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A Valuable Observation on Pectin as an Eco-friendly Material for Valuable Utilisation in Textile Industry

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Abstract

In this study, we highlighted the use of eco-friendly natural gum from pectin as a thickener to decrease the environmental effect. The use of pectin to enhance the dyeing process by treating natural and commercial raw materials. Natural materials are substances of great interest since they play a significant part in our daily lives. A wide range of technical and industrial uses for dyeing or printing cloth, paper, leather, and other materials. Some of the synthetic materials used in our daily life are poisonous, carcinogenic, and can irritate the skin and eyes. Many harmful and allergenic synthetic colors are now prohibited.

Keywords: pectin; Eco-friendly Material; Textile industry

1. Introduction

The textile printing branch is becoming a widely-known technology for all fibers, textiles, and garments in the textile wet processing industries. Printing is a kind of coloring in which colors are applied to particular regions of the cloth rather than the entire fabric. [1, 2]

The resultant colorful patterns offer attractive and aesthetic qualities, which increase the value of fabric above flat fiber. [3-9] The dye substance is glued to the design area with the assistance of a thickening agent. For effective printing, correct colors, brand sharpness, level, great hand, and efficient application of dye are all necessary. The thickener kind used affects all these factors. [10] Thickener has been utilized as an Essential component in textile fiber printing. They are high molecular, highly viscous, robust, lengthy hydration times compatible with other printing pulp components, and colorless. [7, 11-16] The printing paste is supplied with flexibility and adherence to creating designs avoiding bleeding. The main objective of printing pastes is to hold, attach and move the dye into the fabric. [17, 18]

2. Thickeners

2.1. Definition

In textile printing, thickeners are large molecular components with high viscosity weight that have given a thick water paste, which gives the printing paste stickiness and flexibility. Those thickeners can keep the design features even at high pressure, avoiding spreading.[10] Thickeners are defined as viscous ingredients, which give flexibility and plasticity to printing pastes to apply on the surface of the fabric with a particular pattern and without leaking or dispersal.[19]

2.2. Essential Properties of Thickener

- The resistance of printing paste to storage, pressure, and temperature.
- The properties of the dry film that was generated.
- Colors yielding impacts (for example, diffusion and fixation).
- Simplicity in preparation.
- Removing from the fabric's surface.
- Low cost and easy to obtain.
- It is simple to clear by rinsing after drying.
- Printing paste dispersion is homogeneous.
- Environmental consequences
- Printing types and methods.

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- Fabric kind selected.
- Compatibility and durability with various printing materials, such as dyes and additives.
- Provide clear outlines that do not leak or spread.
- Good mechanical characteristics to avoid dry film-forming.
- Diffusion is optimal for the greatest color production.
- Good condensed water-absorbing to ensure free space for dye and water molecules to permeate into the fibers.
- It should not be used to hold the dye or to keep it away from the cloth.[19, 20]

2.3. Extraction of endosperm from seeds

The hull and cotyledons are removed mechanically, physically, or chemically to obtain endosperm. Extracting gum from P juliflora seeds in water overnight at room temperature, removing the hull and germ by filtration Gum was extracted from the filtrate by precipitating it in ethanol, then drying it at 45 degrees Celsius and milling it. In the case of a chemical method, whole seed treatment with acid at high temperatures carbonized the hull, which was then washed off. Sodium hydroxide treatment of P chilensis seeds manually separating the hull, endosperm, and cotyledons at high temperatures.[21]

Polysaccharides are monosaccharide polymers. It is derived from a variety of natural sources, including plant sources (like pectin and guar gum), microbial sources (such as alginate, dextran, and xanthan gum), and animal sources (chitosan and chondroitin). Polysaccharides have a wide range of molecular weight and a complex chemical composition which contribute to diversity in their property. Polysaccharides can be effectively chemically and biochemically modified due to the presence of distinct derivable groups on molecular chains, resulting in a wide range of polysaccharide derivatives.[22]

Polysaccharides are a type of carbohydrate that is highly complicated. They have excellent mechanical strength and can be used to make fibers, films, adhesives, rheology modifiers, hydrogels, emulsifiers, and drug delivery agents. Some polysaccharides, for example, have been shown to improve drug-human mucosa contact due to their high mucoadhesive properties. Seed endosperm is a hydrogel composed of polymers, primarily polysaccharides that are released by seed coat epidermis upon imbibition. Myxospermy is a feature found in several plant species, such as Arabidopsis thaliana (Arabidopsis), where the paste is composed of two layers.**[21]**

2.4. Classification of Thickener

Thickeners may be classified as illustrated in **Figure 1**. **[23]**

2.4.1. Emulsions

The term "emulsion" refers to the spread of two immiscible liquid phases within each other. One liquid (the inner component) is suspended in another liquid in the shape of very small droplets (the outer phase). These are mainly suspensions of inner hydrocarbon oil (white spirit, minerals spirits) in a continuous liquid phase oil-in-water (o/w) emulsion or particles of an aqueous solution in hydrocarbon oil-in-water (w/o) emulsion. In the presence of an emulsifying agent, a stable emulsion is generated.[24]

