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Pectin Review Article

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Abstract

Pectin is a naturally occurring polysaccharide that is mostly present in plant cell walls. Pectin is made up of a complex mixture of polysaccharides that are mostly esterified D-galacturonic acid units. In the food industry, pectin is used in jams, jellies, frozen foods, and more recently in low-calorie foods as a fat and/or sugar replacer. In the pharmaceutical industry, it is used to reduce blood cholesterol levels and gastrointestinal disorders. Other applications of pectin include use in edible films, paper substitute, foams and plasticizers, etc. Pectin's structural heterogeneity endows it with distinct gelling, thickening, and stabilising qualities, rendering it an indispensable component in the manufacturing of jams, jellies, and other culinary items. Pectin has been investigated in biomedical research for tissue engineering, drug delivery, and wound healing. Because pectin-based hydrogels and nanoparticles may encapsulate and shield bioactive substances, they are being investigated as carriers for controlled medication delivery. Therefore, this review focuses on the importance of pectin for today's food, pharmaceutical and cosmetic industries, compiling information on its composition and properties as determined by its origins, especially from waste biomass of the fruits and vegetables processing industry, on commercial applications and research needs. The suitability of the different extraction methods was also discussed, considering cost, energy consumption and productivity. Furthermore, the biodegradation of pectin as a complex process performed by a set of enzymes was also reviewed along with application purposes. Finally, future perspectives reveal pectin to

be an astounding functional food ingredient requiring continuous research work.

Keywords: Pectin, polysaccharide, extraction methods, gelling agent, food industry, pharmaceutical applications, biomedicine.

1. Introduction

One naturally occurring, adaptable, and nontoxic heteropolysaccharide is pectin, which comes from the cell walls of higher terrestrial plants. It makes up between 0.5 to 4.0% of the total fresh weight of plants and is a major constituent of the cell walls of all higher plants (Picot-Allain et al., 2022). A white to light brown powder known as pectin. Louis Nicolas Vauquelin initially isolated this chemical in 1790 from the tamarind fruit. Henri Braconnot first used the word pectin in 1825, derived from the Greek word "pektikos," which means to solidify or coagulate (Dominiak et al., 2014). Because it can bind water and improve viscosity, pectin, a natural polymer made of galacturonic acid units, is frequently employed in the food business. Early in the 20th century, pectin was first made available for purchase in Germany. These days, it is made in China, the USA, Europe, Latin America, and other countries to exacting safety and quality requirements. 35,000 tonnes of pectin were produced year worldwide. Due to its special structural and biochemical qualities, pectin, a plant-based hydrocolloid, is frequently added as an ingredient to a wide range of food products, the pharmaceutical industry, and other applications. These include the creation of edible films, plasticizers, paper alternatives, and foams. Since different plants produce pectin with varying functional qualities, the term "pectin" is used to refer to a variety of polymers that differ in their neutral sugar concentration, molecular weight, and chemical structure. Pectin molecules can be used for a wide range of applications due to their various functional groups and specific structural modifications (Freitas et al., 2021, Zhang et al., 2015, Ngouémazong et al., 2015). This is primarily because of their easy accessibility, non-toxic qualities, and low cost of production (Martau et al., 2019). This polymer is frequently linked to cellulose, hemicellulose, and lignin, among other components of the cell wall (Harholt et al., 2010).

2. Sources of Pectin

The utilisation of fruit and vegetable sources as a commercial source of pectin extraction is not just dependent on their high pectin content (Thakur et al., 1997). The concentration of pectin in plant cell walls steadily declines from the primary cell wall to the plasma membrane, with the middle lamella containing the largest concentration of pectin. Owing to their high output and advantageous physicochemical characteristics, which find numerous uses in the food and pharmaceutical industries, citrus fruits and apples are the main sources of pectin extraction. Commercially produced pectin is a white to light brown powder made from citrus fruits. It is used as a food stabiliser in fruit juices and milk drinks, as well as a source of dietary fibre and an edible gelling agent, particularly in jams and jellies, dessert fillings, medications, and sweets (Gerlat and Paula, 2000). On the other hand, cocoa husk (Mollea and Chiampo et al., 2008), sunflower heads (Shi and Chang et al., 1996), sugar beet (Funami and Nakauma et al., 2011), pumpkin (Cui and Chang 2014), watermelon (Petkowicz and Vriesmann L et al., 2017), pears (Franchi and Marzialetti et al., 2014), and potato pulp (Yang and Mu et al., 2018) are some additional sources of pectin. About 10-15% of apple pomace and 20-30% of citrus peel have pectin in them. On a dry weight basis, pectin content ranges from 10% to 20% in sugar beetroot and sunflower head residues (Gawkowska et al., 2018). Apricots have 1%, cherries have approximately 0.4%, oranges have approximately 0.5–3.5%, carrots have approximately 1.4%, and rose hips have approximately 15%. Scientific research is showing a great deal of interest in new pectin supplies derived from several crops, including chayote, pumpkin, aubergine, and Opuntia ficus indica cladodes.

