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Pectin: methods of extraction and biomedical application

Sara ZA. Mahdy[a], Alaa S. Amin [a], Ragab Abouzeid[b], Islam M. I. Moustafa[a], Ahmed M. Youssef [c], El Sayed El Habbasha[d]

[a] *Chemistry Department, Faculty of Science, Benha University, Cairo, Egypt.*
[b] *Cellulose and Paper Department, National Research Centre, Cairo, Egypt, P.O. 12622*
[c] *Packaging Materials Department, National Research Centre, 33 El Bohouth St. (former El Tahrir St.), Dokki, Giza, P.O. 12622, Egypt.*
[d] *Field crops Research Department., National Research Centre, Cairo, Egypt, P.O. 12622*

Abstract

Pectin is a naturally occurring biopolymer found in various plant tissues, such as fruits, vegetables, and some seaweeds. It is a complex polysaccharide composed of a chain of galacturonic acid units that can form a gel when combined with sugar and acid under certain conditions. This unique property of pectin makes it useful in many different applications in the pharmaceutical and biotechnology industries. Pectin is a versatile biopolymer with a wide range of applications in various industries, especially in pharmaceuticals, food and biotechnology. This study will discuss the origins and extraction of pectin from the orange peel as well as its chemical structure and general characteristics. Furthermore, pectin-based hybrid materials, composite materials and emulsions are synthesized, characterized and evaluated.

***Keywords*:** pectin, source and structure of pectin, extraction of pectin, applications of pectin.

1. Introduction

Pectin is a naturally occurring polysaccharide found in the cell walls of most higher plants. It has been used for centuries in food as a thickening and gelling agent, and in the cosmetic and pharmaceutical industries for its stabilizing properties. Orange peel is often considered waste by orange juice producers and is either discarded or used as animal feed or fertilizer. However, the peel contains high amounts of pectin, which can be extracted and sold for use in various industries. Pectin extraction from orange peel is a relatively simple process that involves boiling the peel in water and then filtering and drying the resulting solution [1]. The extracted pectin can then be used as a gelling agent in food, as a binder in pharmaceuticals, or as a natural thickener in cosmetics. By extracting pectin from orange peel, farmers and producers can create additional value from what was once considered waste. This not only reduces waste and environmental impact, but also provides a new revenue stream for farmers and producers.

The use of orange peel for pectin extraction is a great example of sustainable and innovative practices that can benefit both the environment and the economy. Pectin's ability to form gels and stabilize emulsions make it useful in a wide range of applications. In the food industry, it is used to thicken and stabilize jams, jellies and other fruit products, as well as in the production of dairy products like yogurt and cream cheese. Pectin is also used in the production of baked goods, where it helps to improve texture and extend shelf life. In the cosmetic industry, pectin is used as a natural thickener and stabilizer in creams, lotions, and shampoos. It is also used to create gel-based products like face masks and hair gels. In the pharmaceutical industry, pectin is used as a binder and disintegrant in tablets and capsules. It can also be used as a controlled-release agent for drugs, as well as in wound dressings and other medical products. The pectin's natural origin, versatility, and safety make it a valuable ingredient in a wide range of applications.

A variety of orange peel is left unused when an orange juice producer is crushed it while squishing its oranges. This peel is taken into consideration through some farmers to be waste and to feed the cattle or possibly as fertilizer. This orange peel serves as the foundation of our system, via the usage of a variety of devices; pectin may be extracted from the orange peel, which can be sold later. The orange peel serves a higher purpose in this way. The roots, branches,

*Corresponding author e-mail: sarazain5566@gmail.com.; (Sara ZA. Mahdy).
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leaves, and cell walls of higher plants' oranges are heavily populated with pectin. It is a polysaccharide polymer complex and the main constituent of dietary fibre, with strong gelling properties and emulsion stability. Pectin is often used in dairy, pharmaceutical, chemical, and other particular applications. As an orange waste, orange peel contains a lot of pectin and can be utilised as a raw material for pectin production [2].

In the presence of saccharine and small amounts of organic acids [typically citric acid], pectin is gelatinized and this property is utilised by the agrochemistry and pharmaceutical industries for pectin isolation. Pectin is made up of all the esterified polygalacturonic acids at a unique degree of neutralisation. Pectin is also utilised in a number of orange-focused products as a gelling ingredient, including jams, marmalades, jellies, orange yoghurt, and yoghurt preparations, Orange filling and desserts for baking items [3]. Pectin is a species known as complex polysaccharide mixtures that make up polysaccharides, approximately one third of the dry material of the cell-wall. Many plant form. In plants, the work of pectin is to contribute structural strength to the cell wall and to cell-to-cell adhesion [4]. A plant's pectin can be water-soluble, soluble in chelator or protopectin. For of unique plant type, the methods of extraction will differ depending on the actual composition. Pectin is increasingly utilised as thickeners, stabilisers, and water binders. Used in yoghurts, pastry glazes and as a stabiliser for milk and orange juice blends and drinkable yogurts [5].

Pectin additionally serves as a deformed fat substitute for imitate the taste of lipids in low-calorie foods and short-chain galacturonic acid is considered clarifying agent in orange juice. Pectin is too already investigated its practicality in the pharmaceutical industry. In certain cases, Pectin has also been recommended as a carrier for drugs that they are intramuscularly injected. The role of pectin is to delay the drug's absorption to allow for a more prolonged effect, for example in preparations of insulin-pectin and preparations of pectin-penicillin. Pectin and its derivatives also tend to have certain therapeutic properties that are inherent, particularly in certain cases of digestive tract malfunction. Pectin preparations were used as a supportive measure in Infant diarrhoea cases and other food tract disorders [6]. In the food and beverage business, pectin has been effectively utilised for many years as a thickening agent, a colloidal stabilizer, and a gelling agent. Pectin has been extensively researched and published, however because the polymer is heterogeneous, it is challenging to define as a model system [7].

Pectin extraction has shown to be a difficult process that hasn't yet been resolved utilising a variety of procedures. In recent studies, pectin has been extracted utilising acids, enzymes, and microwave assistance in an effort to capture the state of the art in this field of study [8]. As a waste product from the juicing industry, which processes hundreds of tonnes of citrus [orange, lime, and lemon] yearly, the current commercial pectin extraction procedures are depend on fruit peel. Washing and drying the peel before pectin extraction ensures the preservation needed for storage and/or transport. Then, by use of acid hydrolysis at a high temperature, commercial pectin is extracted. The final product's GalA and neutral sugar content, molecular weight, degree and pattern of methylesterification, and intrinsic viscosity all have a wide variety of uses [9].

1.1. Source of pectin

Pectin can be found in many fruits and vegetables, with the highest concentrations found in citrus fruits, apples, and berries. Apple pomace, citrus and orange peels are currently the most common sources of commercially viable pectin. They create somewhat different pectin, making one or the other better suited to specific applications. Sugar beet and sunflower seed head residues have also been investigated as pectin sources. The study also includes information on the pectin levels of other fruits. In order to conduct a viable pectin production business, a significant quantity of high-quality raw material is required. Pectin is a common component of most plant tissues, acting as a thickening on the cell wall and a cement in the middle lamella, however there are very few sources that may be exploited to make pectins for commerce. Since the ability of pectins to produce gel depends on DM and the molecular size, pectin from various sources does not gel as well as it should as a result of variances in these factors [10].

As the polymer size lowers and the methoxy concentration rises, pectin solubility in water increases. Pectin powder quickly hydrates and forms clumps in water. The solubility of these aggregates proceeds slowly. When pectin molecules come into contact with water, deesterification and depolymerization of the pectin molecules proceed on their own. The pH and temperature of the solution have an impact on the rate of pectin decomposition. The pH of the solution reduced with increased temperature, which controlled the hydration and repulsion of polysaccharide molecules and caused molecular contact in the form of gels. Ionization of carboxylate groups reduced as a result [11]. Additionally, pectin has been extracted from waste biomass using novel techniques, aiding in the management of waste in agriculture and the food processing sector. Several sources of pectin include juice leftovers, banana, mango, orange, lime, and seeds and pomegranate peels [12].

Table 1: shows different sources of pectin [11].

S.No	Source	parted used	Extraction method	Pectin yield[%]	Type of pectin [HMP/LMP]	Ref,
1	Passion fruit	Peel	App	14.8%	HMP	[13]
2	Banana	Peel	App	5–21%	HMP [DE, 50 – 80%]	[14]
3	chick pea	Husk	Acid extraction, APP, and freeze dried	8%	LMP [DE 10%]	[15]
4	krueo Ma Noy	Leaves	App, DPP	21 – 28%	LMP [DE 34 – 42%]	[16]
5	Yellow passion	Fruit rind	App, DPP, Mpp	3–16%	HMP [DE 54 – 59%]	[17]
6	Durian	Rind	App	2 – 10.25%	HMP [DE 50 – 64%]	[18]
7	Mulberry	Mulberry bark With Epidermis[MBE] and without Epidermis [MB]	Extracted using [60 – 100 %] Isopropanol	11.88%	HMP [MP , DE 71.13%]; LMP [MPE – DE, 24.27%]	[19]
8	Yuzu citrus family	Pomace	Extracted with APP and Enzyme [Viscozyme L with 1.2×10^{-2} fungal β-Glucanase	DPP, APP 7.3 – 8%	LMP [APP – DE , 41%;DPP – DE,46.3%]	[20]
9	Caco pods	Husk	Extracted with 1N HNO_3 at different pH and precipitated by ethanol and acetone	7.3 – 8.6%	LMP [DE 36.7% pH 1 , DE 44.3% pH 3]; HMP [DE 52.4% pH 2]	[21]
10	Cashew apple	Pomace	AOP at different pH [1.0, 1.5 and 2.0]	10.7 – 25.3%	LMP [DE, 28 – 46 %]	[22]
11	Cydea barbata Miers [CBM]	Leaves	Extracted with acid and alkali , precipitated the pectin by ethanol	4–8%	HMP [acid treated: 65 – 75%] LMP [Alkali treated: 36% DE	[23]
12	Dragon fruit	Peel	Extracted using HCl, precipitated and purified with 70 and 99.6% isopropanol.	18.59%	LMP [DE, 46.95%]	[24]
13	Jackfruit	Peel	Ultrasonic- microwave-assisted extracted [UMAE] pectin	21.5%	HMP [DE, 62.5%]	[25]
14	Potato	Pulp	Extracted with different acids and precipitated by ethanol	4.08 – 14.34%	LMP [DE, 21.51 – 37.45%]	[26]

[APP (Alcohol-precipitated pectin), DPP (Dialyzed precipitated pectin.), MPP (Metal ion-precipitated pectin), HMP (High methoxyl pectins), LMP (Low methoxyl pectins)]

1.2. Chemistry of pectin

Chemically, pectin is a heteropolysaccharide composed of linear chains of galacturonic acid, a sugar acid derived from glucose, linked together by α-1, 4-glycosidic bonds. The chains may be modified by the addition of other sugars such as rhamnose and arabinose, as well as acetyl or methyl groups, which affect the properties of the resulting pectin. The structure of pectin makes it a versatile molecule with a range of functions in food processing. When heated in the presence of sugar and acid, pectin forms a gel that is commonly used in jams, jellies, and fruit preserves. It can also be used as a thickener in products such as sauces, dressings, and yogurts, and as a stabilizer in beverages and dairy products. The properties of pectin depend on factors such as its degree of esterification, which affects its ability to

gel, and its molecular weight, which affects its viscosity. Understanding the chemistry of pectin is important for the development of food products with specific textural and sensory properties [27 – 29].

The capacity of pectins to create gel depends on the degree of esterification [DE] and molecular size. Therefore, a fruit's detection of a significant amount of pectin by itself does not make it a source of commercial pectin [30]. Commercial pectins are currently almost exclusively made from apple pomace or citrus peel, both of which are residues from the production of juice [or cider]. Pectin makes up 15–20% of the dry matter in apple pomace. Citrus peel comprises 20–30% [31]. Pectin from various sources will not gel the same manner owing to variations in these qualities as the capacity of pectin to form gel is determined by degree of esterification [DE] and its molecular size. By boiling the raw material with a hot, diluted mineral acid that has a pH of around 2, pectin is commercially extracted. The heated pectin extract is successfully purified of the solid residue. This is difficult since the liquid phase is viscous and the solids are already soft.

As pectin's molecular weight and concentration rise, its viscosity also increases. By filtering the pectin extract via a filter aid, it may be further clarified. Next, a vacuum is used to concentrate the cleared extract. An alcohol [usually isopropanol] can be added to the concentrated liquid from either citrus or apple to create powdered pectin. The pectin is isolated as a stringy gelatinous material that is dried and powdered after becoming pressed and washed to remove the mother liquid. Around 70% of the pectin produced by this technique is esterified [or methoxylation]. Hydrolysis of some of the ester groups is required to create other types. Acidic activity is usually used to do this, either before or during a protracted extraction, in the concentrated liquid, or in the alcoholic slurry before separation and drying. A variety of calcium-reactive low-methoxyl pectins can be produced using this method. Certain ester groups are changed into amide groups when pectin is hydrolyzed with ammonia, resulting in amidated low methoxyl pectin [32].