Emulsions are formed by dissolving the oil in water and then water in oil. Their usage pollutes wastewater with poorly biodegradable or no biodegradable compounds as water-in-oil emulsions with highly dissolved solids. Mineral oils are formed in wastewater from water treatment facilities and destroyed in minute quantities by microorganisms. Although both phases of the thickening are unstable and have no influence on handling or fastness, the use of emulsified thickeners (o/w type) results in printed fabric with outstanding fastness qualities, a great degree of cleverness, clear outlines, and a smooth handle. The use of huge quantities of white spirit has three primary problems that restrict its usage in many regions: the danger of explosion during fabric drying if the airflow is insufficient, pollution, and increasing expenses owing to rising oil prices and diminishing availability of oil goods.[25, 26].

Synthetic thickeners

Synthetic thickeners are polymers with a lengthy chain having carboxylic groups that are partially bonded. The compounds can drastically expand in water and produce high-viscosity gels when neutralized.[26, 27] Synthetic polymers are employed for their production includes alcohol, polyvinyl, polyacrylic acid, and polyacrylamide. They are the outcome of their respective monomers' polymerization. They are often quite expensive compared with natural and semi-synthetic products. The principal advantage of synthetic thickeners is that they can be adapted to a particular environment.[25]

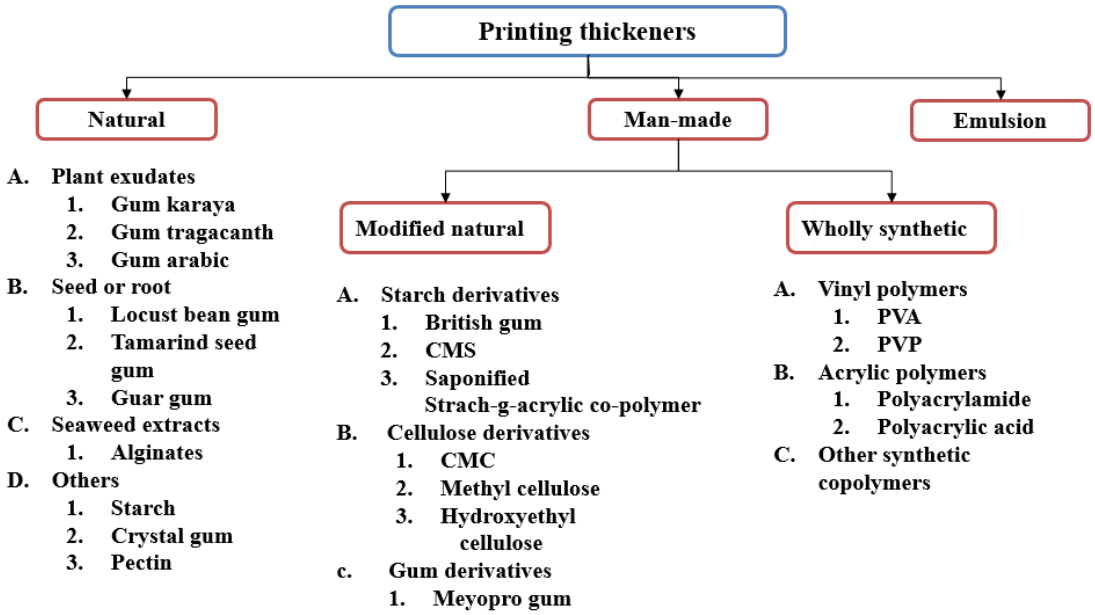

Figure 1: Classification of printing thickeners

The following characteristics exist for manufactured thickening agents:

- Exceptional purity.
- Quick stock thickening preparation.
- Recipe for quick printing.
- Excellent running characteristics.
- Maximum depth of darkness and print brilliance.
- The print paste is stable.[20, 28]

2.4.2. Natural Thickener

Are Polysaccharides derived from naturals, such as plant exudates, seaweeds, seeds, and roots, are commonly utilized. Some of them seem to be appropriate for printing with a specific color category, but they should be chemically adapted to satisfy the standards for printing.[25] Natural thickening agents are biopolymers with a high molecular weight depending on polysaccharides and a lot of hydroxyl groups.[15, 29-31] Normally, natural goods are also renewable sources of continuous production that do not pollute.[32]

The following are the most effective natural thickeners [10]

- Starch and its derivatives.
- Soluble Cellulose derivatives.
- Gums.