Table 1: Pectin content in agro-industrial residues

Source	**Type of waste**	**Pectin content (dry weight, %)**	**References**
Citrus (Rutaceae)	Orange peel	16.70–24.80	(Kaya et al., 2014)
	Lemon peels	13.00–30.60	
	Lime peel	26.90–33.60	
	Grapefruit peel	21.60–28.00	
	Sweetorange peels	23.02	(Marín et al., 2007)
	Citrus waste	25.00	(Pourbafrani et al., 2010)
	Lemon juice waste	1.00–8.00	(Dimopoulou et al., 2019)
	Kinnow mandarin waste	22.60	(Oberoi et al., 2011)
Apple (Malus sp.)	Apple peel	1.21–14.50	(M. Kumar et al., 2020)
	Apple pomace	33.50	(MoralesContreras et al., 2020)
Sugar beet (Beta vulgaris)	Sugar beet pulp	15.00–32.00	(Hutnan et al., 2000)
Sunflower (Helianthus annuus L.)	Dry sunflower heads	29.50	(Muthusamy et al., 2019)
Pea (Pisum sativum)	Pea pod	8.30	(Müller-Maatsch et al., 2016)
Fava bean (Vicia faba)	Faba bean hulls	9.57–15.75	(Korish, 2015)

Source	**Type of waste**	**Pectin content (dry weight, %)**	**References**
Green beans (Phaseolus vulgaris)	Green beans cutting waste	8.10–8.30	(Christiaens et al., 2015)
Carrot (Daucus carota)	Rejected carrots	8.70–9.10	
	Carrot steam peels	8.90–9.10	
Wheel cactus (Opuntia robusta)	Fruit peel	14.64–15.71	(Mota et al., 2020)
Tomato (Lycopersicon esculentum Mill.)	Tomato waste	15.10–35.70	(Grassino et al., 2016)
	Tomato peel	17.00–25.00	(Casa et al., 2021)
Mango (Mangifera indica)	Mango peel	18.50–39.40	(Girma & Worku, 2016)

3. Pectin Structure

Three classes of polysaccharides, cellulose, hemicellulose, and pectin, make up the majority of the cell wall of primary plants (Freitas et al., 2020 and Badaró et al., 2020). Pectin is also present on the middle lamella of upper plants (Yang et al., 2018; Ngouémazong et al., 2015, Grassino et al., 2016)**.** Pectin is a complex polysaccharide family that is vital for plant growth and development because it provides a barrier from the outside world and mechanical resistance (Wang et al., 2018**).**

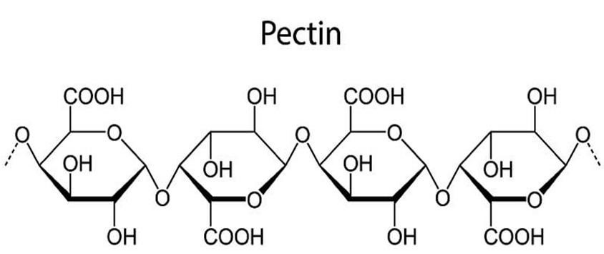

Figure 1: Structure of Pectin

Pectin is a complex polysaccharide that is mostly made up of D-galacturonic acid that has been esterified and is arranged in an alpha-(1-4) chain. In the natural product, methoxy groups are typically esterified with acid groups along the chain. On the free hydroxy groups, acetyl groups may also exist. The rhamnose group, which occasionally appears in the galacturonic acid main chain, interferes with the development of the chain helix. It is also known that various neutral sugars that are found in side chains are present in pectin. Xylose, galactose, and arabinose are the most prevalent side chain sugars. The pectin molecule is described as having smooth and hairy sections due to the sidechains, which tend to appear in groups. Separating pectins into low methoxy pectins (less than 50% esterified) and high methoxy pectins (>50% esterified) is possible.

4. Chains of Pectin:

Pectin chains are categorised into three categories based on the degree and type of substitution: homogalacturonan, rhamnogalacturonan I, and rhamnogalacturonan II. Homogalacturonan, often known as "smooth" chains, is a simple, non-substituted chain of polygalacturonic acid that makes up over 60% of all the pectins found in cell walls (Christiaens et al., 2015). Rhamnogalacturonan I (RG-I) is a structurally defined polymer composed of spatially regulated polymers with a lengthy backbone sequence of alternating galacturonic acid units and D-rhamnose (Willats et al., 2006). While rhamnogalacturonan II is made up of a homogalacturonan backbone substituted with a wide range of complex glycan side chains, containing numerous ranges of neutral sugars, xylogalacturonan (XG) is made up of the galacturonic acid in the backbone linked by xylose in branches.

4.1 Homogalacturonan (HG):

Homogalacturonan (HG), a linear homopolymer of a-1, 4-linked galacturonic acid that makes up 65% of pectin, is the most prevalent pectic polysaccharide. According to (O'Neill et al.,1990)**,** HG is partially methylesterified at the C-6 carboxyl, and it might also contain additional possibly crosslinking esters with an unclear structure (Jackson et al., 2007 and MacKinnon et al., 2002). It may also be O-acetylated at O-2 or O-3. Along with the structurally more varied pectic polysaccharide rhamnogalacturonan I (RG-I), the other pectic polysaccharides are significantly more complicated in structure than HG. These include the substituted HGs rhamnogalacturonan II (RG-II), xylogalacturonan (XGA), and apiogalacturonan (AP).

4.2 Substituted HG: rhamnogalacturonan II (RG-II)

10%pectin is made up of RG-II, the most structurally complicated pectin (O'Neill et al., 1990). With an HG backbone made up of at least 8 and probably more—1, 4-linked a-D-GalA residues, its structure is largely constant across plant species. Its side branches are adorned with 12 different types of sugars arranged in over 20 different connections.

