of cases) for extracting starch. The enzymolysis begins with alpha-amylase breaking down the starch, the rest breaks down into saccharides, which are then digested by yeasts, guaranteeing that not any starch remaining in the product [91, 111].

Surfactants are typically used for treating banana peels (40 percent of cases). The only objective of doing so is to increase yield through higher pectin solubilization and a decrease in solution surface tension.

4. Scientific literature

An overview of the scientific publications was made from 2003 to 2023 using PubMed database through two search queries i) Pectin [Title/Abstract] AND ii) (ultrasound) OR (ultrasonic) [Title/Abstract] AND iii) extraction [Title/Abstract] AND iv) (food)) OR (food waste [Title/Abstract]). The results are represented in Figure 5. A total of 22,482 (93.3%) publications with the number growing exponentially from 2003 to 2023 confirms the great interest in pectin UAE and its future prospects. Around 3144 articles were published in the year 2023. This large number of research publications follow the increase in the pectin use and request and, consequently, in the research of new extraction strategies and sources, demonstrating the future potential of the polysaccharide.

5. Current trends & future outlook

In this review, we examined patents related to the extraction of pectin from food and food waste, their purpose and the characteristics of each of the identified groups.

Pectin is the complex polysaccharide group contained in the primary cell wall and intercellular regions of the plants, affecting their flexibility and mechanical strength [31]. As depicted in Figure 2, pectin-based products demonstrate various applications such as food [82], agriculture [121, 122], pharmacy and health promotion [13, 83], packaging [1, 123], water treatment [124] and 3D-printing [125].

The key process of pectin production is extraction from natural sources; the polysaccharide content in raw materials reaches up to 25% depending on the biomass [78]. The exponentially growing number of scientific publications emphasize the prospects for the use of pectin and the demand in development of extraction methods that allow the isolation of pectin with specified parameters or component composition.

 DOI: 10.15826/chimtech.2024.11.2.13

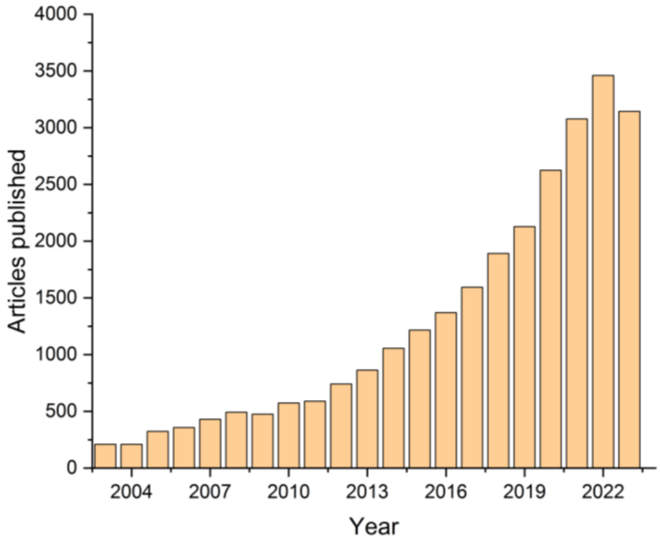

Figure 5 Trend in publication activity related to the UAE of pectin from food and food waste in the period 2003 – 2023.

However, according to patent analysis this trend is downward and is gradually giving a way to works aimed at increasing the resource efficiency of the extraction, which results in a comprehensive conversion of raw materials and subsequent isolation of several groups of substances including pectin.

In order to prevent the degradation of valuable components, scientists also target the developing of soft technologies. This allows them to fulfill the second trend, which is the environmental friendliness of pectin isolation, and provides additional cost reduction due to the wastewater volume decrease. In turn, this leads to developing more sustainable process with higher raw material conversion, and the diversity of the resulting products will make it more stable towards market fluctuations.

Summarizing the data, further development of pectin industry will definitely target the comprehensive processing of previously unexplored raw materials, including those atypical for pectin production. Another way is the combining existing technological approaches, aimed to intensifying the separation of pectin fractions within one process, which will increase the target product cost becoming promising for industrial implementation. This agrees with recent conclusion of scientific literature stating that the combination of several techniques can significantly improve pectin yield and make the extraction process more efficient and environmental friendly [126]. However, the literature provides higher variety of extraction methods, which have not yet been combined with the UAE approach. These are, for example Ohmic heating extraction and subcritical water extraction [127] as well as ultra-high pressure approach [128] and deep eutectic solvent extraction [129]. There are still some uninvestigated fields for the combined UAE method development and extraction process enhancement.

6. Conclusions

The ultrasound assisted approaches for pectin extraction from food and food waste sources were assessed in this patent research study. Based on the research methodologies, a total of 54 patent documents emerged between 2003 and 2023, with the greatest number occurring between 2016 and 2017.

Of these, 18 have been granted patents and 36 are patent applications. The relevant patents that were chosen explain distinct UAE modes and how they combine with extraction-intensifying methods to separate pectin from different types of food and food waste while controlling the desired product's characteristics. Five methods were implemented to intensify the extraction process: surfactant application, enzyme application, microwave, vibration, and supercritical solvents. Each method report benefits as well as drawbacks, and its use is contingent upon the particulars of what is needed and the raw material. The results of this study show that there is growing interest in combining or replacing conventional extraction techniques with ultrasound assisted extraction to lower extraction-related costs and adverse environmental impacts. The preference for using food waste as the main source points to an increasing emphasis on developing solutions to address the current need for reducing the impact of food waste on the environment.

• Supplementary materials

No supplementary materials are available.

• Funding

The work was financially supported by the Ministry of Science and Higher Education of Russian Federation No 075-15-2023-602 (NIP TPU n 20.0060. МГ.2023).

• Acknowledgments

None.