1.3. Chemical structure

The chemical structure of pectin makes it a versatile molecule with a range of functions in food processing. The properties of pectin depend on factors such as its degree of esterification [DE], molecular weight, and degree of branching, which can be controlled through processing and modification techniques. Pectin is polymolecular and polydisperse, like the majority of other plant polysaccharides, and its composition differs according to the source and the isolation circumstances. Any sample of pectin will include variables that vary from molecule to molecule, like the molecular weight or the content of certain subunits. Despite being discovered more than 200 years ago, the composition and structure of pectin are still not fully understood. Because pectin can alter during plant separation, storage, and processing of plant material, it is exceedingly challenging to determine the structure of pectin [33]. Furthermore, the primary components may be accompanied by impurities. Currently, it is believed that D-galacturonic acid [GalA] units, linked together in chains by á-[1 – 4] glycosidic linkage, constitute the majority of pectin [34].

These uronic acids include a variety of carboxyl groups, some of which are present naturally as methyl esters and others of which are commercially treated with ammonia to produce carboxamide groups. Pectin has a chain-like structure with a molecular weight range of 50,000 to 150,000 daltons and a few hundred to about 1000 saccharide units. Molecules within a sample and between samples might vary greatly from one another, and estimates may change depending on the testing method used [32]. Pectin is a complex heteropolysaccharide that serves several different purposes in the cell walls of numerous terrestrial plants. It is frequently discovered alongside other substances like cellulose, polyphenols, or lignin that are existing in plant cell walls [35].

The primary building blocks of pectin are galacturonic acid units. The carboxyl groups of uronic acid residues can exist in the polymer structure in a variety of ways, such as free molecules or as salts containing sodium, calcium, or other small counterions. According to the pectin's source and/or the extraction technique, they may occasionally also be present as naturally-esterified groups, particularly when combined with methanol. Since free carboxyl groups are present, pectin solutions have acidic pH levels. Depending on the kind of plant, galacturonic acid makes up around 70% of pectin, and it is present in all pectic polysaccharides via links at the O-1 and O-4 sites [36]. Pectin possesses a linear anionic backbone, with "hairy sections" containing non-ionic side chains and "smooth regions" exhibiting no side chains [37, 12].

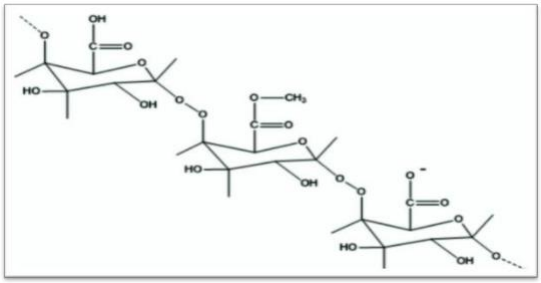

Figure 1: Repeating segment of the protein molecules.

1.4. Type of pectins

There are several types of pectin that differ in their chemical structure, properties, and applications. The main types of pectin are: High methoxy pectin [HM pectin]: This type of pectin has a high degree of esterification [DE > 50%] and is commonly used in products that require firm gels, such as jams, jellies, and fruit preserves. HM pectin requires the presence of sugar and acid to form a gel. Low methoxy pectin [LM pectin]: LM pectin has a low degree of esterification [DE < 50%] and requires the presence of calcium ions to form a gel. It is commonly used in products that require soft gels, such as dairy products, fruit preparations, and beverages. Amidated pectin: Amidated pectin is modified by the addition of amino groups to some of the carboxyl groups in the GalA units. This modification reduces the sensitivity of pectin to pH and calcium ions and makes it more stable under a wide range of conditions.

Amidated pectin is commonly used in acidic dairy products, fruit preparations, and beverages. Modified pectin: Modified pectin is produced by modifying the structure of the pectin molecule through chemical or enzymatic treatments. Examples of modified pectin include low methoxy amidated pectin, highly branched pectin, and enzymatically hydrolyzed pectin. Modified pectin can have specific properties that make it suitable for particular applications, such as thickening or stabilizing. The choice of pectin type depends on the desired texture, stability, and processing conditions of the final product. The type of pectin, along with other ingredients such as sugar, acid, and calcium, can be optimized to achieve the desired texture and sensory properties of the product [38 – 40].

The percentage of carboxyl groups that are esterified and exist in the pectin structure is the degree of esterification [DE], a crucial characteristic for defining the pectin uses. DE is frequently used to categorise the various pectin types [Figure 2]. Different emulsifying, texturizing, and gelling capabilities are shown depending on the DE. Because the long hydrocarbon chains of esters have a hydrophobic nature, the water solubility often decreases as DE increases. On the other hand, as the DE rises, the rate of gelation likewise improves, leading to pectins that rapidly gel [41]. Additionally, pectins' total molecular weight, neutral sugar content, and quantity all have a significant impact on the rheological characteristics of pectins [42]. Because of its ability to thicken and gel, high methoxyl pectin [HMP] is mostly employed in the food industry. According to reports, HMP is highly sensitive to acidity and necessitates a large amount of sugars to gel [43]. Because of the existence of hydrophobic interactions and hydrogen bonding among the pectin chains, HMP gels at low pH levels and high concentrations of soluble solids.

As a neutral sugar, sucrose can regulate hydrophobic interactions or directly interact with polymer chains in HMP to facilitate gelation. Three-dimensional crystalline networks are formed when HG fragments cross-link to form gels [44]. The process of HMP gel formation is intricate, and throughout the past few decades, it has been the focus of numerous studies. The production of HMP gels has been explained using the glass transition theory. Due to the high viscosity of the molecules, the system kinetics are slowed, which causes the co-solute concentration to rise and water content to decrease, resulting in the formation of gel. The combined effects of HMP and sucrose cause the behavior to change from sol to gel at pH 3, and three-dimensional networks may develop when excluded volume effects and attractive contacts are excluded [45].

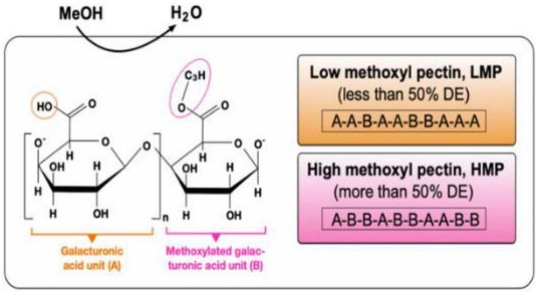

Figure 2: Low and high methoxyl pectin structures [12]

LMP gel strength was studied by Han et al using calcium, soluble solids, pH, and pectin concentrations [46]. Using the rheological characteristics of pectin gels, they hypothesized various processes. As calcium concentrations and pH levels around the isoelectric point [pH = 3.50] increased, calcium bridges were formed at dissociated carboxyl groups, which increased the gel's storage modulus and strength. Additionally, hydroxyl groups in neutral sugars like sucrose stabilize the gel and contribute to hydrogen bonding that immobilizes free water [47, 12].

1.5. General properties of pectin

Pectin is a complex polysaccharide with a range of properties that make it useful in a variety of applications. Here are some general properties of pectin: Gelling ability: Pectin can form gels in the presence of sugar and acid [in the case of high methoxy pectin] or calcium ions [in the case of low methoxy pectin]. The degree of esterification of pectin affects its ability to form a gel. Thickening ability: Pectin can thicken liquids due to its high molecular weight and its ability to bind water molecules. Stabilizing ability: Pectin can stabilize emulsions and suspensions due to its ability to bind to proteins and other molecules. Solubility: Pectin is soluble in water and forms viscous solutions at low concentrations. pH sensitivity: Pectin is sensitive to pH, with a lower pH promoting gel formation in high

methoxy pectin and a higher pH promoting solubility. Temperature sensitivity: Pectin gels can be affected by temperature, with higher temperatures leading to weaker gels and lower temperatures leading to stronger gels. Compatibility with other ingredients: Pectin is compatible with a wide range of other ingredients, including sugars, acids, calcium, proteins, and hydrocolloids. The properties of pectin can be modified through processing and modification techniques, such as varying the degree of esterification, degree of branching, and molecular weight. Understanding the properties of pectin is important for the development of food products with specific textural and sensory properties [48].

Pectins are commonly dissolved in pure water. Typically, pectinic and pectic acid salts with monovalent cations readily dissolve in water, while those with divalent and trivalent cations are either insoluble or only slightly soluble. When dry pectin powder is introduced to water, it tends to quickly absorb moisture and form clumps. These clumps consist of partially hydrated pectin particles surrounded by a highly hydrated outer layer. To prevent the formation of these clusters, one can either mix dry pectin powder with a water-soluble carrier substance or use specially treated pectin that has improved dispersibility [49 – 50]. Although pectin solutions at intermediate concentrations exhibit non-Newtonian, pseudoplastic behavior, pectin solutions at dilute concentrations are Newtonian.

Similar to solubility, the viscosity of a pectin solution is influenced by factors such as its molecular weight, pH, degree of esterification (DE), concentration, and the presence of counterions. Gelation, solubility, and viscosity are often interrelated. For instance, factors that enhance gel strength tend to increase gel formation propensity, reduce solubility, and elevate viscosity, and vice versa. Pectins possess several characteristics owing to their linear polyanion-like structural composition (polycarboxylate). Because of coulombic repulsion and the distribution of ionic charges across the molecule, monovalent cation salts of pectin become highly ionized when in a solution [51].

The polymer chains are prevented from aggregating by the same coulombic repulsion between the carboxylate anions. [The DE of course, decides how many negative charges there will be] Each polysaccharide chain will also be highly hydrated, particularly each carboxylate group. Each polymer chain in solutions of monovalent salts of pectins is hydrated, extended, and independent, resulting in solutions with stable viscosity [32].

1.6. Gel formation properties of pectin

Pectin's capacity to create gels is the basis for its most significant use. HM-pectin gels with acid and sugar. There are several distinct restrictions imposed by the pectin's unique structure. While other ions like aluminium or copper can precipitate under specific circumstances, HM-pectin, unlike LM-pectin, does not have sufficient acid groups to gel or precipitate with calcium ions. According to Oakenfull, hydrogen bonds and hydrophobic interactions are significant forces in the synthesis of molecules of pectin [52]. The free carboxyl groups on pectin molecules and the hydroxyl groups on nearby molecules produce hydrogen bonds, which are what causes gel to form. The majority of the unesterified carboxyl groups are present in the pectin molecules as partly ionised salts in a neutral or very slightly acidic dispersion. The carboxyl ions are transformed into unionised carboxylic acid groups when acid is added. This reduction in negative charges reduces the repelling forces between pectin molecules, and also the attraction amongst pectin and water molecules.

Sugar competes with water, causing the pectin to become even less hydrated. These circumstances make it harder for pectin to keep in a dispersrd state. A continuous network of pectin holds the aqueous solution when the unstable dispersion of less hydrated pectin cools, and it creates a gel. The degree of esteriication has an impact on the rate of gel formation as well. A greater DE results in a quicker setting. In comparison to slow-set pectins [i.e. pectin with a DE of 58 – 65%] , rapid-set pectins [i.e. pectin with a DE of above 72%] gel at lower soluble solids and higher levels [53].

2. Extraction of pectin

Pectin can be extracted from various plant sources. There are different methods for the extraction of pectin from plant materials, and the choice of method depends on the type of plant material, the desired properties of the pectin, and the available equipment [Figure 3].

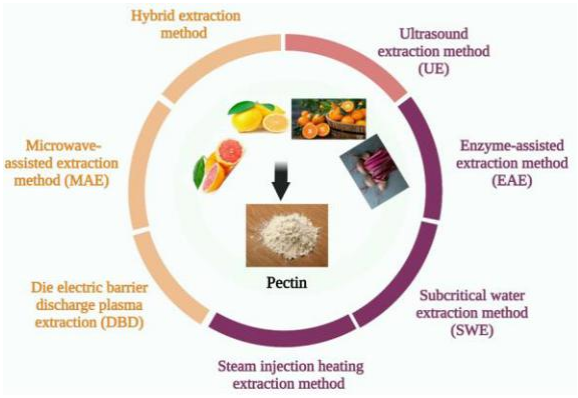

Figure 3: Extraction of pectin with different methods.

2.1. Dielectric barrier discharge plasma extraction [DBD]

Dielectric barrier discharge [DBD] plasma extraction is a method that can be used to extract pectin from various plant sources. In DBD plasma extraction, a gas such as helium or argon is passed

through a narrow gap between two electrodes, creating a plasma discharge. The plasma generates reactive species such as radicals, ions, and photons that can break down the cell walls of the plant material and release the pectin. Increased interest in non-thermal plasma extraction's use in food processing has been observed during the last few decades. In the operation of food processing, the non-thermal plasma known as dielectric barrier discharge [DBD] plasma has been extensively used in microbiological decontamination or enzyme inactivation. By utilizing the various chemically active components present in the plasma, DBD has the capacity to break specific bonds to disrupt the secondary structure or to bring about chemical alterations in side chains [54].

Additionally, DBD may be used to break down biomacromolecules such protein, chitosan and polysaccharides [55]. By introducing a high-energy electron from DBD colloids into water, hydroxyl free radicals attack the pectin chains, leading to the degradation of pectin into smaller molecules. RSM has been employed to optimize the conditions for extracting pectin from pokan peel using DBD [56]. Under specific conditions involving an input voltage of 40 V, pH 2.0, a duration of 5.5 minutes, and a solid-to-liquid ratio of 1:30 (g/mL), it is possible to achieve a maximum pectin yield (27%). However, prolonged exposure to plasma or excessively high energy levels within the system can lead to pectin degradation, which occurs over time. Consequently, extraction durations exceeding 5.5 minutes or voltages higher than 40 V can limit both recovery and pectin yield. Subsequently, the DBD treatment was adjusted to target pectin degradation, primarily affecting the HG region and to some extent degrading the side chains in the RG-I region.