4.3 Other substituted HGs:

The expression of xylogalacturonan (XGA) and apiogalacturonan (AP), two further substituted galacturonans, is more constrained. XGA is an HG that has had its xylose blinking at position O-3. Though it has also been found in Arabidopsis stems and leaves, XGA is most commonly found in reproductive tissues. The recently discovered XGA biosynthesis gene is activated in reaction to pathogen invasions. Aquatic monocots like Lemna contain apiogalacturonan (AP), HG replaced at O-2 or O-3 with apiofuraose.

4.4 Rhamnogalacturonan I (RG-I):

About 20–35% of pectin is made up of RG-I. It has a disaccharide repeat as its backbone, and the kind and quantity of sugars, oligosaccharides, and branching oligosaccharides that are connected to it show a strong degree of cell type and development-dependent expression. Side chains of the RG-I backbone might be single, linear, or branching.

5. Types of Pectin

When the degree of esterification is more than 50%, pectin is categorised as high methoxyl or high ester pectin; when the degree of esterification is less than 50%, pectin is referred to as low ester or low methoxyl pectin. (Wang et al., 2018; Freitas et al., 2021). The specific configuration of pectin's structure results from the esterification of galacturonic acid residues on the continuous polygalacturonic acid chain of homogalacturonan, which have methyl groups at C-6 and acetyl groups at O-2 and O-3 (Yapo et al., 2009**).** Although plants such as high methoxyl and low methoxyl pectin do not naturally yield amidated pectin, it can be made artificially by converting some non-esterified carboxyl groups into amide groups. Ammonia and the carboxymethyl groups (-COOCH3) on the pectin molecule combine to form amide pectin (Leijdekkers et al., 2013, Zhang et al., 2018). The percentage of pectin's carboxylic acid groups that are present in amide form is known as the degree of amidation (DA). High methoxyl pectin gels occur in the presence of water, a mean pH of less than 3.5, and soluble solids at greater concentrations. The creation of hydrophobic interactions between methyl esters and intermolecular hydrogen bonding is what gives high methoxyl pectin gels their stability. These are used in the making of sweets, pastries, jams, jellies, and marmalades. Due to ionic interactions between free carboxyl groups in galacturonic acid and divalent or polyvalent ions, low methoxyl pectin forms gels in the presence of divalent calcium ions or multivalent cations at appropriate concentrations; for example, Ca^{2+} ions over a 2.0–6.0 pH range (Freitas et al., 2021, Martau et al., 2019, Marenda et al., 2019). (Cho et al., 2019). According to Marenda et al., (2019), they are typically employed to improve the texture and stability of water-soluble soy extract as well as food and dairy products.

6. Bio-Synthesis of Pectin:

Although polysaccharide synthesis occurs in Golgi vesicles, it is possible those certain preceding actions occur in the endoplasmic reticulum or that some assembly occurs in the cell wall. In the early phases of growth in the expanding cell walls of plants, pectin is synthesised in the golgi system from UDP-D-galacturonic acid (Sakai et al., 1993). The Golgi apparatus is a multifaceted organelle consisting of protein-containing vesicles. It is divided into four distinct regions: the trans-Golgi, medial, trans-Golgi, and trans-Golgi network. Through the cis-, medal-, and trans-Golgi cisternae, the synthesis takes place synchronously in several Golgi stacks (Nebenführ and Staehelin 2001). During the synthesis of pectin in the Golgi lumen, glycosyl residues from nucleotide-sugars are transferred by glycosyltransferases enzymes into polysaccharide acceptors. During synthesis, some glycosyl residues acquire changes. Due to the complexity of pectin structures, production of pectin requires a significant number of enzymes. According to (Mohnen et al., 2008), the synthesis of HG, RG-I, and RG-II requires the involvement of around 67 enzymes, including glycosyltransferases, methyltransferases, and acetyltranferases, as well as numerous activities. According to Xiao and Anderson (2013) and Goldberg et al., (1996), pectin is polymerized in the cis-golgi, methyl esterified in the medial-golgi, and substituted with side chains in the trans-golgi cisternae.

7. Pectin Extracted From Raw Materials

Pectin is commercially extracted using acid and a high temperature from raw materials like citrus peel and apple pomace. Pectin yield and quality are influenced by temperature, pH, and extraction technique (Wang et al., 2007). Pectin extraction and characterisation for a variety of plant materials have been researched. Pectin extraction from pumpkin, soy hull, peach pomace, sugar beetroot, Ambarella, apple pomace, mango, banana peel, cocoa husks, citrus peel, jackfruit waste and Saba banana waste was the focus of many studies (Shkodina et al., 1998; Kalapathy and Proctor 2001; Pagàn et al., 2001; Levigne et al., 2002; Singthong et al., 2005; Koubala et al., 2009; Li Ping et al., 2010; Chan and Choo 2013; Kanmani et al., 2014; Begum et al., 2014; Castillo-Israel et al., 2015).

8. Extraction Methods of Pectin:

The most popular techniques for obtaining pectin from raw materials are aqueous extraction (Oosterveld et al., 2000), autoclave (Xu et al., 2014; Kazemi et al., 2019), direct boiling, microwave heating, and electromagnetic induction (Rodsamran and Sothornvit 2019). Almost all plants contain the polysaccharide pectin, which helps to preserve the integrity of the cell structure. Plant cell walls include proteopectin, an insoluble type of pectin. The process of high-temperature extraction begins with the hydrolysis of protopectin, which is followed by the dissolution of sugar-cell wall linkages and the release of pectin into the extraction medium. Using organic acids like citric, tartaric, malic, and phosphoric acids, pectin was extracted from apple pomace and compared to mineral acids like sulfuric, hydrochloric, and nitric acids. Citric acid produced the highest yield (13.75%) and was found to be superior to the other acids when considering environmental and economic factors (Canteri-Schemin et al., 2005). Hydrochloric acid (HCl) and nitric acid (HNO3) were used as the extractants in the ultrasound and microwave-assisted extraction procedures to extract pectin from waste lemon, mandarin, and kiwi peel (Karbuz and Tugrul, 2021). In earlier times, acid extraction was used to heat citrus and apple pomace peels in an acidic solution to release the insoluble pectin and turn it into a soluble form. Many emerging technologies, including deep eutectic solvents, enzyme-assisted extraction, subcritical fluid extraction, ultrasound-assisted extration, and microwave-based extraction, or a combination of one or more methods, are now being used for the extraction of pectin from various agro-based industry wastes (Adetunji et al., 2017)