• Author contributions

Conceptualization: A.A.D., A.D.M.
Data curation: A.A.D.
Formal Analysis: A.A.D, A.D.M., M.E.T.
Funding acquisition: A.D.M.
Investigation: A.A.D.
Methodology: A.A.D.
Project administration: A.D.M.
Resources: A.A.D., A.D.M.
Supervision: M.E.T.
Visualization: A.A.D., A.D.M.
Writing – original draft: A.A.D., A.D.M.
Writing – review & editing: M.E.T.

• Conflict of interest

The authors declare no conflict of interest.

• Additional information

Author IDs:

Aleksandr A. Drannikov, Scopus ID 57210816225;
Antonio Di Martino, Scopus ID 57460920100;
Marina E. Trusova, Scopus ID 57204146848.

Websites:

National Research Tomsk Polytechnic University, https://tpu.ru/en/;

Novosibirsk State Technical University, https://www.nstu.ru/.

Brief biography

Aleksandr A. Drannikov holds the position of Engineer at the Research School of Chemistry and Applied Biomedical Science of Tomsk Polytechnic University and junior research fellow in Faculty of Physical Engineering, Novosibirsk State Technical University. With more than 5 years of industrial background also in biomass extraction area Aleksandr does research in drug formulation development and material science basing on plant extractives as active ingredients and drug carrier.

ResearchGate page: https://www.researchgate.net/profile/Aleksandr-Drannikov

Antonio Di Martino, PhD, works as associate professor of Research School of Chemistry and Applied Biomedical Science of Tomsk Polytechnic University. Being a well-recognized expert in material science Antonio is leading the project devoted to polysaccharide extraction from food and food waste for further application of those in hydrogel formation for water treatment.

ResearchGate page: https://www.researchgate.net/profile/Antonio-Di-Martino-3

Marina E. Trusova, Doctor of Science, is a head of Research School of Chemistry and Applied Biomedical Science of Tomsk Polytechnic University. Her expertise in chemical technology provided critical evaluation of the obtained results. Moreover, Marina works in area of organic synthesis and drug formulation development, which allows complex assessment of various problems.

ResearchGate page: https://www.researchgate.net/profile/Marina-Trusova

A list of 10 most significant cited papers

1. Chandel V, Biswas D, Roy S, Vaidya D, Verma A, Gupta A. Current advancements in pectin: Extraction, properties and multifunctional applications. Foods. 2022;11(17):2683. doi:10.3390/foods11172683
2. Picot-Allain MCN, Ramasawmy B, Emmambux MN. Extraction, characterisation, and application of pectin from tropical and sub-yropical fruits: A review. Food Rev Int. 2022;38(3):282–312. doi:10.1080/87559129.2020.1733008
3. Neckebroeck B, Verkempinck SHE., van Audenhove J, Bernaerts T, de Wilde d'Estmael H, Hendrickx ME, van Loey AM. Structural and emulsion stabilizing properties of pectin rich extracts obtained from different botanical sources. Food Res Int. 2021;141:110087. doi:10.1016/j.foodres.2020.110087
4. Zeeb B, Roth M, Endreß HU. Commercial pectins: Handbook of Hydrocolloids, Elsevier, 2021. 20 p.
5. Mei X, Mu T, Yu M, He J, He W, Shi J, Chen X, Guan J, inventors; Institute of Cereal Crops of Xinjiang Academy of Agricul-tural Sciences, assignee. Process method for preparing biologi-cal protein-rich dietary fiber and pectin simultaneously by tak-ing potato residues as raw materials. China patent CN 104000138 B, 2015 Jul 22.
6. Li J, inventor; Li J, assignee. Method for extracting low-fat pectin from passion fruit wine pomace. China patent CN 105461824 A, 2016 Apr 06.
7. Zhao L, Liu Z, inventors; Jiangsu Hagong Drug Machine Technology Co ltd, assignee. Method for preparing citrus essential oil, flavonoid, pectin and dietary fiber. China patent CN 112314955 A, 2021 Feb 05.
8. Lu Z, Li Z, Yu S, Yuan F, Chen Y, inventors; Guangxi Normal University for Nationalities, assignee. Method for combined extraction of flavone and pectin from passion fruit peel. China patent CN 113425754 A, 2021 Sep 24.
9. Li D, Cai A, Huo H, Yan X, Yang J, Tao J, inventors; Guangxi Institute of Botany of CAS, assignee. Method for simultaneous-ly producing raw vinegar and pectin by using mango peel. China patent CN 109182074 B, 2022 Mar 18.
10. Cai A, Li D, Huo H, Yan X, Yang J, Tao J, inventors; Guangxi Institute of Botany of CAS, assignee. Method for simultaneous-ly preparing fruit original vinegar and pectin by taking pectin-rich fruits as raw materials. China patent CN 109337790 B, 2022 Apr 12.

References

1. Mellinas C, Ramos M, Jiménez A, Garrigós MC. Recent trends in the use of pectin from agro-waste residues as a natural-based biopolymer for food packaging applications. Mater. 2020;13(3):673. doi:10.3390/ma13030673
2. Vidović S, Tepić Horecki A, Vladić J, Šumić Z, Gavarić A, Vakula A. Apple: valorization of fruit processing by-products, Elsevier, 2020. 25 p.
3. Sakai T, Sakamoto T, Hallaert J, Vandamme EJ. Pectin, pectinase, and protopectinase: production, properties, and applications. Adv. Appl Microbiol. 1993;39:213–294. doi:10.1016/S0065-2164(08)70597-5
4. Dranca F, Oroian M. Extraction, purification and characterization of pectin from alternative sources with potential technological applications. Food Res. Int. 2018;113:327–350. doi:10.1016/j.foodres.2018.06.065
5. Roman-Benn A, Contador CA, Li MW, Lam HM, Ah-Hen K, Ulloa PE, Ravanal MC. Pectin: An overview of sources, extraction and applications in food products, biomedical, pharmaceutical and environmental issues. Food Chem Adv. 2023;2:100192. doi:10.1016/j.focha.2023.100192