Guar gum is a natural gum produced from Guar seeds and a thickening agent for organics. Guar beans possess a thick, galactomannan-gum endosperm, which is water-gel. Guar gum is widely utilized for food and industry purposes, as it is generally known). Seaweed extracts such as alginate (Sodium alginate thickeners may not chemically bond with the structure of the material or interfere with fiber-reactive coloring, unlike starches and gums. Sodium alginate has several advantages: high permeability, consistent colors, easy washing, absence of sticking with cylinders and scrapers, pleasant feeling with hands.[19]

3. Pectin as an Eco-friendly Material in Textile

3.1. Definition

Pectin is a polysaccharide that is found in all plants. They are found in the cell walls of the middle lamella, as well as the main and secondary cell walls. [33] Pectin is a natural substance that is found in the cell walls of all higher plants, and it has been utilized for a variety of applications from foodstuffs to the food and biopharmaceutical sectors for gel formation, thickening, and stabilization. [34]

Pectin is a polysaccharide that consists of large molecules of galacturonic acid, a sugar derivative. It occurs in plant tissue cell walls. While pectin was found more than 127 years earlier, its structure and morphology are still not entirely known. It's impossible to specify the structure of pectin, because pectin may alter through plant separation, storage, and processing. There are also some contaminants accompanying the major elements. Pectin is a polymer that contains galacturonic acid units for usage in food (at least 65 percent). The acid groups could be free, coupled as an ester of methyl or as salts of sodium, potassium, calcium, or ammonium, and amide could be found in such pectin. Pectin

comprises a chain-like structure from only several hundred to around 1000 saccharide units, corresponding to typical molecular weights between 50000 and 150000 Daltons. [35]

3.2. Structure of pectin

Pectin is a kind of anionic polysaccharide present in higher plants' main cell walls and interstitial areas. Pectin is linear polysaccharides composed primarily of D-galactopyranosyluronic acids linked together by (1,4) glycosides bonds (see **Figure 2**). This typical structure contains L-rhamnopyranosyl units, or "hairy regions," methyl ester groups, and, on rare occasions, neutral-sugar side-chains. Pectin includes galacturonic acid molecules that can be partially methyl-esterified, acetylated or even both. [24-26]

3.3. The Pectin Family

Pectin consists mostly of residues of α-1,4-D-galacturonic acid. Different pectin fields are distinguishable from the other pectin, including homogalacturonan (HG), rhamnogalacturonan I (RGI), rhamnogalacturonan II (RGII), xylogalacturonan (XGA) (AGII). The largest field in the pectin is homogalacturonan, which accounts for around 60 percent of all cell walls of pectin.[36] The HG molecule consists of a linear chain of α-1,4-D-galacturonic acids, that are esterified by certain carboxyl groups of O-2 or/and O-3 in methanol or/and acetyl groups. The base of HG is at minimum 72–100 D-galacturonic acid residual in apple, citrus and sugar beets.[37]

One of the main characteristics linked to gelling capacity is the degree of methylation (DM), which is described as the ratio of methyl-esterified carboxyl groups to the total quantity of galacturonic acid units and can be measured utilizing infrared spectroscopy.[38, 39] Rhamnogalacturonan I consists of repeated α-1,4-D- galacturonic acid and α1,2-L-rhamnose residues. The backbone of RGI extracted from suspension-cultured sycamore cells is approximately 100–300 repeating units long.[40]

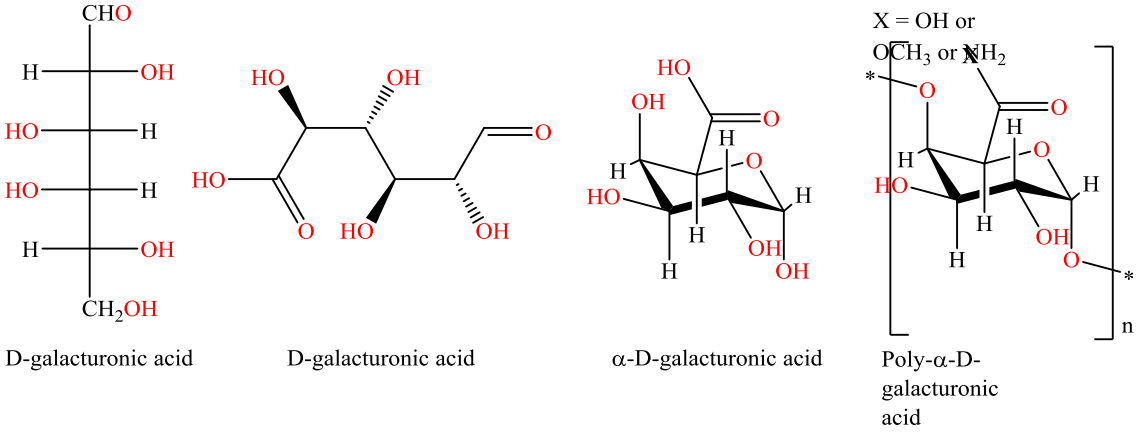

Figure 2: Possible chemical structure of D-galacturonic acid

3.4. Sources of Pectin

While pectin usually appears as either cement in the central lamella and as a thickening on the cell's wall in very many plant tissues, there are extremely few sources for the commercial production of pectin. That's because of the capacity of polysaccharides to form gel based on molecular size and DM, due to differences in these parameters, pectin from various sources does not have such gelling capacity. As a result, detecting a significant amount of pectin in fruit is insufficient to certify that fruit is a producer of industrial pectin (see **Table 1**).[41, 42]