8.1 Conventional acid-based extraction methods

Chemical techniques have been used to extract pectin so that its structural characteristics and functional qualities can be investigated. Four classes of chemical agents are utilised in the extraction of pectin. They are bases and acids, water and buffers, and calcium ion chelators. The most effective extracting agents for pectin are acids because they increase yields by making it easier to extract insoluble pectin that is firmly bonded to the plant material's cell matrix (Assoi et al., 2014; Maria et al., 2015; Yapo 2007). Galactocoronic acid is typically abundant in pectin. Numerous investigations have demonstrated how the intensity of the acid extractant affects the pectin production as well as its chemical and/or physical properties (Liew et al., 2014). The most often utilised acids are acetic, citric, lactic, malic, tartaric (organic), hydrochloric, nitric, oxalic, phosphoric, and sulfuric acids. (Kermani 2015; Min et al., 2011; Lim 2012)

Among the hydrochloric, nitric, and citric acids that were extracted from guava peel, citrus fruits, bananas, and cocoa pods, hydrochloric acid was shown to have the highest pectin production. Temperature and pH varied sequentially from 1 to 3, from 60 to 85 degrees Celsius. (Banu et al., 2012; Bhat and Singh 2014; Bhavya and Suraksha, 2015; Israel-Castillo et al., 2015). High hydrogen ion concentrations promote the hydrolysis of pectin from protopectin. Because of their greater affinity for cations like Ca2+, which stabilise the pectin molecule, acids with higher ionic strengths are more able to precipitate pectin. Nevertheless, pectin with a reduced DM range in which LM pectin was generated by hydrochloric acid

(Chan and Choo 2013). Furthermore, LM pectin can be found in a wide pH range—up to a maximum of 6—according to (Mollea et al., 2008; Yapo et al., 2007).

8.1.1 Apple Pomace

Through intricate chemical and physical processes, apple pomace is a rich source of pectin, cellulose, lignin, and hemicellulose found in plant cell walls. Compared to apple flour, the pomace that was utilised as the raw material produced a lesser output of pectin (Canteri-Schemin et al., 2005). To achieve a higher yield, apple flour must be produced as a step in between during the extraction process. With a degree of esterification of 68.84%, a maximum yield of 14% was obtained after 153 minutes of treatment with either citric or nitric acid (6.2%).

8.1.2 Citrange Fruit

Using traditional heating and electromagnetic induction, pectin was extracted from citrange for 90 min at pH 1.2 and 80 °C. A high pectin yield of 29% was obtained using this electromagnetic induction method, which is equivalent to cooking conventionally. Moreover, both isolated pectins have comparable physicochemical and compositional characteristics. Both techniques produced large yields quickly without changing the pectin's composition or physiochemical characteristics. (Zouambia et al., 2017).

8.1.3 Jackfruit Seed

With a yield of 35.52%, pectin was extracted from the enigmatic slimy sheath of the jackfruit seed coat using oxalic acid at a concentration of 0.05 N and 60 min of incubation at 90 °C. (Kumar et al., 2021). Pectin isolated from jackfruit seeds has a greater level of antioxidant activity and is useful in food, medicine, cosmetics, and health products.

8.1.4 Pineapple Peel

Pectin was extracted from pineapple peels using a variety of organic acids (citric, acetic, and oxalic), inorganic acids (hydrochloric, sulfuric, and nitric acid), and aluminium chloride. (Ukiwe and Alinnor, 2011). Compared to other organic and inorganic acids, aluminium chloride produced a larger output of pectin (2.4%), nitric acid (0.8%), and acetic acid (0.3%). For inorganic acids, the methoxylation degree varied from 2.4% to 5.6%, and for organic acids and aluminium chloride, it varied from 2.8% to 3.9%.

8.2 Nonconventional methods for extraction

Poor yield and a significant environmental impact are the results of conventional acidic extraction procedures due to their corrosive nature, longer processing times, and temperature requirements. The different green approaches to pectin extraction are seen to be sustainable and promising. These include the use of deep eutectic solvent-based, enzyme-based, microwave-, ultrasound-, ohmic-, and subcritical water-based methods.

8.3 Deep Eutectic Solvent-Based Extraction

Different combinations of hydrogen bond donors can be found in deep eutectic solvents, and pectin extraction efficiency can be increased by using hydrogen bond acceptors. An affordable, safe mixture of components that can self-associate through hydrogen bond interactions to generate a eutectic mixture with a melting point lower than the melting points of the constituent parts is called a deep eutectic solvent. Temperatures below 100 °C are typically when deep eutectic solvents (DESs) are liquid. These DESs are far less expensive and environmentally hazardous than traditional ionic liquids, although sharing many of the same physicochemical properties. (Smith et al., 2014).