6. Xie F, Gu BJ, Saunders SR, Ganjyal GM. High methoxyl pectin enhances the expansion characteristics of the cornstarch relative to the low methoxyl pectin. Food Hydrocoll. 2021;110:106131. doi:10.1016/j.foodhyd.2020.106131
7. Chandel V, Biswas D, Roy S, Vaidya D, Verma A, Gupta A. Current advancements in pectin: Extraction, properties and multifunctional applications,. Foods. 2022;11(17):2683. doi:10.3390/foods11172683
8. Zoghi A, Vedadi S, Esfahani ZH, Gavlighi HA, Khosravi-Darani K. A review on pectin extraction methods using lignocellulosic wastes. Biomass Convers Biorefin. 2021;13(7):1–13. doi:10.1007/s13399-021-02062-z
9. Reichembach LH, de Oliveira Petkowicz CL. Pectins from alternative sources and uses beyond sweets and jellies: An overview. Food Hydrocoll. 2021;118:106824. doi:10.1016/j.foodhyd.2021.106824
10. Adimas MA, Abera BD. Valorization of fruit and vegetable byproducts for extraction of pectin and its hydrocolloidal role in low-fat yoghurt processing. LWT. 2023;189:115534. doi:10.1016/j.lwt.2023.115534
11. Roy S, Priyadarshi R, Łopusiewicz Ł, Biswas D, Chandel V, Rhim JW. Recent progress in pectin extraction, characterization, and pectin-based films for active food packaging applications: A review. Int J Biol Macromol. 2023;239:124248. doi:10.1016/j.ijbiomac.2023.124248
12. Lupaşcu T, Petuhov O, Culighin E, Mitina T, Rusu M, Rotaru A. The influence of surface chemistry upon the textural, thermal and sorption properties of apple-pectin adsorbent materials. J Therm Anal Calorim. 2023;148(10):4573–4587. doi:10.1007/s10973-022-11465-7
13. Moslemi M. Reviewing the recent advances in application of pectin for technical and health promotion purposes: From laboratory to market. Carbohydr Polym. 2021;254:117324. doi:10.1016/j.carbpol.2020.117324
14. Araújo LDCB, de Matos HK, Facchi DP, de Almeida DA, Gonçalves BM, Monteiro JP, Martins AF, Bonafé EG. Natural carbohydrate-based thermosensitive chitosan/pectin adsorbent for removal of Pb(II) from aqueous solutions. Int J Biol Macromol. 2021;193:1813–1822. doi:10.1016/j.ijbiomac.2021.11.014
15. Mohrazi A, Ghasemi-Fasaei R. Removal of methylene blue dye from aqueous solution using an efficient chitosan-pectin bioadsorbent: kinetics and isotherm studies. Environ Monit Assess. 2023;195(2):339. doi:10.1007/s10661-022-10900-4
16. Elshahed MS, Miron A, Aprotosoaie AC, Farag MA. Pectin in diet: Interactions with the human microbiome, role in gut homeostasis, and nutrient-drug interactions. Carbohydr Polym. 2021;255:117388. doi:10.1016/j.carbpol.2020.117388
17. Zhang S, Waterhouse GIN, Xu F, He Z, Du Y, Lian Y, Wu P, Sun-Waterhouse D. Recent advances in utilization of pectins in biomedical applications: a review focusing on molecular structure-directing health-promoting properties. Crit Rev Food Sci Nutr. 2023;63(19):3386–3419. doi:10.1080/10408398.2021.1988897
18. Zhang W, Xu P, Zhang H. Pectin in cancer therapy: A review. Trends Food Sci Technol. 2015;44(2):258–271. doi:10.1016/j.tifs.2015.04.001
19. Khotimchenko M. Pectin polymers for colon-targeted antitumor drug delivery. Int J Biol Macromol. 2020;158:1110-1124. doi:10.1016/j.ijbiomac.2020.05.002
20. Hernandez-Hernandez O, Ferreira-Lazarte A, Tiwari B, Villamiel M. Update of high-intensity ultrasound applications for the extraction of pectin from agri-food by-products. TrAC. 2024;175:117728. doi:10.1016/j.trac.2024.117728
21. Muñoz-Almagro N, Montilla A, Villamiel M. Role of pectin in the current trends towards low-glycaemic food consumption. Food Res Int. 2021;140:109851. doi:10.1016/j.foodres.2020.109851
22. Odun-Ayo F, Reddy L. Potential biomedical applications of modified pectin as a delivery system for bioactive substances. Polysaccharides. 2023;4(1):1–32. doi:10.3390/polysaccharides4010001