The [GalA + Ara]/Rha ratio was somewhat reduced to 1.4 compared to the original 2.4, also the pectin had lower linearity and a substantially larger RG-I content of 71.3% compared to 36.5%. Moreover, the DE was decreased from 54.7% to 37.3%. The DBD plasma-induced oxidative cleavage targets the breakdown of GalA hitting the HG region while leaving the RG-I domain intact. Additionally, RG-I enriched pectin with low molecule weight preparation benefits from high input voltage because it creates an improved electric field intensity that allows for more high-energy electron colliding into water molecules, which results in the production of a greater amount of hydroxyl free radical. But, further research is still needed to figure out the specific mechanism of this breakdown.

There is not much study on this subject since the use of DBD plasma for pectin extraction has not garnered much interest. The selectivity of HG domains and the retention of RG-I domains after oxidative breakdown by DBD plasma are the most intriguing features. DBD plasma degradation uses less energy and doesn't require any extra chemical agent. As a result, it is seen to be a very promising technique for extracting RG-I enriched pectin from plant sources. But there are several issues that need to be fixed that prevent the practical application of DBD plasma, namely the high cost and short lifetime of the plasma power supply as well as the alteration of physicochemical properties during the remediation technique [57].

2.2. Hand-pressure extraction

During the hand-pressure procedure, an external pressure is applied to the orange peels [a sort of pressure extraction method], which causes the cell walls to break and release pectin. Along with the pectin, orange peel oil is also produced from the peel. Pectin extraction with this method is typically unfavourable but is typically good for peel oil extraction.

1. Chopped flavedo was weighed and then rinsed three times in deionized water.
2. The cleansed flavedo was wrapped in an 80-mesh piece of fabric.
3. The cloth-wrapped flavedo was manually pressed and deionized water leached.
4. The solvent volume was adjusted to a certain volume in order to that pectin calculations and analysis are based on the same data.
5. The residue was gathered for the further examination.

The pressure technique was employed in various ways, either in conjunction with or separately from microwave extraction, as a pre-processing step in a series of steps for producing pectin from citrus peel. To assess the size of chopped flavedo and albedo in ten different samples, a Vernier Caliper with a precision of ± 0.01 mm was used to measure each particle individually. In this study, "particle size" refers to the length of the granular peel particles, which is the longest of their three dimensions. In order to measure the protein content, a crucial nutrient in food manufacturing, the total nitrogen in the extracted products was examined. The determination of total nitrogen content was performed using the Merck Method 140, which involves the total nitrogen round-cell test carried out with the Merck spectroquant analytical system, comprising a Merck SQ 118 Photometer and a Merck Thermoreactor TR 300. Based on the research conducted by Kennedy, it is possible to estimate the quantity of crude protein by multiplying the total nitrogen content by a factor of 6.25 [58].

The IFJU Method 26 was used to determine the pectin content. The method's basic premise is that pectin is a polymer of α-galacturonic acid, that carbazole ethanol may condense [144]. A constant temperature water bath [Model: Thermoline BTC9090] was used to coagulate the pectin with 95 percent ethanol for 10 minutes at 85 degrees. The pectin was reacted with 5% naphthol-ethanol after

being rinsed with ethanol many times until no sugar was left after discarding the supernatant. When the mixture became purple, it meant there was sugar in the mixture.

Pectin from the products was gathered in a 100 ml volumetric flask with 5 ml of 1 M NaOH after coagulation and purification. 0.5 ml of 0.1% carbazole-ethanol indicator was used to flocculate one millilitre of the pectin mixture. The mixture was white in colour. The mixture was combined with 6 ml of 1 M H_2SO_4 and then placed in an 85°C water bath for 5 minutes. Following a 15-minute cooling period, the concentration of pectin was measured using a spectrophotometer (Varian Model: Cary 50 Spectrophotometer) with a 1 cm cell at a wavelength of $\lambda = 525$ nm. In the preparation phase, pure pectin powder (Sigma product code P9135) obtained from citrus fruit was utilized to create a standard absorption curve for pectin, facilitating the determination of pectin concentration in the extracts using the carbazole spectrophotometer method. The average of the three absorbance readings was calculated. To assess the proportion of extraction in this experiment, the weight difference between the dried raw sample and the dried residue was divided by the weight of the dried raw sample. Subsequently, the weight of the dried residue was determined after heating the samples to a constant weight in a drying oven at 100 °C for 48 hours [59].

2.3. Soxhlet extraction

On a mass of orange albedo, a Soxhlet extraction was carried out to contrast with the microwave extraction. The conical flask served as the experiment's solvent and contained 200 ml of deionized water. A heater [Heidolph, MR30001] was used to heat the solvent until it reached the boiling point. A Whatman single thickness cellulose thimble [33 mm external diameter × 80 mm external length] was filled with 16 g of albedo tissue. When the orange colour of the solution in the Soxhlet extraction chamber matched that of the solution in the flask, the extraction was thought to be finished. At the water's boiling point, the extraction was permitted to continue for 6 hours. The extraction residue and the product were chilled after six hours before undergoing further chemical analysis. Later heating samples to a constant weight in a drying oven at 100 °C for 48 hours, the total solids content of albedo and flavedo [on a wet basis] was determined for both techniques of extraction [59]. The following equation was used to determine the solid contents of flavedo or albedo per unit mass of dried orange peel:

$$\text{Solid content of flavedo [albedo][\% of dried peel]} = \frac{W1 \times T1\%}{W2 \times T2 + W3 \times T3}$$

Where W1 is the weight of flavedo [albedo], W2 is the weight of flavedo, W3 is the weight of albedo, T1 is the total solids of flavedo [albedo], T2 is the total solids of flavedo and T3 is the total solids of albedo.

2.4. High pressure extraction method

The pectin compounds from plant substrates are extracted using high pressure in this approach. Three steps make up the high-pressure extraction procedure: an immediate rise in pressure, pressure maintenance, and pressure release. The plant substrates are subjected to a fluid pressure of 100 – 1000 MPa in the initial step while they are at room temperature. The tissues and cells of the plants are harmed by the high pressure, which also accelerates the mass transfer of solvents from the environment into the plants [60]. Simple mechanical equipment is required for this extraction technique, which increases extraction safety and speeds up the process [61]. Using high hydrostatic pressure and high pressure homogenization of 200 Mpa for 5 min, the pectin extraction from potato peel was assessed. Their results indicated that extracted pectin had a low esterification degree and a high concentration of galacturonic acid. They came to the conclusion that utilising high hydrostatic pressure creates de-esterification because the C-O bond is so highly vulnerable [62].

2.5. Subcritical water extraction method

In recent times, researchers have been exploring the eco-friendly process of subcritical water treatment as a method for degrading pectin. Subcritical water exists between the typical boiling point of water (100 °C) and its critical point (374 °C) [63]. According to Klinchongkon et al., subcritical water has proven effective in hydrolyzing pectin in passion fruit, leading to an increase in galacturonic acid content [64]. Our previous investigations revealed that subcritical water generated through high-temperature, high-pressure sterilization, commonly used in food processing, significantly alters the macromolecular structure of citrus pectin and gradually reduces its molecular weight. Consequently, while increasing the galacturonic acid content in citrus pectin hydrolysates, subcritical water can efficiently break down pectin into smaller molecules, thereby enhancing its functional properties and bioactivities [65].

The term "subcritical water" refers to heated water that is kept in its liquid condition at a critical temperature [between the boiling point at 100 °C and the critical point at 374 °C] and critical pressure [around 1 – 22.1 MPa]. Pectic substances are extracted using this water [60]. Water, a solvent that is environmentally friendly, non-toxic, non-flammable, affordable, and easily accessible, is used in this method of extraction. Some heat-sensitive chemicals may be thermally degraded by this

extraction technique since it requires high temperatures. The subcritical water extraction process is less expensive and quicker because it just needs basic equipment [66]. Lately, the subcritical water extraction has been thoroughly examined and published by [Zhang et al] [67]. This technique was used in a study by to extract pectin from citrus peels [65]. Pectin from orange peels was extracted using this process. Galacturonic acid had a greater concentration and a lower molecular weight in the extracted pectin. Additionally, compared to pectin that is traditionally derived from citrus peels, this pectin showed better functional bioactivities. Furthermore, some research on pectin extraction using this technique is revealed in Table 2.

In a study conducted by Chen et al., citrus pectin was provided by Yantai Andre Pectin Co., Ltd. in Yantai, China [62]. To achieve a final pectin concentration of 1.5% (w/v), citrus pectin powder was dissolved in distilled water at 45 °C for 30 minutes and subsequently filtered through filter paper. The pectin solution was then subjected to hydrolysis in subcritical water at 120 °C for 40 minutes, as described in reference [62], using a D-1 high-pressure pump from Beijing Fa'en Technology and Trade Co., Ltd. The resulting degraded pectin solution was collected and subjected to freeze-drying using an SCIENTZ-18N freeze dryer from Ningbo Scientz Biotechnology Co., LTD in Ningbo, China. Prior to use, the dried pectin was stored at -18°C [65].

2.6. Ultrasound extraction method

A frequency range of 20 kHz is used to describe ultrasound waves. The cavitation bubbles produced by these waves serve as the basis for ultrasonic extraction. These bubbles compromise the integrity of the cell wall and promote the penetration of the solvent into the cell. Combining shock waves and ultrasound causes the cell to inflate and become more hydrated, which results in the formation of pores in the cell wall [68]. This process is rapid, efficient, and requires less amount of solvent. Additionally, it uses little energy and operates at low temperatures, making ultrasonic extraction a sustainable method, because of the significant energy savings [60, 69]. The use of ultrasound to extract pectin from grapefruit and tangerines was improved by [70]. The ultrasound extraction method demonstrated more pectin recovery from grapefruit [26.05%] and tangerine [13.46%] in 30 and 15 min, respectively, when compared to the conventional method. They claimed that the extracted pectin has good rheological and functional characteristics.

In a different work [Minjares-Fuentes et al], used ultrasound extraction method to extract pectin with a high average molecular weight [110 to 205 kDa] from grape pomace [71]. To improve the extraction procedure [temperature, extraction time, and pH], they used RSM and BBD as tools. According to their studies, at optimal conditions [75 °C, 60 min, and pH 2.0], the ultrasound extraction method produced an increased yield of extracted pectin [20% more] in comparison to the conventional extraction approach. Additionally, several analyses on pectin extraction utilising this technique are shown in Table 2 [62].

2.7. Microwave assisted extraction [MAE]

An electromagnetic wave called a microwave [MW] consists of two perpendicular oscillating fields, electric and magnetic fields. MWs have electromagnetic spectrum frequencies between 300 MHz and 300 GHz. MWs are frequently employed as energy vectors or information carriers, with the latter application typically making use of frequency bands at 0.915 and 2.450 GHz; The majority of household microwave ovens run at 2.450 GHz [12.2 cm wavelength; 0.94 J/mol energy] [72]. A matrix and/ or solvent that has been exposed to MW radiation rotates its polar molecules at such a frequency, producing heat in the process. But only if the material has dielectric losses, or if any of the energy is absorbed, can heat be produced. Later, the equation for the dissipation factor [δ] is used to calculate the absorbed energy:

$$\tan \delta = \varepsilon'' / \varepsilon'$$

Where ε″ and ε′ are the real [dielectric constant] and complex [dielectric loss factor] part of dielectric permittivity, [ε*= ε′ – jε″], respectively [73]. The capability of an irradiation molecule to get polarised by an electric field is shown by ε′, and the efficiency with which electromagnetic energy is converted into heat is indicated by ε″ [73].

Throughout the medium, there is a homogeneous temperature distribution that is one benefit of this type of heating whereby, as Venkatesh and Raghavan noted, unlike in typical thermal processing, there is no temperature gradient [73]. Dipole rotation, which involves polar molecules' dipoles reversing, and ionic conduction, which involves the displacement of charged ions present in the solvent, are the two methods by which energy is transferred in microwave heating [74 – 75].

2.8. Enzyme-assisted extraction [EAE] Enzyme-assisted extraction [or EAE] is one technique that has been promoted as a potential solution for the unexpected but among other advantages, the inevitability of trace chemical solvents in products from solvent-based extraction techniques [76]. It has become crucial to find alternate solvent-conservative techniques for these processes, like this one, as demand to produce sustainable chemical processes [including extraction] on the food and pharmaceutical sectors grows. In order to clarify juice, enzymes are frequently used. Moreover, Carrageenan, alginate, and agar hydro-colloids were reviewed, highlighting the varied implications that this procedure has on the physico-chemical characteristics of the marine polysaccharides [77]. The ability of enzymes to

catalyse processes like a very selective kind of hydrolysis mostly because of the way they work, that either decreases the quantity of solvent/chemical required or increases yield for the same amount of solvent [78].

To an extent that is impossible with acid-based hydrolysis The cellulose/xyloglucan network is set in a matrix of pectin along with a protein network; the plant cell wall is made up of an entangled network of polysaccharides containing cellulose, hemicellulose [like xyloglucan], and pectindand protein [79] . Cellulases, hemicellulases, and proteases are selective cell wall component-degrading enzymes with low pectinolytic activity that are widely utilised to cause hydrolytic activities in the corresponding non-pectin plant cellwall components. This calls for thorough understanding of the chosen enzyme[s]' catalytic function as well as the ideal EAE conditions under which they should be used [80].