8.3.1 Dragon Fruit Peel

Industrial pectin was bright yellow in colour, but the pectin extracted from the dragon fruit peel using a 5:2:5 ratio of choline chloride to glucose to water was yellow to brownish in hue. (Tien et al., 2022). The extracted pectin has a high molecular weight (5.05×10^5 Da) strong antioxidant activity (8.14 mg GAE/g), and falls into the high methoxyl pectin (59.76%) and pseudoplastic material group.

8.3.2 Mango Peel

Comparing the deep eutectic solvent method of extracting pectin from mango peel to the traditional acid extraction method, (Chen et al., 2022) used choline chloride, betaine, and L-proline in combination with organic acids. Greater pectin yields (30–38.72%) were obtained from betaine–citric acid and choline chloride–malic acid combinations than from acid extraction.

8.4 Enzyme-Assisted Extraction

Plant cell walls include a complex network of several polysaccharides, including pectin. Enzymes that break down cell walls with the least amount of pectinolytic activity will be used to hydrolyze the nonpectic components. Enzymes have the ability to accelerate processes, reduce extraction times, consume less alcohol during precipitation, and boost yield. Popular enzymatic methods for pectin extraction include the use of protopectinases, which are microbial enzymes that can solubilize protopectin. (Puri et al., 2012).

8.4.1 Apple Pomace

Using an enzyme (Celluclast 1.5 L) at a concentration of 20–60 L/g and over varying times (12–24 h), pectin was extracted from apple pomace at 40–60 °C. 48.3 °C, approximately 18 hours of extraction time, and 42.5 L/g of pomace enzyme concentration are the ideal extraction parameters. These values produce a pectin yield, galacturonic acid content, and esterification degree of 6.76%, 97.46%, and 96%, respectively. The extracted pectin's chemical makeup resembled that of commercial apple and citrus pectin. (Dranca and Oroian, 2019)

8.5 Microwave- and Ultrasound-Assisted Extraction

Heat is produced by microwaves through the processes of ionic conduction and dipole rotation when they interact with polar materials like water and some organic plant matrix components. Through a synergistic effect that speeds extraction and increases extraction yield, mass and heat transfers happen in the same direction during microwave heating. (Vinatoru et al., 2017). A high-frequency sound wave that is higher than 20 kHz is called ultrasound. In extraction, ultrasonic pulses with frequencies between 20 and 100 kHz are frequently employed. The food sector has made extensive use of ultrasound because of its physical and/or chemical characteristics. (Azmir et al., 2013).

8.5.1 Banana Peels

The pectin extracted from the banana peels was impacted by the extraction solution's pH. Lower pH levels cause pectin's galacturonic acid content to decrease due to changes in its chemical structure, but they also improve pectin output. (Happi Emaga et al., 2008). The extraction of pectin from banana peels with microwave assistance, both intermittent and continuous, demonstrated its effectiveness and potential for optimal outcomes. The extraction parameters employed in the continuous process were microwave power (300–900 W), time (100–300 s), and pH (1-3). In the intermittent process, the parameters were microwave power (300–900 W), pulse ratio (0.5–1), and pH (1-3). Pectin yields from the pulsed (pulse ratio of 0.5) and continuous (900 W and pH 3 for 100 s) microwave-assisted extraction were 2.18% and 2.58%, respectively. (Swamy and Muthukumarappan, 2017).

8.5.2 Palm

Pectin yields from the conventional acidic extraction (80 °C at pH 4 and 6) of matured and juvenile sugar palm flesh were 20% and 8%, respectively. The suggested procedure is to use ethanol-based precipitation at pH 7 after microwave-assisted extraction at 800 W for 3 min at pH 2 to increase the pectin yield (23.5%).(Rungrodnimitchai, 2011).

8.5.3 Watermelon Rind

The watermelon rinds' equivalent weights ranged from 1249.7 to 2007.8 and their pectin yields from 3.9% to 5.8% as a result of the microwave extraction process. The extracted pectin exhibited a degree of methylation ranging from 3.9% to 10.8%. The degree of esterification result ranged from 56.86% to 85.76% and revealed a rather high methoxyl pectin concentration (>50%). After receiving 279.3 W of microwave radiation for 12 minutes, the pectin with a greater amount of galacturonic acid was obtained. (Sari et al., 2018).

8.6 Ohmic Heating Extraction

Joule's law states that the ohmic heating method produces heat through the electric current passing through the selected food material. It is among the most advanced thermal processes available, and it operates quickly and reliably. This technique has been applied to both extract useful components from plants and preserve food. (Ueno et al., 2008). Through volumetric heating, ohmic heating rapidly warms the heterogeneous system, enabling appropriate mass and heat transfer during extraction. In addition to cutting down on processing time, this approach gets rid of pectin's variable properties. Ohmic heating is a useful technique for improving pectin quality. (Gavahian et al., 2019).

8.6.1 Orange Waste

A voltage gradient of 30 V/cm, pH 1.5, a solid-liquid ratio of 1:20 g/mL, a shorter heating time of 15 s, and the use of a lower acid content are the ideal extraction conditions for pectin from orange juice wastes during ohmic heating at 90.8 °C. These conditions result in a higher pectin yield with a high degree of esterification and galacturonic acid. (Saberian et al., 2018).