23. Owusu FWA, el Boakye-Gyasi M, Bayor MT, Osei-Asare C, Johnson R, Osei YA, Asare VA, Mensah KA, Acquah Jnr PG, Otu DAB, Asante, R. Pharmaceutical assessment of watermelon rind pectin as a suspending agent in oral liquid dosage forms. Biomed Res Int. 2022;2022:1–9. doi:10.1155/2022/9526404
24. Sun R, Niu Y, Li M, Liu Y, Wang K, Gao Z, Wang Z, Yue T, Yuan Y. Emerging trends in pectin functional processing and its fortification for synbiotics: A review. Trends Food Sci Technol. 2023;134:80–97. doi:10.1016/j.tifs.2023.03.004
25. Riyamol, Gada Chengaiyan J, Rana SS, Ahmad F, Haque S, Capanoglu E. Recent advances in the extraction of pectin from various sources and industrial applications. ACS Omega. 2023;8(49):46309–46324. doi:10.1021/acsomega.3c04010
26. Jiang WX, Qi JR, Liao JS, Yang XQ. Acid/ethanol induced pectin gelling and its application in emulsion gel. Food Hydrocoll. 2021;118:106774. doi:10.1016/j.foodhyd.2021.106774
27. Agostinho L, Rocha-Filho P. Preparation and characterization of a topical delivery system for nanoemulsions using a composite film of pectin and tapioca. Cosmetics. 2024;11(2):63. doi:10.3390/cosmetics11020063
28. Picot-Allain MCN, Ramasawmy B, Emmambux MN. Extraction, characterisation, and application of pectin from tropical and sub-yropical fruits: A review. Food Rev Int. 2022;38(3):282–312. doi:10.1080/87559129.2020.173300
29. Neckebroeck B, Verkempinck SHE., van Audenhove J, Bernaerts T, de Wilde d'Estmael H, Hendrickx ME, van Loey AM. Structural and emulsion stabilizing properties of pectin rich extracts obtained from different botanical sources. Food Res Int. 2021;141:110087. doi:10.1016/j.foodres.2020.110087
30. Frosi I, Balduzzi A, Moretto G, Colombo R, Papetti A. Towards valorization of food-waste-derived pectin: recent advances on their characterization and application. Molec. 2023;28(17):6390. doi:10.3390/molecules28176390
31. Belkheiri A, Forouhar A, Ursu AV, Dubessay P, Pierre G, Delattre C, Djelveh G, Abdelkafi S, Hamdami N, Michaud P. Extraction, characterization, and applications of pectins from plant by-products. Appl Sci. 2021;11(14):6596. doi:10.3390/app11146596
32. Wongkaew M, Chaimongkol P, Leksawasdi N, Jantanasakulwong K, Rachtanapun P, Seesuriyachan P, Phimolsiripol Y, Chaiyaso T, Ruksiriwanich W, Jantrawut P, Sommano SR. Mango peel pectin: recovery, functionality and sustainable uses. Polymers. 2021;13(22):3898. doi:10.3390/polym13223898
33. Torkova AA, Lisitskaya KV, Filimonov IS, Glazunova OA, Kachalova GS, Golubev VN, Fedorova TV. Physicochemical and functional properties of Cucurbita maxima pumpkin pectin and commercial citrus and apple pectins: A comparative evaluation. PLOS ONE. 2018;13(9):e0204261. doi:10.1371/journal.pone.0204261
34. Medvedkov YB, Yerenova BY, Pronina YG, Penov ND, Belozertseva OD, Kondratiuk NV. Extraction and characteristics of pectins from melon peel: Experimental review. J Chem Technol. 2021;9:650–659. doi:10.15421/jchemtech.v29i4.252250
35. Priyangini F, Walde SG, Chidambaram R. Extraction optimization of pectin from cocoa pod husks (Theobroma cacao L.) with ascorbic acid using response surface methodology. Carbohydr Polym. 2018;202:497–503. doi:10.1016/j.carbpol.2018.08.103
36. Kazemi M, Khodaiyan F, Hosseini SS, Najari Z. An integrated valorization of industrial waste of eggplant: Simultaneous recovery of pectin, phenolics and sequential production of pullulan. Waste Manag. 2019;100:101–111. doi:10.1016/j.wasman.2019.09.013
37. Ninčević Grassino A, Ostojić J, Miletić V, Djaković S, Bosiljkov T, Zorić Z, Ježek D, Rimac Brnčić S, Brnčić M. Application of high hydrostatic pressure and ultrasound-assisted extractions as a novel approach for pectin and polyphenols recovery from tomato peel waste. Innov Food Sci Emerg Technol. 2020;64:102424. doi:10.1016/j.ifset.2020.102424