It is possible to distinguish among two methods of extracting pectin by EAE: [i] utilising enzymes which break down pectin and aid in the isolation of pectin fragments, such as galacturonic acid, and [ii] employing enzymes that can break down plant cell walls and isolate pectin [81]. Although the latter strategy is widespread, examples of the former are also found at the work by [Zhao et al]. He investigated the de-esterification of commercial HM pectin into LM utilising the enzyme pectin methyl esterase [PME] and high hydrostatic pressure [HHP] in combination [82]. Additionally, [Zykwinska et al] showed that the EAE method may produce LM pectin from a source of HM pectin by directly adding PME together with cellulases and proteases [76, 83].

2.9. Steam injection heating

Conditions for extraction P: 188.7 kPa; T: 95 – 100 °C; HCl solution with pH 2.0 as solvent; sample to solvent ration: 1 – 25; sequential extraction three times with 3 min each. Raw material used in this method is Albedo. Result that came from this process as follow, Sequence 1: 6.9% pectin; sequence 2: 7.5% pectin; sequence 3: 2.5% pectin; total: 16.9% pectin; all on dried albedo Base [84, 59].

Table 2: Conditions of pectin produced from ligocellulosic wastes using new techniques [62].

Substrate	Main process condition	Yield in recovery%	Extraction method	Ref.
Apple pomace	120 s, 560 W, Citric acid, pH 2.2	23.32	Microwave	[85]
orange peel	7 min, 400 W, 0.1 M HCl, pH 1.2	28	Microwave	[86]
black carrots pomace	5 min, 900 W, Acetic acid, pH 2.5, 110 °C	-	Microwave	[87]
Walnut processing wastes	10 min, 200W, Citric acid, pH 1.5	12.78	Ultrasound	[89]
lime peel	3 min, 700 W, 0.05 M HCl	15.91	Microwave	[90]
dragon fruit peel	65 min, 800W, HCl , pH 2.07	18.5	Microwave	[91]
sweet lemon peel	3 min, 700 W, Citric acid, pH 1.5	25.31	Microwave	[92]
oranges peel	3 min, 500 W, 59.83° C, pH 2	24.2	Microwave	[93]
pomelo peel	390 – 650 W, 3 – 7 min, pH 1-3	0.05 – 2.93	Microwave	[94]
sour orange peel	300 – 700 W, 1 – 3 min, pH 1.5-3	5.2 – 26.4	Microwave	[95]
orange peel	160 – 480 W, 1 – 3 min, pH 1 – 2	7.42 – 18.59	Microwave	[96]
watermelon rind	160 – 480W , 1 – 3 min , pH 1 – 2	13.09 – 24.18	Microwave	[97]
banana peel	300 – 900W , 1.5 – 5 min , pH 1 – 3	1.09 – 2.17	Microwave	[98]
passion fruit peel	356 – 450W , 3 – 9 min , pH 2	30	Microwave	[99]
custard apple peel	18.04 min, 20 KHz, 63.22 °C, 1 M HCl, pH 2.3	8.93	Ultrasound	[100]
sour orange peel	10 min, 150 W, Citric acid, pH 1.5	28.07	Ultrasound	[101]
pistachio green hull	24 min , 150 W, pH 1.5	12	Ultrasound	[102]
dragon fruit peel	120 min , Citric acid , pH 2, 132 kHz ,70°C	28.20	Ultrasound	[103]
mango peel	20 min, 20 kHz, 50% Ethanol	-	Ultrasound	[104]
fresh sunflower heads	8 Bar, 120 °C, 20 min	-	Subcritical water	[105]
berg fruits	150 Bar, 120 °C	5.70	Subcritical water	[106]
passion fruit peel	Celluclast 1.5 L, 35 – 85 °C, 0.5 – 2 h	2.59 – 9.17	Enzymatic	[107]
passion fruit peel	protopectinase- SE, 30 U/ml, 37 °C, 6 h , pH 3; solid-to-liquid ratio,15 g/60 ml	-	Enzymatic	[108]
artichoke waste	Celluclast, 7.8U/g, pH 5, 50 °C, 48 h	22.1	Enzymatic	[109]

2.10. Hybrid extraction methods

During the pectin extraction, there has been a rising tendency toward the synergistic application of two or more cutting-edge methods. For instance, improvement of ultrasound-subcritical water [110], Improving microwave-ultrasound [111], ultrasound enzyme improvement [112]. They were applied to extract the pectin. During the extraction process, the ultrasound may boost mass transfer and the microwave can enhance heat transfer. Pectin-rich pulp from sugar beets was extracted by subcritical water and ultrasonic-assisted treatment [110]. In comparison to pectin [Rha content of 0.4% – 0.7%], which extracted using just subcritical water, the extract pectin [with 54.6% HG region and 35.9% RG-I] featured substantially more neutral side chains and Rha [4.5%]. The ideal circumstances for a reaction of L/S ratio 44.03, extraction pressure 10.70 MPa, and extraction duration 30.49 min led to the highest yield [24.63%].

The decreased Mw and greater neutral sugar [30.9% – 68.2%] indicate that the HG region of the pectin backbone might be attacked by ultrasonic pretreatment. To make it possible for the selective recovery of pectin, it is imperative to optimise and standardise the integration of two or more specific innovative extraction processes. Sequential ultrasound-microwave were applied in order to extract pectin from pomelo peel [UMAE]. In comparison to UAE [yield 14.3%, DE 64.4%] , MAE [yield 27.7%, DE 64.1%], and microwave-ultrasound assisted extraction [yield 30.5%, DE 67.0%], assisted extraction technique has the greatest yield [36.3%] and lowest DE value [59.8%]. In addition, pH has a far bigger effect on pectin production than microwave power does on DE [111]. Ultrasound and hemicellulase were used to extract pectin from wasted carrots. The greatest yield was 27.1% as opposed to only using cellulose, which only helped to liberate the pectin from the cellulase matrix [12.4%]. With a gelling capability, the extract pectin has a low DE [24.0 – 49.9%] [113]. While it has been demonstrated that the hybrid extraction increases pectin production, few studies have illustrated how it affects the RG-I region, which calls for more research [57].

2.11. Conventional extraction method

Conventional pectin extraction methods involve the use of various chemicals and are water-based. The most commonly used industrial method for pectin extraction is direct boiling, but it requires many hours to achieve a satisfactory yield [114]. Prolonged heating in this process can lead to thermal degradation of pectin through beta-elimination of the HG backbone and significant debranching, resulting in lower-quality pectins. Therefore, heating is often supplemented with the addition of several chemicals to facilitate the release of pectin from the cell wall and reduce the extraction time. Numerous studies have examined how the composition of the extraction solvent affects the structure of pectin [115].

Confirmation of the structural variations in pumpkin extracts obtained using different solvents has been reported [116]. To isolate pectins, the researchers employed hot water, diluted HCl, ethylenediaminetetraacetic acid (EDTA), as well as diluted and concentrated NaOH solutions. Previous studies have shown that the first three solvents yield pectins with significant levels of polymolecularity and lower RG-I content (ranging from 1.4% to 28.0%) compared to pectins extracted using alkali (ranging from 39.3% to 49.6%) [117]. A high xylose content in alkaline-extracted pectin allows co-extraction of hemicelluloses such as xyloglucan and glucuronoxylan. Using citric acid concentrations ranging from 0.05 to 1.0 M, Kurita, Fujiwara, and Yamazaki extracted citrus peel pectin from water with citric acid [118].

The highest percentage of RG-I, which reached 57.5%, was achieved when using 0.5 M citric acid at neutral pH conditions and a temperature of 65 °C. It was observed that citric acid did not degrade pectin, as indicated by the lower degree of methylation (DM) at 8.4% and wider molecular weight distributions (ranging from 50 to 2000 kDa) in pectin extracted with the acid [118]. Oxalate is another chelating agent capable of solubilizing high-molecular-weight pectin with a high DM [119-121]. The quantity of ionic linkages in plant tissue pectin, which is associated with the concentration of Ca2+ and the distribution of free acid groups in the HG pectin domain, influences the extraction process with chelating agents. There is a positive correlation between pectin yield and lower pH levels, indicating hydrogen bonding between pectin and cellulose-hemicellulose.

Hydrochloric acid extraction yields a higher amount of pectin (15.59%) compared to water extraction (0.95%) or sodium hexametaphosphate extraction (5.17%) [122]. At different pH levels, uronic acid residues and their linkages have different stabilities, leading to distinct structural characteristics of pectin obtained by alkaline or acid extractions. Additionally, Ara, Gal, and Rha sugars are increasingly susceptible to acid hydrolysis, while GalA is the most resistant, resulting in less stable GalA-Rha or Rha-GalA linkages compared to GalA-GalA linkages [119]. Links between uronic acid residues are more resilient than linkages between neutral sugars and uronic acid under high temperatures (> 65 °C) and highly acidic conditions (pH 2.0) [123]. In contrast to strong acid extraction, pectin extracted with an alkaline solvent at low temperatures contains a significantly higher RG-I content while preserving neutral side chains.

After processing the orange peel residue with 0.6% NaOH at 32 °C for 10 min while stirring, the pH level was adjusted to (6 – 7). Pectin treated with

HCl at pH 3 - 4 contained 44% RG-I region, compared to 82.5% in the resultant pectin measured by monosaccharide analysis and AFM [124]. Ara and Gal side chains are less degraded by KOH treatment, and under extreme alkaline conditions, Ara side chains debranch more significantly than Gal side chains, indicating that Ara residues are more sensitive to changed conditions than Gal residues [125]. Pectin that has been extracted using an alkaline method has a lower molecular weight and often has a 2 – 5 times higher RG-I region concentration than pectin that has been extracted using more traditional [126]. The β-elimination reaction, that breaks the glycosidic links amongst the methylated galacturonic acid units, results in a reduction in molecular weight [127].

As a result of various extraction methods and plant materials, RG-I content and neutral side chains vary. Sugar beets, oil pumpkins, citrus peels, and potato pulp are ideal plant materials for recovering RG-I. Acid-extracted pectin has a high HG content [GalA > 65%] and a high DM and DA. Hydrolysis of protopectin occurs in environments with a low pH [128], increases protopectin's solubility and stimulates Ca^{2+} and Mg^{2+} elimination, therefore allowing for larger isolated pectin yields with HG enrichment. Alkaline-extracted pectin often contains low DM [due to saponification reaction], high RG-I content [49.6% – 82.5%, based on temperature and pH], and low yields. RG-I oligomers with branching arabinan and galactose side chains are more abundant in the extracted fractions as a result of alkali-induced GalA instability. Pectin breakdown brought on by alkaline treatment prevents the product from being precipitated with alcohol, which results in lower yields [129]. Pectin that has been extracted using an organic acid or chelating agent has a high molecular weight and a low DM. Organic acids are less capable of hydrolyzing than mineral acids because of their lower dissociation constant. Pectin extracted using organic acids frequently has the RG-I content that falls among pectins extracted using strong acids and by alkaline condition [130].

3. Application of pectin

Pectins have long been a fundamental component of foods for humans. It is legal everywhere in the globe. Pectin was recommended as a safe ingredient, According to the united FAO/WHO committee on food additives, with no upper limit on tolerable daily consumption other than that set by good manufacturing practise. Pectin serves as a gelling agent, texturizer, thickening, emulsifier, and stabiliser in a wide range of foods. Pectin has recently been utilised in low-calorie meals to replace fat or sugar. Pectin's ability to be assimilated into many food systems is made possible by the polar and nonpolar portions of its molecules, which give rise to its multifunctionality. Several parameters, including the degree of methoxylation and molecular size, affect the functioning of the pectin molecule. Functionality is assessed by pectin grades for commercial use since these criteria are too difficult to ascertain in the industrial application of pectins. Under typical settings of pH 3.2 to 3.5, sugar 65 to 70%, and pectin at the ranges of 1.5 to 2.0%, pectin grades are determined by the number of parts of sugar that one part of pectin will gel to an appropriate firmness. The market offers pectins in grades ranging from 100 to 500.

Their major basis for use as a food hydrocolloid is their capability to gel [110]. Pectin selection for a certain food is influenced by a variety of variables, as well as the desired texture, pH, the presence of ions and proteins, processing temperature, and the anticipated shelf life of the product. The need for functional/active packaging materials is growing as a result of the globalisation of the food market and the rising need for processed foods that are shelf-stable and maintain the nutritional value of the food [131].

One of the most important natural renewable polymers, pectin is present everywhere in nature and serves as the primary building block for all biomass. Pectin and its derivatives, which are flexible by nature and act as oil, moisture, and aroma barriers as well as decrease food oxidation and respiration rate, are utilised in a variety of biodegradable packaging materials [132].

3.1. Industrial application of the green extraction techniques

Despite the fact that green extraction methods have demonstrated a number of benefits in small-scale laboratory investigations, upscaled production problems have made it difficult for industry to implement many of these methods for orange peel. First, replacing traditional extraction methods with modern green strategies like ultrasound requires a substantial financial investment. Second, In comparison to conventional processes, several of the newly developed green extraction techniques needed professional operators, which may make the production cost enhanced. Third, the use of some green extraction processes is restricted to academic and research institutions because to the absence of ongoing large-scale production designs. Future economic and engineering research may overcome the aforementioned issues and lead to increased industrial use of green extraction methods globally [133].