Today the primary sources of economically viable pectorine are apple pomace and citrus peels. Moreover, they generate somewhat distinct pectin that makes one or the other more appropriate for particular purposes.[43] Sugar beet and remnants from the sunflowers' seed heads are some other suppliers of pectin examined. [44, 45] Other fruits' pectin content is also mentioned in the literature

Pectin is heteropolysaccharides or water-soluble polysaccharides. They are distinguished by their natural origin since they exist in plant cell walls as well as central plaques of intercellular gaps. They serve as the skin-forming substance and govern water management in this capacity. Pectin derived from apple pomace and the citrus peel has been the most widely used.[46]

Pectin liquid solubility and viscosity are related to molecular mass, percentage of esterification,

preparation content, pH, and the presence of counter ions in the solution. Viscosity, solubility, and gelation are all physiological characteristics. Factors that promote gel strength, for example, will enhance the ability to gel, reduce solubility, and increase viscosity, and vice versa. Pectin characteristics are determined by their structure.[47]

3.5. Extraction of pectin

The extracting of pectin is regulated with the mass transfer; hence the suitability of the separation process can be evaluated either by quantity of extract obtained as well as the purity of the extracted material. To separate pectin using natural origin, various processes were used, such as traditional heat separation techniques and novel approaches utilizing ultrasound, microwave, and enzyme. [48]

Direct boiling and microwave heating seem to be the most widely utilized technique for pectin extraction.[49] The usual method for extracting pectin, which requires around 2 hours to get a fair return on pectin, is direct boiling. The pectin extracted experiences thermal deterioration due to a rather long time of direct heating.[50] On either hand, it requires not more than 15 minutes for microwave heating to obtain a good quantity of pectin. Generally, pectin yielding methods utilizing microwave heating is much more successful and also provide superior quality goods. Pectin yield also relies on the kinds of solvents used for extraction and the usage of additional chelating agents like EDTA and CDTA that can assist remove pectin from the cell wall. [51]

Table 1: Pectin content in fruits

Fruit	% Pectic substances (wet weight)
Apple *(Malus spp*.)	0.5 – 1.6
Apple pomace	1.5 – 2.5
Banana *(Musa acuminata* L.)	0.7 – 1.2
Beet pulp (*Beta vulgaris)*	1.0
Carambola (*Averrhoa carambola)*	0.66
Carrot (*Daucus carota*)	0.2 – 0.5
Giant granadilla (*Passiflora quandrangularis* L.*)*	0.4
Guava (*Psidium guajava* L.)	
Lemon pulp (*Citrus limon*)	0.77 – 0.99
Lychee (*Litchi chinesis* S.)	2.5 – 4.0
Mango (*Mangifera indica* L.)	0.42
Orange peel (*C. sinesis)*	0.26 – 0.42
Papaya (*carcia papaya*)	3.5 – 5.5
Passion fruit (*passiflora edulis* S.)	0.66 – 1.0
Passion fruit rind	0.5
Peaches (*Prunus persica*)	2.1 – 3.0
Pineapple (*Ananas comosus* L.)	0.1 – 0.9
Strawberries (*Fragaria ananassa*)	0.04 – 0.13
Tamarind (*Tamarindus indica* L.)	0.6 – 0.7
Thimbleberry (*Rubus rosalfolius*)	1.71
Tomato fruit (*Lycopersicon esculentum*)	0.72
	0.2 – 0.6

3.5.1. Water-based extraction

The pectin is extracted utilizing acidified water in the traditional water-based extraction method (pH up to 2) at a maximum temperature of 70°C Pectic compounds are precipitated utilizing ethanol or isopropyl alcohol after the operation has been run for 2-4 hours. [52]

Also, for the extraction of pectin from plant tissues, a broad number of different compounds have been described. The easiest and earliest technique for eliminating pectic compounds is extraction with warm water. Mineral acids, such as sulfuric, hydrochloric, and phosphoric acids, seem to be the most commonly utilized acidifying chemicals. Several organic acids and salts, including oxalic acid, ammonium oxalate, tartaric acid, polyphosphates, and some others, have been employed. Extremely weak pectin yield was achieved with the Zeocarb extractant from dries orange peel at 85 - 90°C.[51]

That double separation of pectin from apple pomace has been shown to produce more and improve the strength of the products at 85-88°C with one hour using the cationic resin. Pectin is economically extracted by pH treatment of the raw material at approximately 2. The exact duration of extraction time varies depending on the raw material, the kind of pectin needed, as well as the manufacturer. The heated pectin extract is extracted from the solid residue as effectively as feasible. The particles are soft now and the fluid phase is viscous. It is not simple. The viscosity increases with the amount of pectin and the molar mass of the pectin rises. Effective extraction and solid isolation and operational costs are compromised. A filtering aid can be used to clarify the pectin extract further. The

purified extract is subsequently pressured concentrated. The concentrated fluid from apple or orange with alcohol could be mixed in the powdered pectin (usually isopropanol). The pectin is cut as a thronged gelatine mass, and the liquid, dry and powdered, is squeezed and swept away.[47]

3.5.2. Conventional extraction

Acidic (pH 1.5–3) aqueous medium is typically used to separate pectin, which is typically done from 75 to 100°C for 1–3 hrs. Pectin production and purity are affected by a variety of variables, involving heating rate, solid-liquid ratio, pH, grain size, and extraction duration (see

Table 2).