38. Xie F, Zhang W, Lan X, Gong S, Wu J, Wang Z. Effects of high hydrostatic pressure and high pressure homogenization processing on characteristics of potato peel waste pectin. Carbohydr Polym. 2018;196:474–482. doi:10.1016/j.carbpol.2018.05.061
39. Caroço RF, Kim B, Santacoloma PA, Abildskov J, Lee JH, Huusom JK. Analysis and model-based optimization of a pectin extraction process. J Food Eng. 2019;244:159–169. doi:10.1016/j.jfoodeng.2018.09.016
40. Benassi L, Alessandri I, Vassalini I. Assessing green methods for pectin extraction from waste orange peels. Molec. 2021;26(6):1766. doi:10.3390/molecules26061766
41. Marić M, Grassino AN, Zhu Z, Barba FJ, Brnčić M, Rimac Brnčić S. An overview of the traditional and innovative approaches for pectin extraction from plant food wastes and by-products: Ultrasound-, microwaves-, and enzyme-assisted extraction. Trends Food Sci Technol. 2018;76:28–37. doi:10.1016/j.tifs.2018.03.022
42. Mao G, Wu D, Wei C, Tao W, Ye X, Linhardt RJ, Orfila C, Chen S. Reconsidering conventional and innovative methods for pectin extraction from fruit and vegetable waste: Targeting rhamnogalacturonan I. Trends Food Sci Technol. 2019;94:65–78. doi:10.1016/j.tifs.2019.11.001
43. World Intellectual Property Organization. The Patentscope. https://patentscope.wipo.int, 2023 (accessed 15 October 2023).
44. European Patent Office. Espacenet patent search. https://worldwide.espacenet.com, 2023 (accessed 15 October 2023).
45. Federal Institute of Industrial Property. Information retrieval system. https://www.fips.ru/iiss/db.xhtml, 2023 (accessed 15 October 2023).
46. Eurasian Patent Office. Eurasian patent information system (EAPATIS). Available online: http://www.eapatis.com/, 2023 (accessed 15 October 2023).
47. United States Patent and Trademark Office. USPTO database (PatFT-AppFT). https://uspto.gov/patents/search, 2023 (accessed 15 October 2023).
48. World Intellectual Property Organization. IPC Publication. www.wipo.int/classifications/ipc/ipcpub, 2023 (accessed 15 October 2023).
49. Konovalov AI, Ofitserov EN, Sosnina NA, Minzanova ST, Fedorov AD, Smolentsev AV, inventors; Institut organicheskoj khimii im. A.E. Arbuzova Kazanskogo Nauchnogo tsentra RAN, Zakrytoye aktsionernoye obshchestvo "Forsat", Kompanija IFF "Investments Ltd", assignee. Method of pectin preparing. Russian Federation patent RU 2123266 C1, 1998 Dec 20.
50. Lv X, Zhao S, Ning Z, Zeng H, Shu Y, Tao O, Xiao C, Lu C, Liu Y. Citrus fruits as a treasure trove of active natural metabolites that potentially provide benefits for human health. Chem Cent J. 2015;9(1):68. doi:10.1186/s13065-015-0145-9
51. Nosov SI, Bondarev BE, Cherkashin KI, Regulation of land reallocation based on the preservation of the most valuable agricultural land. IOP Conf Ser Earth Environ Sci. 2019;320(1):012001. doi:10.1088/1755-1315/320/1/012001
52. Misra NN, Martynenko A, Chemat F, Paniwnyk L, Barba FJ, Jambrak AR. Thermodynamics, transport phenomena, and electrochemistry of external field-assisted nonthermal food technologies. Crit Rev Food Sci Nutr. 2018;58(11):1832–1863. doi:10.1080/10408398.2017.1287660
53. Ozhimkova EV, Sidorov AI, Sul'man MG, Manaenkov OV, inventors; Gosudarstvennoe obrazovatel'noe uchrezhdenie vysshego professional'nogo obrazovanija "Tverskoj gosudarstvennyj tekhnicheskij universitet", assignee. Method of pectin substances extraction from plant materials. Russian Federation patent RU 2339395 C1, 2008 Nov 27.
54. Agaev NM, Agaev RN, Agaev FN, inventors; Agaev Nariman Musaevich, Agaev Ramiz Narimanovich, Agaev Farid Nariman ogly, assignee. Method of processing plant raw materials to produce pectin and food products containing pectin and line for this implementation. Russian Federation patent RU 2354140 C1, 2009 May 10.
55. Lee HH, inventor; Lee HH, assignee. Method for extracting pectin from pineapple peel assisted by ultrasonic wave. China patent CN 101942036 A, 2011 Jan 12.
56. Yue X, Li Y, Wu Y, Hu J, inventors; Nanjing College of Chemical Technology, assignee. Method for extracting pectin from banana peels. China patent CN 102382205 A, 2012 Mar 21.
57. Wang Y, Chen K, Zeng G, Zhang J, Wei X, Chen F, Wang Y, Hong L, inventors; Chongqing Hengyuan Jintong Technology Co Ltd, assignee. Method for extracting pectin based on tobacco. China patent CN 102260355 B, 2013 June 12.
58. Fu X, Chen H, Luo Z, inventors; South China University of Technology SCUT, assignee. Environment-friendly preparation method of beet pectin. China patent CN 103483465 A, 10 2014 Sep 10.
59. Sun J, Li L, Li C, Sheng J, He X, Zheng F, Li J, Liao F, Liu G, Ling D, inventors; Institute of Agro Products Processing Science, Technology of Guangxi Academy of Agricultural Sciences, assignee. Method for extracting pectin from pitaya stem. China patent CN 104513324 A, 2015 Apr 15.
60. Xiao K, Dai Y, Tan L, Shi F, Xue F, Kou M, Shen Y, Wang C, inventors; China Tobacco Chuanyu Industrial Co Ltd, assignee Method for extracting pectin from tobacco waste by using ultrasonic and organic acid. China patent CN 104710544 A, 2015 Jun 17.
61. Jatsun SF, Mishchenko VJ, Chen X, inventors; Jatsun SF, Mishchenko VJ, Chen X, assignee. Method for extracting pectin from orange peel. China patent CN 105237654 A, 2016 Jan 13.
62. Chen F, inventor; Qinzhou Qinbei Productivity Promotion Center, assignee. Method for high efficiently extracting pectin from banana peels. China patent CN 105418792 A, 2016 Mar 23.
63. Cao X, inventor; Anhui Wang Run Biotechnology Co Ltd, assignee. Method for extracting pectin from shaddock peel through enzymolysis and ultrasonic waves. China patent CN 106349405 A, 2017 Jan 25.
64. Cao X, Ning C, inventors; Dou Hao Bio Tech Ltd Chongqing, assignee. A kind of method for extracting pectin from pomelo peel using enzymolysis ultrasound. China patent CN 106883311 A, 2017 Jun 23.
65. Ben Y, Su Z, Liu D, Yu H, inventors; Guangdong Pharmaceutical University, assignee. A kind of extracting method of citrus pectin polysaccharide. China patent CN 107033256 A, 2017 Aug 11.
66. Ma L, Zhang B, Long L, inventors; Chongqing Huida Lemon Technology Group Co Ltd, assignee. The extracting method of pectin in a kind of lemon peel slag. China patent CN 108219028 A, 2018 Jun 29.
67. Hou W, Wang H, Yi Y, Xu W, Wang L, Min T, inventors; Wuhan Polytechnic University, assignee. Method for extracting pectin with high gelatinization degree from sophora fruit peel. China patent CN 110563857 A, 2019 Dec 13.
68. Dong Y, inventor; Nanjing Siborn Biotechnology Co Ltd, assignee. Preparation method for extracting pectin from orange peel. China patent CN 111217936 A, 2020 Jun 02.
69. Zhao X, Liu W, Li F, Liu C, inventors; Qilu University of Technology, assignee. Extraction method of peach pectin. China patent CN 108892741 B, 2020 Nov 24.
70. Sun S, Tang Y, Zhang T, Yuan H, Cui Q, Cui H, inventors; Chongqing Meng Tai Bio Tech Ltd, assignee. Production method of dry and wet raw material blended pectin. China patent CN 112457431 A, 2021 Mar 09.
71. Gu L, Tang X, Huang Z, Li Z, Peng J, Li J, Zhang L, Yang H, inventors; Yuxi Tabacoo Co Of Yunnan Province, Kunming University of Science and Technology, assignee. Method for extracting pectin from tobacco stems by using ultrasonic waves and mixed acid. China patent CN 115490782 A, 2022 Dec 20.
72. Gao L, Wu F, Tao Y, Wu C, Wang X, inventors; Shenyang Normal University, assignee. Method for extracting pectin from banana peel by ultrasonic synergistic ammonium oxalate method. China patent CN 104031172 A, 2014 Sep 10.