8.6 Subcritical Water Extraction Technique

Subcritical water extraction involves heating water above its typical boiling point without altering its phase by applying greater pressure. The extraction method that uses water as an extraction solvent is also known as superheated water extraction and compressed hot water extraction. (Zakaria and Kamal, 2016). Under many other responsibilities, this technique has been described and applied in the food and environmental sectors. (Plaza and Turner, 2015). Lower viscosity, lower surface tension, an enhanced mass transfer rate, and excellent dispersion are some benefits of raising the temperature of the water used for extraction. At 200 °C, water's dielectric constant drops from 79 at 25 °C to 33, making it feasible to extract both ionic and nonionic components. Most people agree that the subcritical water-based extraction method is safe. Therefore, the extraction of different bioactive ingredients utilised in the food and pharmaceutical industries is appropriate for this technique. (Ueno et al., 2008).

9. Advantages and Disadvantages of Extraction Methods

The creation of acidic wastewater and equipment corrosion from the conventional acid-based extraction procedures cause major environmental difficulties in addition to being time- and energy-intensive. As a result, there is growing interest in the use of alternative, environmentally friendly methods to speed up the extraction process, such as deep eutectic solvents, enzymes, microwaves, supercritical water, and ultrasound. Many benefits come with microwave-assisted extraction, such as a higher yield of extracted material, less thermal degradation, and selective heating of the material. As a result of using less solvent during the extraction process, this method is also known as "green." (Chen, 2013). Ultrasound-based extraction is thought to be more ecologically friendly than conventional acid extraction processes and offers a number of benefits, including shorter extraction times, smaller, more energy-efficient equipment, less solvent usage, and higher extraction yields. Subcritical water extraction can prevent the breakdown of extracted chemicals that occurs during traditional acidic water extraction by maintaining an ideal temperature and enhancing mass transfer. (Brunner 2009). This method yields high-quality goods and has various benefits, such as a fast extraction procedure and the removal of organic solvents. The benefits of ohmic heating include quick and even heating, reduced energy usage, cheaper maintenance expenses, and a decreased danger of fouling in heat transfer regions. The ohmic heating-based extraction technology has a few drawbacks, including a small frequency range and challenges in monitoring and managing the extraction process. (Sakr and Liu, 2014). High extraction yields can be achieved with the enzyme-assisted extraction method, which also doesn't require complicated processing settings. (Gagaoua, 2018). A few drawbacks of the enzyme-assisted extraction method are the expensive cost of the enzymes, longer processing times, incomplete breakdown of plant cell walls, and challenges with process scaling up. (Nadar et al., 2018). The few benefits of deep eutectic solvents are their lack of toxicity, biodegradability, volatility, cheaper manufacturing costs, and higher extraction yield; yet, their high viscosity is seen to be a barrier for commercial uses. (Botelho, et al., 2022).

10. Physicochemical characterization of the pectin

Pectin is used in the food and pharmaceutical industries as a filler, agglutinator, and to boost the foaming strength of gases. Pectin's characteristics, such as its acetyl value, degree of esterification and methoxyl content, among others, determine its suitability for usage in various applications. For pectin used in commerce, the purity of the product is determined by the amount of anhydrouronic acid present, which must be at least 65%.

10.1 Pectin Yield:

The pectin yield was calculated using equation

$$\text{Pectin yield (g/100g)} = \frac{\text{Weight of dried pectin (g)}}{\text{Weight dried tamarind powder taken for extraction}} \times 100$$

10.2 Determination of Moisture and Ash content:

Moisture and ash content of pectin was determined by the method of AOAC (1995) and AOAC (1975) respectively.

10.3 Determination of Equivalent Weight:

Equivalent weight was determined by Ranganna's method (1995). 0.5g sample was taken in a 250ml conical flask and 5ml ethanol was added. 1g of sodium chloride and 100ml of distilled water were added. Finally 6 drops of phenol red was added and titrated against 0.1N NaOH. Titration point was indicated by purple colour. This neutralized solution was stored for determination of methoxyl content.

Equivalent weight was calculated by following formula:

$$\text{Equivalent weight} = \frac{\text{Weight of sample} \times 1000}{\text{ml of alkali} \times \text{Normality of alkali}}$$

10.4 Determination of Methoxyl Content (MeO)

Determination of MeO was done by using the Ranganna's method (1995). The neutral solution was collected from determination of equivalent weight, and 25ml of sodium hydroxide (0.25N) was added. The mixed solution was stirred thoroughly and kept at room temperature for 30min. After 30 min 25ml of 0.25N hydrochloric acid was added and titrated against 0.1N NaOH. Methoxyl content was calculated by following formula:

$$\text{Methoxyl content \%} = \frac{\text{ml of alkali} \times \text{Normality of alkali} \times 3.1}{\text{Weight of sample}}$$

10.5 Determination of Total Anhydrouronic Acid Content (AUA)

Total AUA of pectin was obtained by the following formula (Mohamed & hasan, 1995).

$$\text{\% of AUA} = \frac{176 \times 0.1z \times 100}{w \times 1000} + \frac{176 \times 0.1y \times 100}{w \times 1000}$$

When molecular weight of AUA (1 unit) = 176g

Where,

z = ml (titre) of NaOH from equivalent weight determination.

y = ml (titre) of NaOH from methoxyl content determination.

w = weight of sample

10.6 Determination of Degree of Esterification (DE)

The DE of pectin was measured on the basis methoxy and AUA content (Owens et al., 1952) and calculated by flowing formula.

$$\text{\% of DE} = \frac{176 \times \text{\%MeO}}{31 \times \text{\%AUA}} \times 100$$

11. Biomedical Applications of Pectin:

Humans cannot digest or absorb pectin, but they can benefit from its prebiotic qualities when it interacts with good bacteria in the large intestine. (Blanco-Pérez et al., 2021). The gut bacteria breaks down pectin and produces secondary metabolites that are beneficial to the host's health. (Tan and Nie,, 2020). As was already mentioned, a number of studies have documented the benefits of pectin consumption for health, including the prevention of inflammatory and allergic disorders. (Blanco-Pérez et al., 2021), aiding in cancer therapy (Palko-Łabuz et al., 2021), lowering blood sugar and cholesterol levels (Yanlong Liu et al., 2016).