3.2. Pectin's effect on human health

Pectin's broad use in health promotion may be influenced by its probiotic transport capacity as well as by its prebiotic and nutraceutical properties. Today's market is flooded with medications designed to treat pancreatic inflammation and pathologies of the stomach, many of which have a variety of unfavourable side effects. Below is a list of other effects of pectin on health:

– Lowering liver fat and blood cholesterol.

– Retards the absorption of glucose and stabilizing blood pressure.

– The intestines are where toxic substances, in particular heavy metals, are absorbed.

– Pancreatic exogenous hormones are impacted.

– It attaches to harmful bacteria and their toxins in the intestine, holding them back from taking action [134].

A component of the microbial population that resides in the human intestine breaks down the non-digestible carbohydrate pectin [135].

3.3. Pectin and structurally modified pectin in pharmaceuticals

Pectin, a naturally occurring polysaccharide, has various pharmaceutical applications due to its unique properties. Some of its applications include: Pectin can be used to formulate drug delivery systems, such as nanoparticles and hydrogels, due to its ability to form gels in the presence of divalent cations like calcium ions. This property makes pectin an excellent candidate for targeted drug delivery to the colon, where calcium ions are abundant. Pectin can be used in wound healing applications due to its ability to form a protective film on the wound surface, reducing the risk of infection and promoting healing. Pectin hydrogels have been shown to accelerate wound healing in animal models. Pectin can bind to bile acids in the gut, reducing the amount of cholesterol that is absorbed by the body. This property makes pectin a potential natural therapy for managing hypercholesterolemia. Overall, pectin and structurally modified pectin have a wide range of potential pharmaceutical applications, and further research is needed to fully explore their potential in these areas [136].

3.4. Pectin in the regulation of blood cholesterol level

Pectin, a soluble dietary fiber found in fruits and vegetables, has been shown to have a cholesterol-lowering effect when consumed as part of a healthy diet. Pectin works by binding to bile acids in the gut, which are made from cholesterol and released into the intestine to aid in digestion. When pectin binds to bile acids, they are excreted in the feces, reducing the amount of cholesterol that is reabsorbed into the bloodstream. The cholesterol-lowering effect of pectin is dependent on several factors, including the type and amount of pectin consumed, as well as the individual's overall diet and lifestyle. It is important to note that while pectin can be beneficial in reducing cholesterol levels, it should not be used as a substitute for medical treatment in people with high cholesterol or other cardiovascular risk factors. Pectin can be a beneficial addition to a healthy diet for its cholesterol-lowering effects, along with its other potential health benefits [136].

3.5. Uses of pectin in food industry

Pectin is widely utilized in the food industry for its ability to thicken, stabilize, and gel food products. It is frequently employed to give jams, jellies, and fruit preserves their characteristic texture. When pectin is combined with sugar and acid, it forms a gel that sets the fruit mixture into a spreadable consistency. Pectin can be used as a stabilizer in dairy products such as yogurt, cream cheese, and sour cream. It helps to prevent syneresis, or the separation of liquids from solids and improves the texture and mouthfeel of these products. It is often used in confectionery products such as gummies, fruit snacks, and marshmallows to provide a soft, chewy texture. Also, it can be used as a thickener and stabilizer in beverages such as fruit juices, smoothies, and fruit nectars. It can help to improve the viscosity and mouthfeel of these products. So, pectin is a versatile ingredient in the food industry that can be used to improve the texture, stability, and overall quality of a wide range of food products [137].

3.6. Pectin gels in wound healing patches

Pectin gels have been investigated as potential wound healing patches due to their ability to form a protective film over the wound surface and promote healing. Pectin is a natural polysaccharide that is commonly found in the cell walls of fruits and vegetables, and has been used in the food and pharmaceutical industries for its gelling and thickening properties. When pectin is mixed with water and heated, it forms a gel that can be applied to the wound surface. The pectin gel can adhere to the wound and form a protective film, reducing the risk of infection and promoting healing. Pectin gels also have the ability to absorb excess wound exudate and maintain a moist wound environment, which has been shown to promote faster healing.

Several studies have investigated the effectiveness of pectin gels as wound healing patches. For example, a study in rats with skin wounds found that a pectin gel patch applied to the wound surface promoted faster healing compared to a control group. Another study in diabetic mice found that a pectin gel patch promoted faster healing of foot ulcers compared to a standard wound dressing. Pectin gels have the potential to be a natural and cost-effective alternative to traditional wound dressings. Further research is needed to fully explore the potential of pectin gels as wound healing patches, including optimizing the formulation and evaluating their effectiveness in clinical trials [138].

3.7. Pectin gel as a fat replacer

Food producers are under pressure to cut back on the quantity of fat in the diet as a result of the reported health issues [139]. As a result, there is a growing market demand for low-fat meals, and producers are always exploring for new components that can substitute fat in meals. A "fat replacer" or

"fat mimic" is a term used to describe a component that may be used in food items to completely or partially replace fat, especially triglycerides. Studies have shown that pectin microgel may substitute fat in food products. Early studies only regarded pectin that was ionically bonded, or calcium-gelled pectin, to be eligible for use as fat substitutes. Subsequently, it was demonstrated that covalently cross-linked pectin may serve as both an emulsifier and a fat alternative [140]. By adding more viscosity to the liquid phase in the mouth, pectin gel can simulate the mouthfeel of lipids, which is essential to its function as a fat substitute [141].

The degree of tangly [twisted or entangled] interaction among oil granules and the 3D structure of pectin gel determine the rise in product viscosity [Figure 4]. The particle size of fat mimics is another element that affects the function of replacing fat. The production of pectin microgels employing an acceptable size reduction technique was required since the particle size of the pectin gel should be comparable to that of the oil granules in order to be a superior fat substitute. The softness and deformability of the microgel particles, which are similar to those of fat particles, allow them to replicate the physical and sensory properties of emulsified fat [142 – 143].

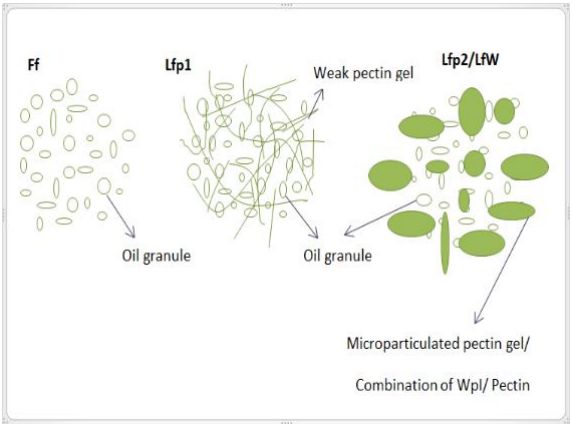

Figure 4: Pectin hydrogel like a fat substitute: a graphic illustration of the theory on how an oil-in-water emulsion and a fat imitation interact [144].

3.8. Pectin hydrogel as a food texturizer

In the food business, granulated starch is a common texture modifier, fat substitute and thickening agent. Granulated starch works well for the aforementioned purposes, but too much of it can cause diabetes. Pectin is effective in changing the texture of food and can take the role of starch granules, according to several researchers. To create hydrogel microspheres, pectin [0% – 0.2% wt/wt] and gelatin [0.5% wt/wt] were combined at a pH higher than the isoelectric point of gelatin [pH 9, 30 °C]. Cationic gelatin and anionic pectin are attracted to one other electrostatically, which achieved by complicated coacervation caused the aforesaid combination to spontaneously form micron-sized particles when the pH was decreased to 5. The main problem was adjusting hydrogel particle size to match starch particle size. The creation and characteristics of hydrogel particles are influenced by the gelatin-to-pectin ratio, which also impacts the biopolymer charge stoichiometry and strength of electrostatic interactions [145 – 146]. The ratios of gelatin and pectin were selected for the preparation of hydrogel particles according to the following requirements: [i] to confirm that the hydrogel microspheres produced were true coacervates among pectin and gelatin and not simply the result of gelation of gelatin molecules [147]; [ii] to achieve a final mixture in a fluid form instead of a gelled form and [iii] to suit structure of the starch granules and its size.

On the contrary hand, the concentration of pectin present had a significant impact on the coacervates' produced distribution of particle sizes and mean particle diameter. Particles in the mixture were discovered to agglomerate at 0.1% [wt/wt] pectin. However, the mixture included discrete, transparent, spherical particles with a comparable morphology and size to swollen starch granules [D3, 2 23 lm] at 0.01% [wt/wt] pectin. To imitate microstructure and the size of starch granules, coacervates were created by combining 0.01% [wt/wt] pectin with 0.5% [wt/wt] gelatin [143].

4. Conclusions

In conclusion , pectin is a natural polysaccharide found in the cell walls of fruits and vegetables that has a wide range of applications in various industries, including food, pharmaceuticals, and cosmetics. The extraction of pectin from plant sources can be achieved through various methods, including hot acid extraction and enzymatic extraction. The choice of extraction method depends on factors such as the source of pectin, the desired quality and quantity of pectin, and the economic viability of the method. In the food industry, pectin is commonly used as a gelling, thickening, and stabilizing agent in a variety of products, including fruit preserves, dairy products, confectionery, and meat products. Structurally modified pectin can also be used as a fat replacer, and pectin oligosaccharides have potential health benefits as prebiotics. Pectin is a versatile and valuable natural ingredient with numerous applications in various industries. Ongoing research into the extraction and modification of pectin will likely lead to even more innovative and useful applications of this important polysaccharide in the future

Table 3: Various pectin-based materials are employed in food packaging applications [12].

Type	Polymer Matrix	Additive	Application	Ref.
Film	LMP-bitter vetch protein	Transglutaminase	Drug delivery system	[148]
Film	LMP	Ascorbic acid	AO system	[149]
Film	HMP	Clove EO	AM system	[150]
Film	HMP	Marjoram EO	AO system	[151]
Film	HMP-Gluconaman	Tea Extract	AO/ AM system	[152]
Film	Pectin – pullulan	AgNPs	AM system	[153]
Film	HM-apple pectin	Chia seed hydrocolloid	AO system	[154]
Film	Chitosan-Starch-Pectin	Mint and rosemary oils	AO/ AM system	[155]
Film	Fish gelatine-HMP	Nisin	Preservation of beef meat	[156]
Film	HMP	Red cabbage extract	pH indicator	[157]
Film	Chitosan-HMP	Anthocyanin	pH indicator	[158]
Nanocomposite	Pectin	AgNPs , laponite	Coating polypropylene to improve barrier /AM Properites	[159]
Nanocomposite	Pectin	Ag/AgCl – ZnONPs	AM system	[160]
Nanofiber	HMP LMP	AgNPs	Reinforcement , AM	[161]
Nanofiber	Polyethylene oxide	-	Reinforcement	[162]
Aerogel	Amidated pectin	TiO_2 , NPs	AM under dark and UV illumination conditions	[163]
Hydrogel	LMP-Chitosan	Garlic and holy basil Eos Camelia oil	Incorporate to cellulose bag to improve AM properites	[164]
Oleogel	HMP	Tp-palmitate	Drug delivery system	[165]
Emulsion	HMP	Clove EO	Bream fillets coating	[166]
Microemulsion	Chitosan-HMP	Cinnamaldhyde	AM system	[167]
Nanoemulsion	Food-grade pectin	Curcumin and garlic Eos	Coating chicken fillets	[168]
Nanoemulsion	HMP	Oregano , thyme ,lemongrass mandarin Eos	AM system	[169]
Nanoemulsion	HMP	Lemongrass EO	Addition in Cassava starch film to improve biodegradation properties	[170]

[EO: essential oil; AM: antimicrobial; AO: antioxidant]

5. Conflicts of interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence this work.

6. Formatting of funding sources

There is no funding to report

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8. References

[1] Quebedeaux B, Bliss F. Horticulture and human health: contributions of oranges and vegetables. Proc. Symp. 1988. Hort. and Human Health Prentice.

[2] kohn R, Binding toxic cations to pectin, its oligomer fragment and plant tissues, carbohydrate polym, 2002, 2, 273-275.

[3] Tobias I. NdubuisiEzejiofor, N. V. Eke, R. I. Okechukwu, R. N. Nwoguikpe and C. M. Duru.

[2017] Waste to wealth: Industrial raw materials potential of peels of Nigerian sweet orange [Citrus sinensis]. African Journal of Biotechnology, Vol. 10 [33].

[4] S. Wang, F. Chen, J. Wu, Z. Wang, X. Liao, X. Hu, Journal of Food Engineering, 2012, 78, 693–700

[5] May, C. 2014. Industrial pectin's: sources, production, and applications. Carbohydrate Polymers.

[6] Wargovich M. Anticancer properties of oranges, Hort Science. 2009. 35: 573-575.

[7] Sundar Raj, A. A., Rubila, S., Jayabalan, R., & Ranganathan, T. V. [2012]. A Review on Pectin: Chemistry due to General Properties of Pectin and its Pharmaceutical Uses. 1: 550 doi: 10.4172/scientificreports. 550 Page 2 of 4 Volume 1• Issue 12• 2012 in a chain-like configuration; this corresponds to average molecular weights from about 50,000 to 150,000 daltons. Large differences may exist between samples and between molecules within a sample and estimates may differ between methods of measurement.

[8] Sandarani, M. D. J. C. [2017]. Pharmacognosy & Natural Products.

[9] M.; Sousa, A.G.; Crépeau, M.-J.; Sorensen, S.O.; Ralet, M.-C. Characterization of citrus pectin samples extracted under different conditions: Influence of acid type and pH of extraction. Ann. Bot. 2014, 114, 1319–1326.