73. Jiang L, inventor; Jiang L, inventor, assignee. Method for extracting banana peel pectin. China patent CN 105481995 A, 2016 Apr 13.
74. Mishchenko, E.V., inventor; Federal'noe gosudarstvennoe bjudzhetnoe obrazovatel'noe uchrezhdenie vysshego obrazovanija "Jugo-Zapadnyj gosudarstvennyj Mail universitet" (JuZGU), assignee. Vegetal raw material pectin production method. Russian Federation patent RU 2567897 C1, 2015 Nov 10.
75. Avilova IA, Kobelev NS, Belyaev AG, Pogreba EY, inventors; Federalnoe gosudarstvennoe byudzhetnoe obrazovatelnoe uchrezhdenie vysshego obrazovaniya "Yugo-Zapadnyj gosudarstvennyj universitet" (YUZGU), assignee. Method for extracting pectin substances from sugar beet production wastes. Russian Federation patent RU 2628435 C1, 2017 Aug 16.
76. Elizaryev A, Kostryukova N, Vdovina I, Riianova E, Melnikova A, Sadykova A. Low-waste production of pectin from beet pulp. E3S Web Conf. 2020;203:04012. doi:10.1051/e3sconf/202020304012
77. Funami T, Nakauma M, Ishihara S, Tanaka R, Inoue T, Phillips GO. Structural modifications of sugar beet pectin and the relationship of structure to functionality. Food Hydrocoll. 2011;25(2):221–229. doi:10.1016/j.foodhyd.2009.11.017
78. Zeeb B, Roth M, Endreß HU. Commercial pectins: Handbook of Hydrocolloids, Elsevier, 2021. 20 p.
79. Adetunji LR, Adekunle A, Orsat V, Raghavan V. Advances in the pectin production process using novel extraction techniques: A review. Food Hydrocoll. 2017;62:239–250. doi:10.1016/j.foodhyd.2016.08.015
80. Müller-Maatsch J, Bencivenni M, Caligiani A, Tedeschi T, Bruggeman G, Bosch M, Petrusan J, van Droogenbroeck B, Elst K, Sforza S. Pectin content and composition from different food waste streams. Food Chem. 2016;201:37–45. doi:10.1016/j.foodchem.2016.01.012
81. Hua X, Wang K, Yang R, Kang J, Zhang J. Rheological properties of natural low-methoxyl pectin extracted from sunflower head. Food Hydrocoll. 2015;44:122–128. doi:10.1016/j.foodhyd.2014.09.026
82. Yan JK, Wang C, Qiu WY, Chen TT, Yang Y, Wang WH, Zhang HN. Ultrasonic treatment at different pH values affects the macromolecular, structural, and rheological characteristics of citrus pectin. Food Chem. 2021;341:128216. doi:10.1016/j.foodchem.2020.128216
83. Chen J, Cheng H, Zhi Z, Zhang H, Linhardt RJ, Zhang F, Chen S, Ye X. Extraction temperature is a decisive factor for the properties of pectin. Food Hydrocoll. 2021;112:106160. doi:10.1016/j.foodhyd.2020.106160
84. Freitas CMP, Coimbra JSR, Souza VGL, Sousa RCS. Structure and applications of pectin in food, biomedical, and pharmaceutical industry: A review. Coatings. 2021;11(8):922. doi:10.3390/coatings11080922
85. Raji Z, Khodaiyan F, Rezaei K, Kiani H, Hosseini SS. Extraction optimization and physicochemical properties of pectin from melon peel. Int J Biol Macromol. 2017;98:709–716. doi:10.1016/j.ijbiomac.2017.01.146
86. Cho EH, Jung HT, Lee BH, Kim HS, Rhee JK, Yoo SH. Green process development for apple-peel pectin production by organic acid extraction. Carbohydr Polym. 2019;204:97–103. doi:10.1016/j.carbpol.2018.09.086
87. Maran JP, Priya B, Al-Dhabi NA, Ponmurugan K, Moorthy IG, Sivarajasekar N. Ultrasound assisted citric acid mediated pectin extraction from industrial waste of Musa balbisiana, Ultrason. Sonochem. 2017;35:204–209 doi:10.1016/j.ultsonch.2016.09.019
88. Bykov AV, Popov VP, Korotkov VG, Bakiev GF, Tyshchenko VM, inventors; Gosudarstvennoe obrazovatel'noe uchrezhdenie vysshego professional'nogo obrazovanija "Orenburgskij gosudarstvennyj universitet", assignee. Method of pectin production from watermelon rind. Russian Federation patent RU 2333669 C1, 2008 Sep 20.
89. Li B, Wu C, inventors; Jiangsu Jiujiu Environment Technology Co Ltd, assignee. Process for extracting pectin from citrus peel. China patent CN 102174121 B, 2012 May 30.