It has been noted that pectin extracting has made use of both acetic and citric acids. The hydrolysis ability of acids is lower than that of mineral acids. For extraction of pectin, hydrochloric and nitric acids were widely employed.[53] Pectin extraction using apple peel has been studied using mineral acid, hydrochloric acid, and food-grade organic acids, tartaric, malic, and citric acids. The pectin quantity achieved after treatment using tartaric, malic, and citric acids was equivalent to all of that achieved after treatment using 0.1 M hydrochloric acid (pectin yield based on the dry mass of powdered material: 6.4 percent). Pectin extraction may be made more eco-sustainable by using organic acids rather than mineral acids. Pectin extracted utilizing 0.1 M citric acid had such a particle size of 5.3 10–5 g/mol, whereas pectin extracted by 0.1 M hydrochloric acid had such a particle size of 4.8 10–5 g/mol. Utilizing 0.1 M citric acid, pectin was substantially methoxylated (degree of esterification: 65.2 percent).[54]

Pectin may be solubilized by acidic treatment at high temperatures, increasing pectin production.[53] In addition, heating applied disrupts plant cell walls, allowing pectin extraction from the plant material. A high-temperature treatment and consequent thermal gradient are required for the traditional technique of pectin extraction. As a result of the hydrolysis of pectin into short-chain molecules, ethanol production is reduced. [54] A room-temperature extraction, on either hand, only yields 0.83 percent unbound pectin from tissue cell walls was soluble in water at room temperature. [55]

3.5.3. Ultrasound-assisted extraction

These technical objects radiate at frequencies above the range of human hearing of 16 Hz to 20 kHz and are called ultrasonic waves. Ultrasound-assisted extraction uses ultrasonic waves, which range from around 20 to 100 kHz. When microbubble size and mass transfer resistance are affected by ultrasound frequency, the extraction procedure should be considered. Cavitation in liquid is reduced with an increase in ultrasonic frequency, as well. As per tests, extraction times can be shortened and yields can be increased with ultrasound-assisted extraction. Acoustic waves create microbubbles that collapse into micro jets, disturbing cell structures and enhancing solvent absorption and mass transfer kinetics as a result.

Membrane swells and hydration are stimulated when liquids enter cells, increasing a cell pore, which enhances diffusion and speeds up the mass transfer.[56].

Ultrasound-assisted extraction has been shown to provide more pectin at a low temp and less extraction time than traditional hot extraction. [57] Mango peel pectin was extracted by standard hot extraction technique as well as ultrasound. The pectin yield was 8.1 percent after 10 minutes of ultrasonic treatment at 85°C. Utilizing the traditional technique for 30 min at 85°C, the conversion rate was 5.4%. Ultrasound-assisted extraction decreased extraction time while increasing pectin output, based on these findings (see **Table 3**).

In addition, ultrasonic power intensity is a significant extraction component. Pectin output was improved by increasing the strength of ultrasonic, which disrupted plant cells and enhanced pectin extraction. This is due to the cavitation bubble collapsing as the intensity increases.[58]

Greater power intensity, on the other hand, may result in a drop in pectin extraction; it also was noted. "Saturation effect" which is created by the significant number of water vapor encircling the probe tip may decrease energy transmission to the reaction medium. Bubble deformation and it is non-spherical collapsing may decrease the energy productivity of bubble collapsing.[59]

Food-grade acids like citric and acetic acid are combined with ultrasound-assisted extraction to produce environmentally friendly biopolymers

Table 2: physicochemical properties of extracted pectin using conventional hot extraction method