11.1 Free radical and antioxidant effect:

Pectin's ability to chelate metal ions is exactly what gives it its antioxidant capacity, and it depends on the source material, the extraction process, and the pectin's degree of esterification. (Freitas et al., 2021). Examined the alteration of citrus pectin and assessed the significance of flaxseed/sunflower emulsion oxidative stability and esterification degree. The oxidative stability of the emulsions significantly affected the degree of esterification, and low methoxyl pectin (DE ≤ 33%) showed more potential for lipid antioxidants than high methoxyl pectin (DE ≥ 58%). As a result, low methoxyl pectin can be used as a natural alternative to synthetic antioxidants with success.

11.2 Antimicrobial effect:

Pectin is a polymer with a complicated structure and soluble characteristics that makes up the cell wall of higher plants. Pectin is a common food additive that is a polysaccharide but lacks antibacterial activity. Pectin is a bio-based polymer with the qualities of biodegradability, biocompatibility, nontoxicity, renewability, and affordability that make it suitable for use in a range of applications without risk. (Picot-Allain et al., 2022). However, because the right functional groups are missing, pectin lacks antibacterial properties.

11.3 Anticancer properties of Pectin:

11.3.1 Breast cancer:

Every year, around 1.7 million new instances of breast cancer are diagnosed worldwide, making up 25.2% of all cancer cases (WHO). After diagnosis, 15% of patients die from breast cancer, second only to lung cancer. (Han et al., 2017), (Kabir et al., 2016). When gene alterations result in aberrant cell growth and proliferation, complex, molecular breast cancer develops. (Sledge and Miller, 2003). Chemicals generated from pectin cause apoptosis and slow down cell development. (Mukhtar et al., 2012). MCP's additive and synergistic effects have been investigated in human breast cancer cells. When combined with MCP, the polybotanical compounds BreastDefend (BD) or ProstaCaid (PC) decreased the highly metastatic potential of human breast cancer MDA-MB-231 cells. MCP may also stop mice from developing human breast cancer by lowering angiogenesis, a key process in the establishment of tumours. One possible mediator of MCP's prevention of breast and prostate cancer cell adhesion, migration, and invasion is the α-galactosidase binding protein Gal-3. (Rahman et al., 2020).

11.3.2 Colon Cancer:

Colon cancer is becoming a more serious health problem due to its rising death rate. It is now estimated to account for over 10% of all cancer cases worldwide and is expected to rise to 60% by 2030, representing over 2.2 million cases, making it the third most common cancer in both sexes globally. Numerous in vitro studies using different human colon cancer cell lines have been published in an effort to better understand the role of pectin in colon cancer. Furthermore, the theory that a diet high in fibre pectin (FP) lowers signalling via the Wnt/β-catenin and cyclooxygenase (COX) pathways, leading to lower levels of the antiapoptotic transcription factor peroxisome proliferator-activated receptor delta (PPARD), have also been evaluated in vivo. (Vanamala et al., 2008).

In vitro models of colon carcinogenesis, including as HT29, HT115, and CaCo-2 cell lines, have also been used to investigate the anti-cancer properties of phenolics from apple garbage. When apple phenolics were utilised to stop DNA damage, a mechanism linked to tumour formation, they observed a noticeably lower rate of HT115 cell invasion. Additionally, HT29 cells' exposure to hydrogen peroxide (H2O2)-induced damage was greatly decreased, and CaCo-2 cell barrier function was raised—a process linked to a decreased risk of tumour promotion and metastasis. (McCann et al., 2007).

11.3.3 Anti-inflammatory effect:

When the immune system is seriously compromised, inflammation is a normal physiological process. Many diseases progress more quickly when inflammation is present. It has been observed that polysaccharides with anti-inflammatory properties include starch, glucan, gum acacia, inulin, and pectin. Many academics interested in the areas of immunological modulation, hypoglycemia, anti-tumor, and anti-inflammatory properties have focused on polysaccharides. (Cheng et al., 2016), (Wu et al., 2015), (Sun et al., 2021). Because of their low toxicity and few adverse effects, plant polysaccharides have the potential to suppress inflammation and be turned into medication. Reducing chronic inflammation is a major method to avoid various progressive illnesses in humans, including cancer, metabolic diseases, neurological disorders, and cardiovascular disease. Inflammation has been identified as a major risk factor for these illnesses. (Leivas et al., 2016). Consuming dietary fibres like polysaccharides found in plant cell walls improves the effectiveness of treating inflammatory conditions. Inflammation pathology is a complex process that is initiated by microbial pathogens, including bacteria, prion, viruses, and fungus. (Bezerra et al., 2018; Vitaliti et al., 2014). The body's initial line of defence is made up of macrophages. Because lipopolysaccharides (LPS) can activate macrophages, they are commonly used as an inflammatory model. It has been possible to extract a water-soluble polysaccharide from starfruit (Averrhoa carambola L.). The starfruit is a delicious tropical fruit with a wide range of pharmacological properties that is often drunk as fruit juice. In a formalin model, this polysaccharide showed antinociceptive and anti-inflammatory qualities, indicating that it may have health advantages and be helpful in therapeutic intervention for the treatment of inflammatory pain. A halophytic shrub that grows annually is called Suaeda fruticosa (L.) Forssk. (Oueslati et al., 2014). Research has shown that the polysaccharides found in S. fruticosa (SFP) may offer a novel avenue for the production of antioxidants and analgesics, as well as a promising dietary and therapeutic supplement. (Mzoughi et al.,2018). Peptide polysaccharides that have been isolated from S.fruticosa exhibit considerable potential for antioxidant activity. This activity includes the scavenging of free radicals, lipid peroxidation, and decreased impact.