90. Mu T, Peng X, Zhang M, Sun H, Shu W inventors. Institute of Food Science and Technology of CAAS, assignee A kind of method extracting pectin. China patent CN 103304681 B, 2016 Mar 16.
91. Niu Q, Bai G, Zhang G, Li H, He X, inventors; Bozhou Runnuo Enterprise Management Consulting Co ltd, assignee. A kind of ultrasonic extracting method of pectin. China patent CN 102399302 B, 2011 Oct 31.
92. Yan H, Han Z, Wu D, Wei F, Weng L, Zhang Y, inventors; Heyuan Jin Products Agricultural Science, Technology Innovation Research Institute, assignee. A kind of preparation method that pectin is extracted from passion flower-fruit peel. China patent CN 107033257 A, 2017 Aug 11.
93. Kong K, inventor; Kong K, assignee. The extracting method of orange peel pectin. China patent CN 107266608 A, 2017 Oct 20.
94. Zhang L, Zhang P, Li Z, inventors; Zaozhuang University, assignee. A kind of pectin for the method and its preparation that pectin is prepared from pomegranate peel residue. China patent CN 106008744 B, 2017 Dec 22.
95. Shuai L, Liao L, Duan Z, Kang C, Song M, Zhu D, Yang J, inventors; Hezhou University , assignee. A kind of method that polysaccharide is extracted in the pericarp from passion fruit. China patent CN 107573438 A, 2018 Jan 12.
96. Wu K, Liao X, Fu W, Li W, inventors; Guangdong Medical University, assignee. A kind of clausenae Lansium pectin preparation method and the clausenae Lansium pectin using this method preparation. China patent CN 108641014 A, 2018 Oct 12.
97. Hao J, Li C, Zhao D, Han X, Qiao W, Bai L, inventors; Hebei University of Science and Technology, assignee. A method of extracting pectin from persimmon slag. China patent CN 109232769 A, 2019 Jan 18.
98. Zheng Z, Zhang Y, Du H, Huang S, Xing J, inventors; Zhiwei Tianjin Polytechnic University, assignee. A method of extracting plant pectin from hemp hemp skin. China patent CN 109485746 A, 2019 Mar 19.
99. Tang Z, Su J, Shao J, Han F, Cang H, Xu Q, inventors; Yangcheng Institute of Technology, assignee. A method of pectin is extracted from passion fruit pericarp. China patent CN 109535278 A, 2019 Mar 29.
100. Ma S, Yang C, Wei L, Sun Q, Huang L, inventors; Guangxi Agricultural Vocational College, assignee. Method for extracting low-molecular-weight pectin from banana peel. China patent CN 111500656 A, 2020 Aug 07.
101. Li S, Zhuang H, Li Z, Han L, Chu S, Li W, Meng S, inventors. Wuhan Xudong Food Co.,Ltd., assignee. Method for extracting pomegranate peel residue pectin by electrolytic water. China patent CN 107266609 B, 2021 Feb 05.
102. Zhao, H., inventor; Hefei Bensheng Biotechnology Co Ltd, assignee. Method of extracting pectin from premna microphylla leaves. China patent CN 105884929 A, 2016 Aug 24.
103. Guo Y, Sheng H, Song Q, inventors; Guo Y, Sheng H, Song Q, assignee. Preparation method of low-methoxy pectin. China patent CN 105968228 A, 2016 Sep 29.
104. Zdunek A, Pieczywek PM, Cybulska J. The primary, secondary, and structures of higher levels of pectin polysaccharides. Compr Rev Food Sci Food Saf. 2021;20(1):1101–1117. doi:10.1111/1541-4337.12689
105. Litvinets SG, Martinson EA, Zlobin AA, inventors; Federal'noe gosudarstvennoe bjudzhetnoe obrazovatel'noe uchrezhdenie vysshego professional'nogo obrazovanija "Vjatskij gosudarstvennyj universitet", assignee. Method for extraction of pectin substances in native state from rosehip fruit shells. Russian Federation patent RU 2485804 C2, 2013 Jun 27.
106. Chen H, Bai X, Yan Q, Deng Z, Li G, Yang H, inventors; Hainan north latitude eighteen degree food processing Co., Ltd., assignee. Fruit stem pectin of dragon fruit and preparation method and application thereof. China patent CN 106349404 A, 2017 Jan 25.
107. Zhang Y, Yu M, Qian Y, Yuan C, Zheng J, Wang Z, inventors; Zhejiang University of Technology ZJUT, assignee. A kind of sunflower pectin oligosaccharide extract and the preparation