[10] Beli R. Thakur,1 Rakesh K. Singh,1 and Avtar K. Handa2

[11] Vanitha, T., & Khan, M. [2019]. Role of pectin in food processing and food packaging. Pectins-extraction, purification, characterization and applications.

[12] Mellinas, C., Ramos, M., Jiménez, A., & Garrigós, M. C. [2020]. Recent trends in the use of pectin from agro-waste residues as a natural-based biopolymer for food packaging applications. Materials, 13[3], 673.

[13] Kulkarni SG, Vijayanand P. Effect of extraction conditions on the quality characteristics of pectin from passion fruit peel [Passiflora edulis f. flavicarpa L.]. LWT- Food Science and Technology. 2010;43:1026-1031. DOI: 10.1016/j. lwt.2009.11.006

[14] HappiEmaga T, Ronkart SN, Robert C, Wathelet B, Paquot M. Characterisation of pectins extracted from banana peels [Musa AAA] under different conditions using an experimental design. Food Chemistry. 2008;108:463-471. DOI: 10.1016/j. foodchem.2007.10.078

[15] Urias-Orona V, Rascon-Chu A, Lizardi-Mendoza J, Carvajal-Millan E, Gardea A, Ramírez-Wong B. A novel pectin material: Extraction,characterizationandgelling properties. International Journal of Molecular Sciences. 2010;11:3686-3695. DOI: 10.3390/ijms11103686

[16] Singthong J, Cui SW, Ningsanond S, Douglas Goff H. Structural characterization, degree of esterification and some gelling properties of Krueo Ma Noy [Cissampelos pareira] pectin. Carbohydrate Polymers. 2004;58:391- 400. DOI: 10.1016/j.carbpol.2004.07.018

[17] Yapo BM. Pectin quantity, composition and physicochemical behaviour as influenced by the purification process. Food Research International. 2009;42:1197-1202. DOI: 10.1016/j.foodres. 2009.06.002

[18] Wai WW, Alkarkhi AFM, Azh Easa AM. Effect of extraction conditions on yield and degree of esterification of durian rind pectin: An experimental design. Food and Bioproducts Processing.2010;88:209-214.DOI: 10.1016/j.fbp.2010.01.010

[19] Liu H, Xu XM, Guo SD. Comparison of full-fat and low-fat cheese analogues with or without pectin gel through microstructure, texture, rheology, thermal and sensory analysis. International Journal of Food Science and Technology.2008;43:1581-1592.DOI: 10.1111/j.1365-2621.2007.01616.x

[20] Lim J, Yoo J, Ko S, Lee S. Extraction and characterization of pectin from Yuza [Citrus junos] pomace: A comparison of conventional-chemical and combined physical-enzymatic extractions. Food Hydrocolloids. 2012;29:160-165. DOI: 10.1016/j.foodhyd.2012.02.018

[21] Yapo BM, Koffi KL. Extraction and characterization of gelling and emulsifying pectin fractions from cacao pod husk. Journal of Food and Nutrition Research. 2013;1[4]:46-51. DOI: 10.12691/jfnr-1-4-3

[22] Yapo BM, Koffi KL. Extraction and characterization of highly gelling low methoxy pectin from cashew apple pomace. Food. 2014;3[1]:1-12. DOI: 10.3390/foods3010001

[23] Mackaman P, Tangsuphoom N, Chavasit V. Effect of extraction condition on the chemical and emulsifying properties of pectin from Cyclea barbata Miers leaves. International Food Research Journal. 2014;21[2]:799-806

[24] Rahmati S, Abdullah A, Momeny E, Kang OL. Optimization studies on microwave assisted extraction of dragon fruit [Hylocereus polyrhizus] peel pectin using response surface methodology. International Food Research Journal. 2015;22[1]:233-239

[25] Xu SY, Liu JP, Huang X, Du LP, Shia FL, Dong R, et al. Ultrasonic-microwave assisted extraction, characterization and biological activity of pectin from jackfruit peel. LWT- Food

Science and Technology. 2018;90:577-582. DOI: 10.1016/j.lwt.2018. 01.007

[26] Yang JS, Mu TH, Ma MM. Extraction, structure, and emulsifying properties of pectin from potato pulp. Food Chemistry. 2018;244:197-205. DOI: 10.1016/j.foodchem.2017.10.059

[27] Maxwell E.G., Belshaw N.J., Waldron K.W., Morris V.J. Pectin—An Emerging New Bioactive Food Polysaccharide. Trends Food Sci. Technol. 2012;24:64–73. doi: 10.1016/j.tifs.2011.11.002

[28] Mukhiddinov Z.K., Khalikov D.K., Abdusamiev F.T., Avloev C.C. Isolation and Structural Characterization of a Pectin Homo and Ramnogalacturonan. Talanta. 2000;53:171–176. doi: 10.1016/S0039-9140[00]00456-2.

[29] Sriamornsak P. Chemistry of Pectin and its Pharmaceutical Uses: A Review. Univ. Int. J. 2003:206–223.

[30] Thakur, B.R., et al. [1997]. Chemistry and uses of pectin – A review. Critical Reviews in Food Science and Nutrition, 37, pp. 47-73.

[31] May, C.D. [1990]. Industrial pectins: Sources, production and applications. Carbohydrate Polymers, 12, pp. 79-99.

[32] Sriamornsak, P. [2003]. Chemistry of pectin and its pharmaceutical uses: A review. Silpakorn University International Journal, 3[1-2], 206-228.

[33] Novosel'skaya, I.L., et al. [2000]. Trends in the science and applications of pectins. Chemistry of Natural Compounds, 36, pp. 1-10.

[34] Mukhiddinov, Z.K., et al. [2000]. Isolation and structural characterization of a pectin homo and ramnogalacturonan. Talanta, 53, pp. 171-176.

[35] Noreen, A.; Nazli, Z.-H.; Akram, J.; Rasul, I.; Mansha, A.; Yaqoob, N.; Iqbal, R.; Tabasum, S.; Zuber, M.; Zia, K.M. Pectins functionalized biomaterials; a new viable approach for biomedical applications: A review. Int. J. Biol. Macromol. 2017, 101, 254–272

[36] Mohnen, D. Pectin structure and biosynthesis. Curr. Opin. Plant Biol. 2008, 11, 266–277.

[37] Naqash, F.; Masoodi, F.A.; Rather, S.A.; Wani, S.M.; Gani, A. Emerging concepts in the nutraceutical and functional properties of pectin—A Review. Carbohydr. Polym. 2017, 168, 227–239.

[38] Thakur B.R., Singh R.K., Handa A.K. Chemistry and Uses of Pectin—A Review. Crit. Rev. Food Sci. Nutr. 1997;37:47–73. doi: 10.1080/10408399709527767.

[39] Besson V., Yapo B., Maxwell G.A., Koffi K., Gnakri D. Cinnamon Apple Pectins: Structural and Rheological Properties. J. Food Stud. 2014;3:1–14

[40] A., Rubila S., Jayabalan R., Ranganathan T.V. A Review on Pectin: Chemistry due to General Properties of Pectin and its Pharmaceutical Uses. Sci. Rep. 2012;1:1–4Sriamornsak P. Chemistry of Pectin and its Pharmaceutical Uses: A Review. Univ. Int. J. 2003:206–223.

[41] Sañudo Barajas, J.A.; Ayón, M.; Velez, R.; Verdugo-Perales, M.; Lagarda, J.; Allende, R. Pectins: From the Gelling Properties to the Biological Activity; Nova Publishers: Hauppauge, NY, USA, 2014; pp. 203–224.

[42] Morales-Contreras, B.E.; Rosas-Flores, W.; Contreras-Esquivel, J.C.; Wicker, L.; Morales-Castro, J. Pectin from Husk Tomato [Physalis ixocarpa Brot.]: Rheological behavior at different extraction conditions. Carbohydr. Polym. 2018, 179, 282–289.

[43] Giacomazza, D.; Bulone, D.; San Biagio, P.L.; Marino, R.; Lapasin, R. The role of sucrose concentration in self-assembly kinetics of high methoxyl pectin. Int. J. Biol. Macromol. 2018, 112, 1183–1190.

[44] do Nascimento, G.E.; Simas-Tosin, F.F.; Iacomini, M.; Gorin, P.A.J.; Cordeiro, L.M.C. Rheological behavior of high methoxyl pectin from the pulp of tamarillo fruit [Solanum betaceum]. Carbohydr. Polym. 2016, 139, 125–130.

[45] D.; Bulone, D.; San Biagio, P.L.; Lapasin, R. The complex mechanism of HM pectin self-assembly: A rheological investigation. Carbohydr. Polym. 2016, 146, 181–186.

[46] Han, W.; Meng, Y.; Hu, C.; Dong, G.; Qu, Y.; Deng, H.; Guo, Y. Mathematical model of Ca2+ concentration, pH, pectin concentration and soluble solids [sucrose] on the gelation of low methoxyl pectin. Food Hydrocoll. 2017, 66, 37–48

[47] Yang, X.; Nisar, T.; Liang, D.; Hou, Y.; Sun, L.; Guo, Y. Low methoxyl pectin gelation under alkaline conditions and its rheological properties: Using NaOH as a pH regulator. Food Hydrocoll. 2018, 79, 560–571.

[48] Diana Gawkowska, Justyna Cybulska,* and Artur Zdunek Structure-Related Gelling of Pectins and Linking with Other Natural Compounds: A Review. Polymers [Basel]. 2018 Jul; 10[7]: 762. Published online 2018 Jul 11. doi: 10.3390/polym10070762.

[49] Rolin C [1993] Pectin. In Industrial gums. Whistler RL, BeMiller JN [eds],[3rdedn], New York: Academic Press.

[50] Hercules Incorporated [1999] Food gum products description: General description of pectin.

[51] Paoletti, S. [1986]. In Chemistry and function of pectins, eds. M.L. Fishman and J.J. Jen. [Washigton DC: American Chemical Society].

[52] Oakenfull DG [1991] The chemistry of high-methoxyl pectins. The chemistry and technology of pectin 87-108.

[53] Sundar Raj, A. A., Rubila, S., Jayabalan, R., & Ranganathan, T. V. [2012]. A Review on Pectin:

Chemistry due to General Properties of Pectin and its Pharmaceutical Uses. 1: 550 doi: 10.4172/scientificreports. 550 Page 2 of 4 Volume 1• Issue 12• 2012 in a chain-like configuration; this corresponds to average molecular weights from about 50,000 to 150,000 daltons. Large differences may exist between samples and between molecules within a sample and estimates may differ between methods of measurement.

[54] Misra, N. N., Pankaj, S. K., Segat, A., & Ishikawa, K. [2016]. Cold plasma interactions with enzymes in foods and model systems. Trends in Food Science & Technology, 55, 39–47.

[55] Hou, Y. M., Dong, X. Y., Yu, H., Li, S., Ren, C. S., Zhang, D. J., et al. [2008]. Disintegration of biomacromolecules by dielectric barrier discharge plasma in helium at atmospheric pressure. IEEE Transactions on Plasma Science, 36[4], 1633–1637

[56] Zhang, S. [2018]. [Doctoral Dissertation]Study on extraction and degradation of citrus pectin by dielectric barrier discharge plasma, Vol. 12Yantai Univesity 73. 2018.04.01.

[57] Mao, G., Wu, D., Wei, C., Tao, W., Ye, X., Linhardt, R. J., ... & Chen, S. [2019]. Reconsidering conventional and innovative methods for pectin extraction from fruit and vegetable waste: Targeting rhamnogalacturonan I. Trends in Food Science & Technology, 94, 65-78.

[58] J.G. Kennedy, Apple pomace and products derived from apple pomace: uses, composition and analysis, Anal. Plant Waste Mater. 20 [1999] 76–119.

[59] Liu, Y., Shi, J., & Langrish, T. A. G. [2006]. Water-based extraction of pectin from flavedo and albedo of orange peels. Chemical Engineering Journal, 120[3], 203-209.

[60] Kumar M, Tomar M, Saurabh V, Mahajan T, Punia S, Contreras MM, Rudra SG, Kaur C, Kennedy JF [2020] Emerging trends in pectin extraction and its anti-microbial functionalization using natural bioactives for application in food packaging. Trends Food Sci Technol 105:223–230.

[61] Xie F, Zhang W, Lan X, Gong S, Wu J, Wang Z [2018] Efects of high hydrostatic pressure and high pressure homogenization processing on characteristics of potato peel waste pectin. Carbohydr Polym 196:474–482.

[62] Zoghi, A., Vedadi, S., Esfahani, Z. H., Gavlighi, H. A., & Khosravi-Darani, K. [2021]. A review on pectin extraction methods using lignocellulosic wastes. Biomass Conversion and Biorefinery, 1-13.

[63] Klinchongkon, K.; Khuwijitjaru, P.; Adachi, S. Properties of subcritical water-hydrolyzed passion fruit [Passifloraedulis] pectin. Food Hydrocolloid. 2018, 74, 72–77

[64] Klinchongkon, K.; Khuwijitjaru, P.; Adachi, S. Degradation kinetics of passion fruit pectin in subcritical water. Biosci. Biotechnol. Biochem. 2017, 81, 712–717.