Fruit	Pectin yield (%)	Treatment conditions				Galacturonic acid (%)	Esterification degree (%)	Ref.
		Temp. (°C)	Time (min)	Acid	pH			
Cubiu peels	14.2 [c]	Boiling	120	Nitric acid	1.5	72	62	[60]
	9.6 [a]	Boiling	120	NS	NS	79	56.9	[61]
Main harvested kiwi fruit	3.27 [a]	50	60	Citric acid	2.8	56.08	82	[62]
	3.27 [a]	50	60	Water	NA	51.87	84	[62]
Early harvested kiwi fruit	1.43 [a]	50	60	Citric acid	2.8	48.80	88	[62]
	1.01 [a]	50	60	Water	NA	42.88	90	[62]
Pomegranate peels	8.5 [a]	86	80	Nitric acid	1.7	62	75	[63]
	11.3 [c]	88	120	Citric acid	2.5	80.95 (g/100g)	53.09	[64]
Mango peel	5.4 [a]	85	30	Nitric acid	2	80.71	67	[57]
Polelo peels	3.11 [b]	90	90	Hydrochloric acid	2	NS	NS	[65]
Ponkan Peels	25.6 [a]	Boiling	100	Nitric acid	1.6	84.5	85.7	[66]
Durian rinds	9.1 [a]	86	43	Hydrochloric acid	2.8			[67]
Citron peels	21.9 [a]	90	180	Water	NA	NS	77	[68]
Cornellan Cherry (whole)	0.83 [a]	Room temp.	60	NS	3	95.1	84	[69]
Honey pomelo peels	17.5 [a]	85	80	Hydrochloric acid	1.24	749 (g/kg)	76.6	[70]
Fresh watermelon rinds	19.3 [a]	Boiling	60	Nitric acid	NS	74.2	63	[71]
Pomegranate peels	11.3 [c]	88	120	Citric acid	2.5	80.95 (g/100g)	53.09	[64]
Wolf apple unripe fruit pulp	33.7 [a]	80	30	Nitric acid	1	NS	77.15	[72]

[a] $\frac{dry\ weight\ of\ extracted\ pectin\ (g)}{dry\ weight\ of\ sample\ (g)} \times 100$; [b] $\frac{dry\ weight\ of\ extracted\ pectin\ (g)}{dry\ weight\ of\ oil\ free\ sample\ (g)} \times 100$; [c] $\frac{dry\ weight\ of\ extracted\ pectin\ (g)}{dry\ weight\ of\ alchol\ insoluble\ residue\ (g)} \times 100$, NS: not specified, NA: not applicable

Table 3: physicochemical properties of extracted pectin using ultrasound-assisted extraction method

Fruit	Sonication	Pectin yield (%)	Treatment conditions				Galacturonic acid (%)	Esterification degree (%)	Ref.
			Temp. (°C)	Time (min)	Acid	pH			
Mango peel	497 W/cm^2	8.1 [a]	85	10	Nitric acid	2	76	61	[57]
Yellow passion fruit peel	644 W/cm^2	12.7 [b]	85	10	Nitric acid	2	66.65	60.36	[73]
Jackfruit peel	NS	14.5 [a]	60	22.5	NS	1.5	NS	NS	[74]
Pomegranate peel	20 kHz	23.9 [a]	62	29	NS	1.3	NS	NS	[75]
Sour or bitter orange	497 W	28.1 [a]	NS	10	Citric acid	1.5	65.3	6.77	[76]

[a] $\frac{dry\ weight\ of\ extracted\ pectin\ (g)}{dry\ weight\ of\ sample\ (g)} \times 100$; NS: not specified

3.5.4. Microwave heating extraction

Additionally, ethanol and ethylenediamine tetraacetic acid were employed as solvents in microwave extraction, and sodium hydroxide has been used to maintain a pH of 2 or below. Compared with water-based extraction microwave heating extraction reduces the extraction period considerably. Extraction duration of 3 hours using water and a 15-minute microwave heating session yields nearly the same quantity of pectin.

During microwave heating, a substance's interior is under a lot of pressure. The extreme heat then changes the physical characteristics of substance tissues, trying to break down the cell wall and enhancing capillary porous tissue structure. This characteristic improves the eventual extraction of pectin by allowing the extracting liquid to penetrate deeper into the tissues. Microwave extraction yielded a greater rate and quantity of extraction than traditional water-based techniques.[51]

3.5.5. Extraction aided by enzymes

The capacity of enzymes to produce interactions with precise specificity and selectivity is essential for enzyme-assisted extraction of pectin. Enzymes employed in pectin separation break plant cell wall elements, enabling pectin liberation and reducing total extraction time.[77]

Enzyme aided separation has numerous advantages, including (a) no equipment damage caused by acids; (2) low operating temperatures, resulting in reduced energy usage, and (3) particular enzymes that generate higher value pectin as a result of their specialization.[78]