method and application thereof. China patent CN 110527703 A, 2019 Dec 03.
108. Bi H, Wei L, Gao T, Du Y, Yang H, Li C, inventors; Northwest Institute of Plateau Biology of CAS, assignee. Preparation method of RG-I type lycium barbarum pectin with anti-aging activity. China patent CN 104987433 B, 2017 Apr 12.
109. Duan F, Chen Y, Li X, Li J, Tian J, inventors; Sichuan University, assignee. Premna microphylla leaf RG-I pectin with antioxidant and anti-inflammatory activities and preparation method and application thereof. China patent CN 112794931 A, 2021 May 14.
110. Ming J, Liu X, Zhao J, inventors; Southwest University, assignee. Premna microphylla low-ester pectin and preparation method and application thereof. China patent CN 112876581 A, 2021 Jun 01.
111. Chen S, Hu W, Ye X, Cheng H, Liu D, Thunthacha C, inventors; Zhejiang University, assignee. Method for acoustic pressure combined assisted extraction of pectin rich in RG-I. International patent WO 2021108977 A1, 2021 Jun 10.
112. Xingqian Y, Weiwei H, Shiguo C, Huan C, Donghong L, inventors; Zhejiang University ZJU, assignee. Ultrasonic-assisted method of extracting a pectin rich in RG-I. United States patent US 11485799 B2, 2022 Nov 01.
113. Segrè A, Falasconi L. Il libro nero dello spreco in Italia: Il cibo, Edizioni Ambiente, Milan, 2011. 124 p.
114. Mei X, Mu T, Yu M, He J, He W, Shi J, Chen X, Guan J, inventors; Institute of Cereal Crops of Xinjiang Academy of Agricultural Sciences, assignee. Process method for preparing biological protein-rich dietary fiber and pectin simultaneously by taking potato residues as raw materials. China patent CN 104000138 B, 2015 Jul 22.
115. Li J, inventor; Li J, assignee. Method for extracting low-fat pectin from passion fruit wine pomace. China patent CN 105461824 A, 2016 Apr 06.
116. Zhao L, Liu Z, inventors; Jiangsu Hagong Drug Machine Technology Co ltd, assignee. Method for preparing citrus essential oil, flavonoid, pectin and dietary fiber. China patent CN 112314955 A, 2021 Feb 05.
117. Lu Z, Li Z, Yu S, Yuan F, Chen Y, inventors; Guangxi Normal University for Nationalities, assignee. Method for combined extraction of flavone and pectin from passion fruit peel. China patent CN 113425754 A, 2021 Sep 24.
118. Li D, Cai A, Huo H, Yan X, Yang J, Tao J, inventors; Guangxi Institute of Botany of CAS, assignee. Method for simultaneously producing raw vinegar and pectin by using mango peel. China patent CN 109182074 B, 2022 Mar 18.
119. Cai A, Li D, Huo H, Yan X, Yang J, Tao J, inventors; Guangxi Institute of Botany of CAS, assignee. Method for simultaneously preparing fruit original vinegar and pectin by taking pectin-rich fruits as raw materials. China patent CN 109337790 B, 2022 Apr 12.
120. Zhang M, Cui SW, Cheung PCK, Wang Q. Antitumor polysaccharides from mushrooms: A review on their isolation process, structural characteristics and antitumor activity. Trends Food Sci Technol. 2007;18(1):4–19 doi:10.1016/j.tifs.2006.07.013.
121. Adi Sulianto A, Adiyaksa IP, Wibisono Y, Khan E, Ivanov A, Drannikov A, Ozaltin K, Di Martino A. From fruit waste to hydrogels for agricultural applications. Clean Technol. 2023;6(1):1–17. doi:10.3390/cleantechnol6010001
122. Christoph S, Barré P, Haye B, Coradin T, Fernandes FM. Environmentally-stable eco-friendly pectin-silica bio-hybrid foams for soil remediation. Giant. 2022;12(100119):1–9. doi:10.1016/j.giant.2022.10011
123. Huang J, Hu Z, Hu L, Li G, Yao Q, Hu Y. Pectin-based active packaging: A critical review on preparation, physical properties and novel application in food preservation. Trends Food Sci Technol. 2021;118:167–178. doi:10.1016/j.tifs.2021.09.026
124. Martínez-Sabando J, Coin F, Melillo JH, Goyanes S, Cerveny S. A review of pectin-based material for applications in water treatment. Mater. 2023;16(6):2207. doi:10.3390/ma16062207
125. Agarwal T, Costantini M, Maiti TK. Extrusion 3D printing with pectin-based ink formulations: Recent trends in tissue engineering and food manufacturing. Adv Biomed Eng. 2021;2(100018). doi:10.1016/j.bea.2021.100018
126. Ling B, Ramaswamy HS, Lyng JG, Gao J, Wang S. Roles of physical fields in the extraction of pectin from plant food wastes and byproducts: A systematic review. Food Res Int. 2023;164:112343. doi:10.1016/j.foodres.2022.112343
127. Buljeta I, Šubarić D, Babić J, Pichler A, Šimunović J, Kopjar M. Extraction of dietary fibers from plant-based industry waste: A comprehensive review. Appl Sci. 2023;13(16):9309. doi:10.3390/app13169309
128. Khubber S, Kazemi M, Amiri Samani S, Lorenzo JM, Simal-Gandara J, Barba FJ. Structural-functional variability in pectin and effect of innovative extraction methods: An integrated analysis for tailored applications. Food Rev Int. 2023;39(4):2352–2377. doi:10.1080/87559129.2021.1952422
129. Bashir I, Dar AH, Dash KK, Pandey VK, Fayaz U, Shams R, Srivastava S, Singh R. Deep eutectic solvents for extraction of functional components from plant-based products: A promising approach. Sustain Chem Pharm. 2023;33:101102. doi:10.1016/j.scp.2023.101102
130. Gagnon Y, Mhemdi H, Delbecq F, van Hecke E. Extended surfactants and their tailored applications for vegetable oils extraction: An overview. OCL. 2021;28:7. doi:10.1051/ocl/2020062
131. Marathe SJ, Jadhav SB, Bankar SB, Singhal RS, Enzyme-assisted extraction of bioactives: Food Bioactives, Springer International Publishing, 2017, 30 p.
132. Nowacka M, Tappi S, Wiktor A, Rybak K, Miszczykowska A, Czyzewski J, Drozdzal K, Witrowa-Rajchert D, Tylewicz U. The impact of pulsed electric field on the extraction of bioactive compounds from beetroot. Foods. 2019;8(7):244. doi:10.3390/foods8070244
133. Hamid Nour A, Ruth Oluwaseun A, Hamid Nour A, Suliman Omer M, Ahmed N. Microwave-assisted Extraction of Bioactive Compounds (Review): Microwave Heating - Electromagnetic Fields Causing Thermal and Non-Thermal Effects, IntechOpen, 2021. 202 p.
134. Khan MK, Ahmad K, Hassan S, Imran M, Ahmad N, Xu C. Effect of novel technologies on polyphenols during food processing. Innov Food Sci Emerg Technol. 2018;45:361–381. doi:10.1016/j.ifset.2017.12.006
135. Chemat F, Cravotto G. Combined extraction techniques. CRC Press. Boca Raton; 2011. 21 p.

 DOI: 10.15826/chimtech.2024.11.2.13