[65] Chen, J., Zhang, C., Xia, Q., Liu, D., Tan, X., Li, Y., & Cao, Y. [2020]. Treatment with subcritical water-hydrolyzed citrus pectin ameliorated cyclophosphamide-induced immunosuppression and modulated gut microbiota composition in ICR mice. Molecules, 25[6], 1302.

[66] Nova MV, Nothnagel L, Thurn M, Travassos PB, Herculano LS, Bittencourt PRS et al [2019] Development study of pectin/ Surelease® solid microparticles for the delivery of L-alanyl-Lglutamine dipeptide. Food Hydrocoll 89:921–932

[67] Zhang J, Wen C, Zhang H, Duan Y, Ma H [2020] Recent advances in the extraction of bioactive compounds with subcritical water: a review. Trend Food Sci Technol 95:183–195

[68] Zhu Z, Wu Q, Di X, Li S, Barba FJ, Koubaa M et al [2017] Multistage recovery process of seaweed pigments: investigation of ultrasound assisted extraction and ultra-fltration performances. Food Bioprod Proces 104:40–47

[69] Chemat F, Rombaut N, Meullemiestre A, Turk M, Perino S, Fabiano-Tixier AS, AbertVian M [2017] Review of green food processing techniques. preservation, transformation, and extraction. Innov Food Sci Emerg Technol 41:357–377

[70] Polanco-Lugo E, Martinez-Castillo JI, Cuevas-Bernardino JC, Gonz/alez-Flores T, Valdez-Ojeda R, Pacheco N, et al [2019] Citrus pectin obtained by ultrasound assisted extraction: physicochemical, structural, rheological and functional properties. CyTA - J Food 17[1]:463–471.

[71] Minjares-Fuentes R, Femenia A, Garau MC, Meza-Velazquez JA, Simal S, Rossello C [2014] Ultrasound-assisted extraction of pectins from grape pomace using citric acid: a response surface methodology approach. Carbohydr Polym 106[1]:179–189.

[72] Letellier, M., & Budzinski, H. [1999]. Microwave assisted extraction of organic

[73] Analusis, 27[3], 259e270

[74] Venkatesh, M. S., & Raghavan, G. S. V. [2004]. An overview of microwave processing and dielectric properties of agri-food materials. Biosystems Engineering, 88[1], 1e18.

[75] Routray, W., & Orsat, V. [2012]. Microwave-assisted extraction of flavonoids: A review. Food and Bioprocess Technology, 5[2], 409e424.

[76] Adetunji, L. R., Adekunle, A., Orsat, V., & Raghavan, V. [2017]. Advances in the pectin production process using novel extraction techniques: A review. Food Hydrocolloids, 62, 239-250.

[77] Puri, M., Sharma, D., & Barrow, C. J. [2012]. Enzyme-assisted extraction of bioactives from plants. Trends in Biotechnology, 30[1], 37e44.

[78] Rhein-Knudsen, N., Ale, M. T., & Meyer, A. S. [2015]. Seaweed hydrocolloid Production: An update on enzyme assisted extraction and modification technologies.Marine Drugs, 13[6], 3340e3359.

[79] Puri, M., Sharma, D., & Barrow, C. J. [2012]. Enzyme-assisted extraction of bioactives from plants. Trends in Biotechnology, 30[1], 37e44.

[80] Fissore, E. N., Ponce, N. M., Wider, E. A., Stortz, C. A., Gerschenson, L. N., &Rojas, A. M. [2009]. Commercial cell wall hydrolytic enzymes for producing pectin-enriched products from butternut [Cucurbita moschata, Duchesne ex Poiret]. Journal of Food Engineering, 93[3], 293e301.

[81] Ptichkina, N. M., Markina, O. A., & Rumyantseva, G. N. [2008]. Pectin extraction from pumpkin with the aid of microbial enzymes. Food Hydrocolloids, 22[1], 192e195.

[82] Panouill_e, M., Thibault, J.-F., & Bonnin, E. [2006]. Cellulase and protease preparations can extract pectins from various plant byproducts. Journal of Agricultural and Food Chemistry, 54[23], 8926e8935.

[83] Zhao, W., Guo, X., Pang, X., Gao, L., Liao, X., & Wu, J. [2015]. Preparation and characterization of low methoxyl pectin by high hydrostatic pressure-assisted enzymatic treatment compared with enzymatic method under atmospheric pressure. Food Hydrocolloids, 50, 44e53.

[84] Zykwinska, A., Boiffard, M.-H., Kontkanen, H., Buchert, J., Thibault, J.-F., & Bonnin, E. [2008]. Extraction of green labeled pectins and pectic oligosaccharides from plant byproducts. Journal of Agricultural and Food Chemistry, 56[19], 8926e8935.

[85] M.L. Fishman, P.N. Walker, H.K. Chau, A.T. Hotchkis, Flash extractionof pectin from orange albedo by steam injection, Biomacromolecules 4 [3] [2003] 880–889.

[86] Dranca F, Vargas M, Oroian M [2020] Physicochemical properties of pectin from Malus domestica 'F.alticeni' apple pomace as affected by non-conventional extraction techniques. Food Hydrocoll 100:105383.

[87] Su DL, Li PJ, Quek SY, Huang ZQ, Yuan YJ, Li GY [2019] Efficient extraction and characterization of pectin from orange peel by a combined surfactant and microwave assisted process. Food Chem 286:1–7.

[88] Sucheta N, Misra N, Yadav SK [2020] Extraction of pectin from black carrot pomace using intermittent microwave, ultrasound and conventional heating: kinetics, characterization and process economics. Food Hydrocoll 102:105592

[89] Asgari K, Labbafi M, Khodaiyan F, Kazemi M, Hosseini SS[2020] High methylated pectin from walnut processing wastes as a potential resource: ultrasound assisted extraction and physicochemical, structural and functional analysis. Int J Biol Macromol 152:1274–1282.

[90] Rodsamran P, Sothornvit R [2019] Microwave heating extraction of pectin from lime peel: characterization and properties compared with the conventional heating method. Food Chem 278:364–372.

[91] Rahmati S, Abdullah A, Kang OL [2019] Effects of different microwave intensity on the extraction yield and physicochemical properties of pectin from dragon fruit [Hylocereus polyrhizus] peels. Bioact Carbohydr Diet Fibre 18:100186.

[92] Rahmani Z, Khodaiyan F, Kazemi M, Sharifan A [2020] Optimization of microwave-assisted extraction and structural characterization of pectin from sweet lemon peel. Int J Biol Macromol 147:1107–1115.

[93] N, Chemat F [2015] Bio-refinery of orange peels waste: a new concept based on integrated green and solvent free extraction processes using ultrasound and microwave techniques to obtain essential oil, polyphenols and pectin. Ultrason Sonochem 24:72–79.

[94] Chen Q, Hu Z, Yao FYD, Liang H [2016] Study of two-stage microwave extraction of essential oil and pectin from pomelo peels. LWT - Food Sci Technol 66:538–545.

[95] Hosseini SS, Khodaiyan F, Yarmand MS [2016] Optimization of microwave assisted extraction of pectin from sour orange peel and its physicochemical properties. Carbohydr Polym 140:59–65.

[96] Prakash Maran J, Sivakumar V, Thirugnanasambandham K,Sridhar R [2013] Optimization of microwave assisted extractionof pectin from orange peel. Carbohydr Polym 97[2]:703–709.

[97] Prakash Maran J, Sivakumar V, Thirugnanasambandham K, Sridhar R [2014] Microwave assisted extraction of pectin from waste Citrullus lanatus fruit rinds. Carbohydr Polym 101[1]:786–791.

[98] Swamy GJ, Muthukumarappan K [2017] Optimization of continuousand intermittent microwave extraction of pectin from banana peels. Food Chem 220:108–114.

[99] Seixas FL, Fukuda DL, Turbiani FRB, Garcia PS, Petkowicz CLO, Jagadevan S, Gimenes ML [2014] Extraction of pectin from passion fruit

peel [Passiflora edulis f. flavicarpa] by microwave- induced heating. Food Hydrocoll 38:186–192.

[100] Shivamathi CS, Moorthy IG, Kumar RV, Soosai MR, Maran JP, Kumar RS [2019] Optimization of ultrasound assisted extraction of pectin from custard apple peel: potential and new source. Carbohydr Polym 225:115240

[101] Hosseini SS, Khodaiyan F, Kazemi M, Najari Z [2019] Optimizationand characterization of pectin extracted from sour orange peel by ultrasound assisted method. Int J Biol Macromol 125:621–629.

[102] Kazemi M, Khodaiyan F, Labbafi M, Hosseini SS [2020] Ultrasonic and heating extraction of pistachio by-product pectin: physicochemical, structural characterization and functional measurement. J Food Meas Charact 14[2]:679–693.

[103] Zaid RM, Mishra P, Tabassum S, Wahid ZA, Sakinah AMM [2019] High methoxyl pectin extracts from Hylocereus polyrhizus's peels: extraction kinetics and thermodynamic studies. Int J Biol Macromol 141:1147–1157.

[104] Guandalini BBV, Rodrigues NP, Marczak LDF [2019] Sequential extraction of phenolics and pectin from mango peel assisted by ultrasound. Food Res Int 119:455–461.

[105] Ma X, Jing J, Wang J, Xu J, Hu Z [2020] Extraction of low methoxyl pectin from fresh sunflower heads by subcritical water extraction. ACS Omega 5[25]:15095–15104.

[106] Dias IP, Barbieri SF, Fetzer DEL, Corazza ML, Silveira JLM [2020] Effects of pressurized hot water extraction on the yield and chemical characterization of pectins from Campomanesia xanthocarpa Berg fruits. Int J Biol Macromol 146:431–443.

[107] Liew SQ, Chin NL, Yusof YA, Sowndhararajan K [2016] Comparison of acidic and enzymatic pectin extraction from passion fruit peels and its gel properties. J Food Process Eng 39[5]:501– 511.

[108] Vasco-Correa J, Zapata ZAD [2017] Enzymatic extraction of pectin from passion fruit peel [Passiflora edulis f. flavicarpa] at laboratory and bench scale. Lebensmittel- Wissenschaft Technol 80:280–285.

[109] Sabater C, Corzo N, Olano A, Montilla A [2018] Enzymatic extraction of pectin from artichoke [Cynara scolymus L.] byproducts using Celluclast®1.5L. Carbohydr Polym 190:43–49.

[110] Chen, H. M., Fu, X., & Luo, Z. G. [2015]. Properties and extraction of pectin-enriched materials from sugar beet pulp by ultrasonic-assisted treatment combined with subcritical water. Food Chem, 168, 302-310. doi:10.1016/ j.foodchem.2014.07.078.

[111] Liew, S. Q., Ngoh, G. C., Yusoff, R., & Teoh, W. H. [2016]. Sequential ultrasound-microwave assisted acid extraction [UMAE] of pectin from pomelo peels. Int J Biol Macromol, 93[Pt A], 426-435. doi:10.1016/ j.ijbiomac.2016.08.065.

[112] Nadar, S. S., & Rathod, V. K. [2017]. Ultrasound assisted intensification of enzyme activity and its properties: a mini-review. World J Microbiol Biotechnol, 33[9], 170. 976 doi:10.1007/s 11274-017-2322-6.

[113] Encalada, A. M. I., Pérez, C. D., Flores, S., K., Rossetti, L., Fissore, E. N., & Rojas, A. M. [2019]. Antioxidant pectin enriched fractions obtained from discarded carrots [Daucus carota L.] by ultrasound-enzyme assisted extraction. Food chemistry, 289, 453–460. https://doi.org/10.1016/j.foodchem.2019.03.078 In this issue.

[114] Li, D. Q., Jia, X., Wei, Z., & Liu, Z. Y. [2012]. Box–Behnken experimental design for investigation of microwave-assisted extracted sugar beet pulp pectin. Carbohydrate Polymers, 88[1], 342–346.

[115] Chan, S. Y., & Choo, W. S. [2013]. Effect of extraction conditions on the yield and chemical properties of pectin from cocoa husks. Food Chemistry, 141[4], 3752–3758

[116] Košťálová, Z., Hromádková, Z., & Ebringerová, A. [2013]. Structural diversity of pectins isolated from the Styrian oil-pumpkin [Cucurbita pepo var. styriaca] fruit.Carbohydrate Polymers, 93[1], 163–171.

[117] Yapo, B. M., Lerouge, P., Thibault, J.-F., & Ralet, M.-C. [2007]. Pectins from citrus peel cell walls contain homogalacturonans homogenous with respect to molar mass, rhamnogalacturonan I and rhamnogalacturonan II. Carbohydrate Polymers, 69[3], 426–435.

[118] Kurita, O., Fujiwara, T., & Yamazaki, E. [2008]. Characterization of the pectin extracted from citrus peel in the presence of citric acid. Carbohydrate Polymers, 74[3], 725–730.

[119] Kaya, M., Sousa, A. G., Crepeau, M. J., Sorensen, S. O., & Ralet, M. C. [2014].Characterization of citrus pectin samples extracted under different conditions:Influence of acid type and pH of extraction. Annals of Botany, 114[6], 1319–1326.

[120] Hadfield, K. A., Rose, J. K. C., Yaver, D. S., Berka, R. M., & Bennett, A. B. [1998]. Polygalacturonase gene expression in ripe melon fruit supports a role for polygalacturonase in ripening-associated pectin disassembly. Plant Physiology, 117[2], 363–373.

[121] Koubala, B. B., Kansci, G., Mbome, L. I., Crépeau, M. J., Thibault, J. F., & Ralet, M. C.