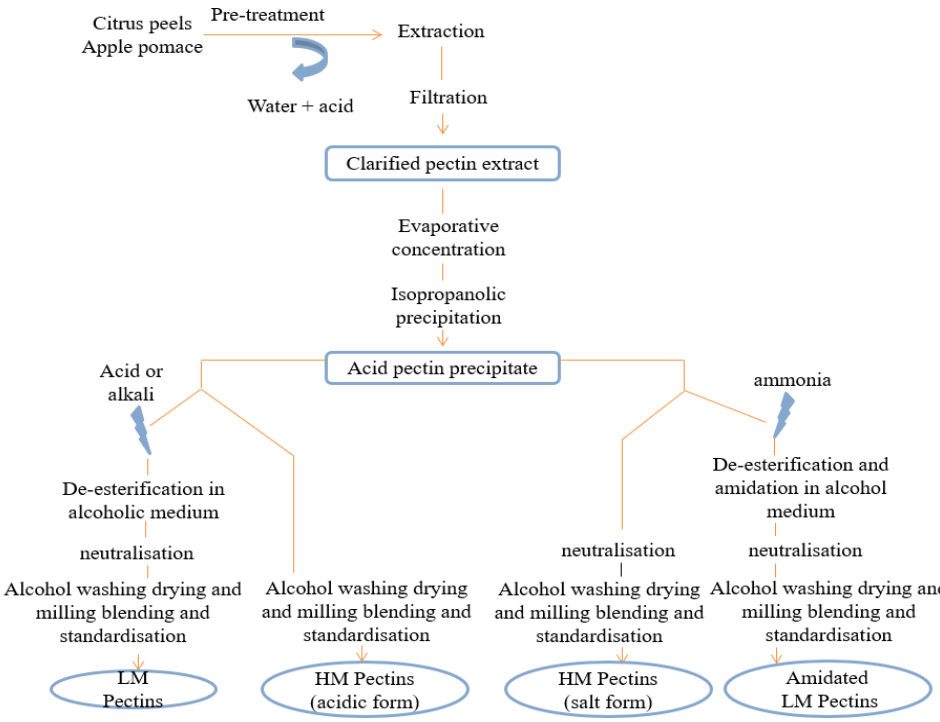

Figure 3: Extraction method of Pectin [79]

For optimal enzyme activity, however, certain temperatures and pH levels must be maintained. Enzyme-assisted extraction suffers from several other drawbacks. Pectin extraction enzymes include proto-pectinases, cellulases, proteases, hemicellulases, and xylanases. Protopectinases solubilize pectin from the insoluble plant protopectin; cellulases hydrolyze β-1,4 linkages in cellulose chains; proteases comprise of a group of enzymes which hydrolyze covalent peptide bonds; hemicellulases depolymerize hemicellulose which is less complex than cellulose; xylanases hydrolyze β-1,4 glycosidic linkages of xylosides.[80]

Table 4: physicochemical properties of extracted pectin using enzyme-assisted extraction method

Fruit	Specific condition	Pectin yield (%)	Treatment conditions				Galacturonic acid (%)	Esterification degree (%)	Ref.
			Temp. (°C)	Time (min)	Acid	pH			
Yellow passion fruit peel	30 U/mL protopectinase	26 [a]	37	45	NS	3	85.4	67.5	[81]
Main harvested kiwi fruit	1.05 mL/kg Celluclast 1.5 L (contains Cellulase)	4.39 [b]	25	30	NS	NS	58.57	85	[62]
Early harvested kiwi fruit		2.14 [a]	25	30	NS	NS	28.96	90	[62]
Lime peel	Laminex C2K(contains and hemicellulose, namely, xylanase, arabinoxylans)	23 [a]	50	240	Citric acid buffer	NS	81.3	82.2	[82]

a $\frac{dry\ weight\ of\ extracted\ pectin\ (g)}{dry\ weight\ of\ sample\ (g)} \times 100$; NS: not specified

3.6. Pectin's general characteristics

Pure water dissolves pectin. Monovalent cation (alkali metal) salts of pectin and pectic acids are generally soluble in water; divalent and trivalent cation salts are insoluble or poorly soluble. Even before dry powdered pectin is mixed with water, it hydrates quickly and forms clumps. These clumps are made up of semi-dry packets of pectin enclosed in a very moist outer coating envelope.[83] The solubility of such aggregates is quite sluggish. Clump-forming can be avoided by dry combining pectin powder with a water-soluble carrier system or by using pectin with increased dispensability due to specific processing treatment.[84]

The pseudo-plastic formation was observed at modest concentrations of pectin. The viscosity of a pectin solution, like its solubility, is affected by its molecular mass, degree of esterification, formulation concentration, pH, and the existence of counters ions in the solution. It is commonly accepted that viscosity, solubility, and gel formation are closely linked concepts. Decreased solubility and increased viscosity are the results of variables that improve gel strength.[85]

Pectins' characteristics are determined by their structure. Since pectins are strongly ionized in solution, the distribution of counter ion tends to retain the monomer in extended shape due to Coulomb's repulsion. Additionally, the coulombic friction between the carboxylate anions hinders polymer chain formation. The DE determines the number of negatively charged. Furthermore, each polysaccharide chain, particularly each carboxylate group, will be extremely hydrated. As every polymer chain is hydrated, stretched, and independently, solutions of monovalent salts of pectins have stable viscosity. As the pH decreases, ionization of the carboxylate groups is inhibited, resulting in less hydration of the carboxylic acid groups. The polysaccharide molecules no longer resist each other along their full length as a consequence of reduced ionization. They now produce a gel.