11.3.4 Anti-diabetic effect:

Pectin with anti-diabetic qualities is derived from several plant compounds. (Kumar et al., 2021). Diabetes mellitus (DM) is a malfunction linked to anabolism and catabolism that affects how well carbohydrates, proteins, and fats are absorbed, which throws off the cells' ability to use calories in a balanced manner. Type 2 diabetes can be successfully treated with citrus pectin. (Liu et al., 2016). In diabetes-induced mice, citrus pectin dramatically improved blood lipid proportions, liver glycogen content, and blood sugar tolerance levels. Additionally, it significantly reduced insulin resistance, which immediately aided in the treatment of diabetes. The entire mechanism of the anti-diabetic action was based on the P13K/Akt signalling pathway, since the injection of pectin induced the phosphorylated Akt protein while decreasing the expression of GSK3ß assertion decreased. Another study that used pectin extracted from passion fruit (Passiflora glandulosa Cav.) demonstrated that the polysaccharide can be highly helpful in decreasing blood glucose levels in rats given alloxan. (Sousa et al., 2015). Analogously, pectin was also isolated from Passiflora edulis, another species of passion fruit. Comparison medications included metformin and glibenclamide. Drawing from the blood levels measured before and after the pectin was administered, it was determined that this variety's pectin can be utilised to effectively treat type 2 diabetes (Silva et al., 2011).

11.3.5 Neuroprotective effect:

Pectins are the natural polymers that make up the cell wall in most plants, around 70% of which is galacturonic acid. One study revealed that pectins improved memory and antidepressant behavior in mice, which was ascribed to activation of Il-6 expression and the JAk-STAT signaling pathway. (Paderin and Popov, 2018).

11.3.6 Regulation of blood cholesterol level:

Like other water-soluble fibres, pectin probably reduced cholesterol through a similar method. It lowers circulating blood cholesterol via increasing the viscosity of the gut, which also increases the production of bile acids from cholesterol and decreases bile acid reabsorption.

Summary:

A plant-based hydrocolloid with distinctive structural and biochemical characteristics is called pectin. It is taken out of waste products from the fruit processing business, like peels. Pectin's novel properties and natural origin have earned it extensively recognised in a multitude of industries, notably food, medicines, nutraceuticals, cosmetics, biomedical, and edible packaging. Using the life cycle assessment technique, this work seeks to comprehend the conventional pectin production process from a sustainability perspective. This allows for new perspectives on the procedure, which encourages a more environmentally friendly and long-lasting method of producing pectin. We think that, all things considered, this viewpoint would help in the process of deciding which environmentally safe and commercially more acceptable ways to produce pectin. Pectin and hydrocolloids generated from it have a vast market. All things considered, we think that this viewpoint would help in the process of making decisions on which environmentally safe and commercially more acceptable green and sustainable ways to use in the pectin production process. Pectin and pectin-derived hydrocolloids have a large and expectedly growing market; pectin finds widespread use in both the food and non-food industries, and new uses are often being found.

Conclusions and Future Perspective:

In conclusion, the methyl esterification and sugar moieties that give pectin its indeterminate molecular weight make it a good heteropolysaccharide. Pectin extraction is a well-documented process; many methods, including enzymatic treatment, ultrasound, and microwave, can be used to get the polysaccharide. By regulating the pectin structure, such as the amount of methyl esterification, side chain content, molecular weight, etc., the extraction procedure eventually influences the characteristics. In many different foods and other uses, pectin is widely employed as an emulsifier, texturizer, and stabiliser. This polymer's influence stems from its excellent gelation, affordability, non-toxicity, elevated stability, and biocompatibility. With the growing popularity of low-calorie foods, pectin will probably be used more often in the future to substitute fat and sugar in these kinds of meals. Apart from the fact that pectin is found in a wide variety of plant species, there are very few commercial sources for its extraction. Consequently, in order to obtain pectin with the appropriate quality qualities, it is imperative to look for alternative sources or alter those that already exist. Owing to its gelling and stabilising qualities, pectin is a crucial part of food and medicine products. It has a synergistic impact with cancer therapy medications and is positively effective in healing wounds. Research into the mechanisms involved in the manufacture of pectin in plants, as well as studies on the metabolism of this substance in humans and other animals, are crucial. Pectins are traditionally extracted from citrus or apple fruits, but in recent years, using unusual sources—such as sunflower head leftovers, mango waste, amaranth, and sugar beet—has become more and more appealing. The degree of esterification, molecular weight, concentration of pectin, ion concentration, and extrinsic variables including pH, ionic strength, and temperature all have a direct impact on the gelation process. As the pharmaceutical industry increasingly embraces renewable and biocompatible materials, the ongoing study of pectin's structure and properties has allowed for a greater understanding of the complex heterogeneity of this polysaccharide and the continued development of new applications of pectin beyond the traditional uses in food. Thus, it is essential to conduct more study on the development of techniques for in-depth examination of the composition and characteristics of pectin polysaccharides.

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