[2008]. Effect of extraction conditions on some physicochemical characteristics of pectins from "Améliorée" and "Mango" mango peels. Food Hydrocolloids, 22[7], 1345–1351.

[122] Ueno, H., Tanaka, M., Hosino, M., Sasaki, M., & Goto, M. [2008]. Extraction of valuable compounds from the flavedo of Citrus junos using subcritical water. Separation and Purification Technology, 62[3], 513–516.

[123] Worth, H. G. J. [1967]. The chemistry and biochemistry of pectic substances. Chemical Reviews, 67[4], 465–473

[124] Zhang, H., Chen, J., Li, J., Yan, L., Li, S., Ye, X., et al. [2018]. Extraction and characterization of RG-I enriched pectic polysaccharides from Mandarin citrus peel. Food Hydrocolloids, 79, 579–586.

[125] Khodaei, N., & Karboune, S. [2014]. Enzymatic extraction of galactan-rich rhamnogalacturonan I from potato cell wall by-product. Lebensmittel-Wissenschaft und - Technologie- Food Science and Technology, 57[1], 207–216.

[126] Fishman, M. L., Chau, H. K., Cooke, P. H., Yadav, M. P., & Hotchkiss, A. T. [2009]. Physico-chemical characterization of alkaline soluble polysaccharides from sugar beet pulp. Food Hydrocolloids, 23[6], 1554–1562

[127] Albersheim, P., Neukom, H., & Deuel, H. [1960]. Splitting of pectin chain molecules in neutral solutions. Archives of Biochemistry and Biophysics, 90[1], 46–51

[128] Sakamoto, T. [1995]. Enzymic pectin extraction from protopectins using microbial protopectinases. Process Biochemistry, 30[5], 403–409.

[129] Yeoh, S., Shi, J., & Langrish, T. A. G. [2008]. Comparisons between different techniques for water-based extraction of pectin from orange peels. Desalination, 218[1–3], 229–237.

[130] Mao, G., Wu, D., Wei, C., Tao, W., Ye, X., Linhardt, R. J., ... & Chen, S. [2019]. Reconsidering conventional and innovative methods for pectin extraction from fruit and vegetable waste: Targeting rhamnogalacturonan I. Trends in Food Science & Technology, 94, 65-78.

[131] Vanitha, T., & Khan, M. [2019]. Role of pectin in food processing and food packaging. Pectins-extraction, purification, characterization and applications.

[132] Ciolacu L, Nicolau AI, Hoorfar J. Global Safety of Fresh Produce. A Handbook of Best Practice, Innovative Commercial Solutions and Case Studies. Sawston, UK: Woodhead Publishing Limited; 2014

[133] Gavahian, M., Chu, Y. H., & Mousavi Khaneghah, A. [2019]. Recent advances in orange oil extraction: An opportunity for the valorisation of orange peel waste a review. International Journal of Food Science & Technology, 54[4], 925-932.

[134] Zoghi, A., Vedadi, S., Esfahani, Z. H., Gavlighi, H. A., & Khosravi-Darani, K. [2021]. A review on pectin extraction methods using lignocellulosic wastes. Biomass Conversion and Biorefinery, 1-13.

[135] Elshahed, M. S., Miron, A., Aprotosoaie, A. C., & Farag, M. A. [2021]. Pectin in diet: Interactions with the human microbiome, role in gut homeostasis, and nutrient-drug interactions. Carbohydrate Polymers, 255, 117388.

[136] Kedir, W. M., Deresa, E. M., & Diriba, T. F. [2022]. Pharmaceutical and drug delivery applications of pectin and its modified nanocomposites. Heliyon, e10654.

[137] Roman-Benn, A., Contador, C. A., Li, M. W., Lam, H. M., Ah-Hen, K., Ulloa, P. E., & Ravanal, M. C. [2023]. Pectin: An overview of sources, extraction and applications in food products and health. Food Chemistry Advances, 100192.

[138] Munarin, F. A. B. I. O. L. A., Tanzi, M. C., & Petrini, P. A. O. L. A. [2012]. Advances in biomedical applications of pectin gels. International journal of biological macromolecules, 51[4], 681-689.

[139] Liu, H., X. M. Xu, and S. D. Guo. 2007. Rheological, texture and sensory properties of low-fat mayonnaise with different fat mimetics. LWT - Food Science and Technology 40 [6]:946–54. doi: 10.1016/ j.lwt.2006.11.007.

[140] Søndergaard, K. M., A. G. Juul, and L. Nørbøge. 2000. Pectin composition as fat replacer and emulsifier. WO2000040098A1, WIPO [PCT].

[141] Swanson, B. G. 2003. Encyclopedia of food sciences and nutrition. 2nd ed. South Africa: Academic Press [Elsevier].

[142] Worthy, W. 1991. Low-calorie fat replacer is based on pectin. Chemical and Engineering News 69:26. doi: 10.1021/cen-v069n041.p026.

[143] Padma Ishwarya S., Sandhya R. & P. Nisha [2022] Advances and prospects in the food applications of pectin hydrogels, Critical Reviews in Food Science and Nutrition, 62:16, 4393-4417, DOI: 10.1080/10408398.2021.1875394

[144] Liu, H., X. M. Xu, and S. D. Guo. 2007. Rheological, texture and sensory properties of low-fat mayonnaise with different fat mimetics. LWT - Food Science and Technology 40 [6]:946–54. doi: 10.1016/ j.lwt.2006.11.007

[145] Kizilay, E., A. B. Kayitmazer, and P. L. Dubin. 2011. Complexation and coacervation of polyelectrolytes with oppositely charged colloids. Advances in Colloid and Interface Science 167 [1-2]:24–37. doi: 10.1016/j.cis.2011.06.006

[146] Schmitt, C., C. Sanchez, F. Thomas, and J. Hardy. 1999. Complex coacervation between beta-lactoglobulin and gum in aqueous medium. Food Hydrocolloids 13 [6]:483–96. doi: 10.1016/S0268-005X[99]00032acacia-6.

[147] WHO. 2013. Global action plan for the prevention and control of noncommunicable diseases 2013–2020. Geneva, Switzerland: WHO.

[148] Porta, R.; Di Pierro, P.; Sabbah, M.; Regalado-Gonzales, C.; Mariniello, L.; Kadivar, M.; Arabestani, A. Blend films of pectin and bitter vetch [Vicia ervilia] proteins: Properties and effect of transglutaminase. Innov. Food Sci. Emerg. Technol. 2016, 36, 245–251.

[149] Chiarappa, G.; De'Nobili, M.D.; Rojas, A.M.; Abrami, M.; Lapasin, R.; Grassi, G.; Ferreira, J.A.; Gudiño, E.; de Oliveira, P.; Grassi, M. Mathematical modeling of L-[+]-ascorbic acid delivery from pectin films [packaging] to agar hydrogels [food]. J. Food Eng. 2018, 234, 73–81.

[150] Nisar, T.; Wang, Z.-C.; Yang, X.; Tian, Y.; Iqbal, M.; Guo, Y. Characterization of citrus pectin films integrated with clove bud essential oil: Physical, thermal, barrier, antioxidant and antibacterial properties. Int. J. Biol. Macromol. 2018, 106, 670–680.

[151] Almasi, H.; Azizi, S.; Amjadi, S. Development and characterization of pectin films activated by nanoemulsion and Pickering emulsion stabilized marjoram [Origanum majorana L.] essential oil. Food Hydrocoll. 2020, 99, 105338.

[152] Lei, Y.; Wu, H.; Jiao, C.; Jiang, Y.; Liu, R.; Xiao, D.; Lu, J.; Zhang, Z.; Shen, G.; Li, S. Investigation of the structural and physical properties, antioxidant and antimicrobial activity of pectin-konjac glucomannan composite edible films incorporated with tea polyphenol. Food Hydrocoll. 2019, 94, 128–135.

[153] Lee, J.H.; Jeong, D.; Kanmani, P. Study on physical and mechanical properties of the biopolymer/silver based active nanocomposite films with antimicrobial activity. Carbohydr. Polym. 2019, 224, 115159.

[154] da Silva, I.S.V.; de Sousa, R.M.F.; de Oliveira, A.; de Oliveira, W.J.; Motta, L.A.C.; Pasquini, D.; Otaguro, H.; da Silva, I.S.V.; de Sousa, R.M.F.; de Oliveira, A.; et al. Polymeric blends of hydrocolloid from chia seeds/apple pectin with potential antioxidant for food packaging applications. Carbohydr. Polym. 2018, 202, 203–210.

[155] Akhter, R.; Masoodi, F.A.; Wani, T.A.; Rather, S.A. Functional characterization of biopolymer based composite film: Incorporation of natural essential oils and antimicrobial agents. Int. J. Biol. Macromol. 2019, 137, 1245–1255.

[156] Bermúdez-Oria, A.; Rodríguez-Gutiérrez, G.; Rubio-Senent, F.; Fernández-Prior, Á.; Fernández-Bolaños, J. Effect of edible pectin-fish gelatin films containing the olive antioxidants hydroxytyrosol and 3,4-dihydroxyphenylglycol on beef meat during refrigerated storage. Meat Sci. 2019, 148, 213–218.

[157] Dudnyk, I.; Janeˇcek, E.-R.; Vaucher-Joset, J.; Stellacci, F. Edible sensors for meat and seafood freshness. Sens. Actuators B Chem. 2018, 259, 1108–1112.

[158] Maciel, V.B.V.; Yoshida, C.M.P.; Franco, T.T. Chitosan/pectin polyelectrolyte complex as a pH indicator. Carbohydr. Polym. 2015, 132, 537–545.

[159] Vishnuvarthanan, M.; Rajeswari, N. Food packaging: Pectin—laponite—Ag nanoparticle bionanocomposite coated on polypropylene shows low O2 transmission, low Ag migration and high antimicrobial activity. Environ. Chem. Lett. 2019, 17, 439–445.

[160] Yu, N.; Peng, H.; Qiu, L.; Wang, R.; Jiang, C.; Cai, T.; Sun, Y.; Li, Y.; Xiong, H. New pectin-induced green fabrication of Ag@AgCl/ZnO nanocomposites for visible-light triggered antibacterial activity. Int. J. Biol. Macromol. 2019, 141, 207–217.

[161] Li, K.; Cui, S.; Hu, J.; Zhou, Y.; Liu, Y. Crosslinked pectin nanofibers with well-dispersed Ag nanoparticles: Preparation and characterization. Carbohydr. Polym. 2018, 199, 68–74.

[162] McCune, D.; Guo, X.; Shi, T.; Stealey, S.; Antrobus, R.; Kaltchev, M.; Chen, J.; Kumpaty, S.; Hua, X.; Ren, W.; et al. Electrospinning pectin-based nanofibers: A parametric and cross-linker study. Appl. Nanosci. 2018, 8, 33–40.

[163] Materials 2020, 13, 673 16 of 17 86. Neši´c, A.; Gordi´c, M.; Davidovi´c, S.; Radovanovi´c, Ž.; Nedeljkovi´c, J.; Smirnova, I.; Gurikov, P. Pectin-based nanocomposite aerogels for potential insulated food packaging application. Carbohydr. Polym. 2018, 195, 128–135.

[164] Torpol, K.; Sriwattana, S.; Sangsuwan, J.; Wiriyacharee, P.; Prinyawiwatkul, W. Optimising chitosan–pectin hydrogel beads containing combined garlic and holy basil essential oils and their application as antimicrobial inhibitor. Int. J. Food Sci. Technol. 2019, 54, 2064–2074.

[165] Luo, S.-Z.; Hu, X.-F.; Jia, Y.-J.; Pan, L.-H.; Zheng, Z.; Zhao, Y.-Y.; Mu, D.-D.; Zhong, X.-Y.; Jiang, S.-T. Camellia oil-based oleogels structuring with tea polyphenol-palmitate particles and citrus pectin by emulsion-templated method: Preparation, characterization and potential application. Food Hydrocoll. 2019, 95, 76–87.

[166] Nisar, T.; Yang, X.; Alim, A.; Iqbal, M.; Wang, Z.-C.; Guo, Y. Physicochemical responses and microbiological changes of bream [Megalobrama ambycephala] to pectin based coatings enriched with clove essential oil during refrigeration. Int. J. Biol. Macromol. 2019, 124, 1156–1166.

[167] C.; Lee, M.C.; Godec, M.; Zhang, Z.; Abbaspourrad, A. Ultrasonic encapsulation of cinnamon flavor to impart heat stability for baking applications. Food Hydrocoll. 2020, 99, 105316.

[168] Abdou, E.S.; Galhoum, G.F.; Mohamed, E.N. Curcumin loaded nanoemulsions/pectin coatings for refrigerated chicken fillets. Food Hydrocoll. 2018, 83, 445–453.

[169] Guerra-Rosas, M.I.; Morales-Castro, J.; Cubero-Márquez, M.A.; Salvia-Trujillo, L.; Martín-Belloso, O. Antimicrobial activity of nanoemulsions containing essential oils and high methoxyl pectin during long-term storage. Food Control 2017, 77, 131–138.

[170] Mendes, J.F.; Norcino, L.B.; Martins, H.H.A.; Manrich, A.; Otoni, C.G.; Carvalho, E.E.N.; Piccoli, R.H.; Oliveira, J.E.; Pinheiro, A.C.M.; Mattoso, L.H.C. Correlating emulsion characteristics with the properties of active starch films loaded with lemongrass essential oil. Food Hydrocoll. 2020, 100, 105428