Pectins with greater severity of methylation, on the other hand, gel at marginally higher pH since they have lesser carboxylate anions at a certainly given pH. Dissolved pectins degrade naturally by de-esterification and depolymerization; the amount of decomposition is affected by pH, water activity, and heat. In general, pH 4 provides the best stability. The appearance of sugar in the pectin solution provides a protective impact, but high temps accelerate the rate of degradation. Degradation of glycosidic bonds owing to hydrolysis is found at low pH levels and high temps. Low pH also promotes de-esterification. De esterification causes an HM-pectin to set more slowly or to progressively adapt LM-pectin properties. HM-pectin is stable at an ambient temp just at near-neutral pH (5-6). Even as heat (or pH) rises, a process known as elimination begins, resulting in chain cleavage and a fast decrease of fluidity and gelling characteristics.[84, 86]

3.7. Rheological properties

Pectin is utilized in a variety of uses as a stabilizer, thickening, emulsifier, gelling, and glazing ingredient. Pectin is a rheology modulator because it affects a material's rheology and is crucial to obtaining acceptable flow properties. According to Rheology, which examines the connections among time, strain, and stress, material distortion, and flow are studied using this method. Sucrose content, pH, temperature, and divalent ion concentration all affect the rheological characteristics of pectin gels. Viscoelastic behavior, flow properties, and viscosity character evaluation give insight into pectin gel rheological. As a result of polymer chain disentanglements, nearly all polymer solutions exhibit shear-thinning behavior, according to this theory. Pectin solutions' rheological characteristics are affected by co-solvents, like sugar, and some other variables, like temperature and pH.

That's also since the intermolecular range among pectin molecules decreases also as the number of pectin rises, increasing intermolecular interactions like hydrogen bonding and molecular entanglements. Viscosity was favorably associated with increased pectin content in many investigations. [87, 88] it is content of pectin, though, is not the sole element that affects viscosity. This even relies on inherent biopolymer features, like galacturonic acid concentration, esterification amount, and molecular mass. As a result of its greater galacturonic acid concentration, mango peel pectin produced employing traditional extraction and ultrasonic at 80°C had a higher viscosity than mango peel pectin generated at 20°C. A high thermal separation of mango peel pectin resulted in a larger molecular mass (2858 kDa and 2320 kDa, correspondingly) than a lower temperature separation (664.5 kDa and 378.4

kDa, respectively). [89]

The existence and amount of divalent ions have also been shown to have a substantial impact on the rheological characteristics of HMP. [90] The scientists showed that gel formation in HM pomelo pectin was caused by divalent ion-driven processes. Furthermore, increasing the size of the ions, i.e. $Ba2^+$ > $Ca2^+$ > $Mg2^+$, led in a rise in pectin gel viscosity.

Heat treatment of a pectin material will undoubtedly change the polymer structure and intermolecular interactions like hydrogen bonds, counter-ions, hydrophobic association, and Van der Waals interactions.[91]

3.8. Application of pectin

- Antioxidant activity suggests that pectin obtained from Indonesian mangosteen peel might be used in biological applications.[92]
- Soybean oil oxidation was slowed by lime peel pectin films incorporating coconut water as a plasticizer and lime peel extract as an antioxidant.[93]
- Hydrogel beads containing grapefruit peel pectin, Biochar, and alginate enhanced copper (II) removal from water.[94]
- Pectin derived from tomato peel is an effective tin corrosion inhibitor that may be utilized in the canning business and food processing processes.[95]
- The solution of pineapple peel pectin extract generated pectin films with enhanced film characteristics, particularly evaporation barrier and antioxidant capabilities.[93]
- Pectin-based films containing sodium alginate and cross-linked with zinc ions shown antibacterial action against Staphylococcus aureus, Escherichia coli, and Candida albicans, suggesting potential application as new bio-active biomaterials for medical device safety and disinfection.[96, 97]
- The water vapor permeability of a biodegradable starch-pectin-titanium oxide nanoparticles (TiO_2-NPs) blends edible film was reduced, supporting its application as food-grade edible films. [98]
- Citrus pectin films activated by marjoram essential oil loaded nano-emulsions and Pickering emulsions shown strong mechanical, water barrier, and antioxidant activities, indicating their potential application as active food packaging.[99]
- Pectin films triggered by marjoram essential oil-laden nanoemulsions and Pickering emulsions exhibited high mechanical, water barrier, and antioxidant properties indicating their possible use as proactive packaged foods.[100]
- Pectin from gabiroba pulp had no cytotoxic effects in regular fibroblast cells (NIH_3T_3) but was cytotoxic in human glioblastoma cells (U251-MG and T98G cell lines) and was associated with an increase in cellular ROS levels, implying that pectin could cause cytotoxicity by changing the cellular redox status.[101]
- The strong affinity, hydrophobicity, and physisorption of dragon citrus fruit pectin for cholesterol emphasize its potential utility as a cholesterol-lowering treatment. [102]
- The use of pectin derived from durian rind improved the absorption of lanthanum, a rare-earth element, from wastewater systems. [103]
- The addition of grapefruit peel pectin to the apple jam recipe improved the texture significantly.[48]
- Using pectin as a thickening and finishing agent.

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