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Role of Pectin in Food Processing and Food Packaging

Thiraviam Vanitha and Mahejibin Khan

Abstract

Pectin is a branched heteropolysaccharide consisting of long-chain galacturonan segments and other neutral sugars such as rhamnose, arabinose, galactose, and xylose. It forms a matrix with celluloses and hemicelluloses and contributes to the cell structure. Due to the presence of several sugar moieties and different levels of methyl esterification, pectin does not have defined molecular weight like other polysaccharides. Pectin has wide applications. It is used as emulsifier, gelling agent, thickener, stabilizer, and fat or sugar replacer in low-calorie foods. Pectin and pectin-derived oligosaccharides can also be used as an important ingredient in functional foods. In recent past, a new application envisaged for pectin polymers as edible films or coating. These films act as natural barrier for exchange of moisture, gases, lipids, and volatiles between food and environment, and protect fruits and vegetable from microbial contamination. The degree of esterification of pectin and other structural modifications defines the functional properties. Herein, various functional properties of pectin in relation to food processing and packaging are discussed.

Keywords: pectin, pectin oligosaccharide, food emulsifier, edible films, functional food, food stabilizer, emulsified food

1. Introduction

Pectin is the major constituent of all plants and makes up approximately two-third of the dry mass of plant primary cell walls. It provides structural integrity, strength, and flexibility to the cell wall and acts as barrier to the external environment [1]. Pectin is also a natural component of all omnivorous diet and is an important source of dietary fiber. Due to the resistant in digestive system and lack of pectin digestive enzymes, human beings are not able to digest pectin directly but microorganism present in large intestine can easily assimilate the pectin and convert it into soluble fibers. These oligosaccharides promote beneficial microbiota in gut and also help in lipid and fat metabolism, glycemic regulation, etc. [2]. Being complex and highly diverse in structure, role of pectin is not only limited to the biological and physiological functions, but it has tremendous potential and contributes substantially in other applications ranging from food processing to pharmaceuticals. Pectin is a water-soluble fiber and used in various food as emulsifier, stabilizer, gelling, and thickening agent.

Commercial pectins are extracted from citrus and apple fruit. On the basis of dry mass, apple pomace contains 10–15% pectin, whereas citrus peel possesses 20–30% pectin. However, pectin has also been extracted in higher amount from several other fruits and their by-products, such as sunflower head, mango peel, soybean hull [3], passion fruit peel [4], sugar beet pulp [5], *Akebia trifoliata* peel [6],

peach pomace [7], banana peel [8], chickpea husk [9], and many more [10–23]. **Table 1** summarizes the different types of pectin extracted from various horticultural crops. But detection and extraction of pectin in higher concentration is not sufficient to qualify that fruit as a source of commercial pectin because of the structural variation and modification in side-chain sugars, and also that pectin from different sources has different gelling properties.

S. No	Source	Parts used	Extraction method used	Pectin yield (%)	Type of pectin (HMP/LMP)	Ref
1	Passion fruit	Peel	APP	14.8%	HMP	[4]
2	Banana	Peel	APP	5–21%	HMP (DE, 50–80%)	[8]
3	Chick pea	Husk	Acid extraction, APP, and freeze dried	8%	LMP (DE, 10%)	[9]
4	Krueo Ma Noy	Leaves	APP, DPP	21–28%	LMP (DE, 34–42%)	[11]
5	Yellow Passion	Fruit rind	APP, DPP, MPP	3–16%	HMP (DE, 54–59%)	[12]
6	Durian	Rind	APP	2–10.25%	HMP (DE, 50–64%)	[13]
7	Mulberry	Mulberry bark with epidermis (MBE) and without epidermis (MB)	Extracted using 60–100% isopropanol	11.88%	HMP (MB–DE, 71.13%); LMP (MBE–DE, 24.27%)	[14]
8	Yuzu, citrus family	Pomace	Extracted with APP and enzyme (Viscozyme® L with 1.2×10^{-4} fungal β -glucanase	DPP, APP (7.3–8%)	LMP (APP–DE, 41%; DPP–DE, 46.3%)	[16]
9	Cacao pods	Husk	Extracted with 1 N HNO ₃ at different pH and precipitated by ethanol and acetone	3.7–8.6%	LMP (DE 36.7% @ pH 1, DE 44.3% @ pH 3); HMP (DE 52.4% @ pH 2)	[17]
10	Cashew apple	Pomace	AOP at different pH (1.0, 1.5, and 2.0)	10.7–25.3%	LMP (DE, 28–46%)	[18]
11	<i>Cyclea barbata</i> Miers (CBM)	Leaves	Extracted with acid and alkali, precipitated the pectin by ethanol	4–8%	HMP (acid treated: 65–75% DE) LMP (Alkali treated: 36% DE)	[19]

S. No	Source	Parts used	Extraction method used	Pectin yield (%)	Type of pectin (HMP/LMP)	Ref
12	Dragon fruit	Peel	Extracted using HCl, precipitated and purified with 70 and 99.6% isopropanol.	18.59%	LMP (DE, 46.95%)	[20]
13	Jackfruit	Peel	Ultrasonic-microwave-assisted extracted (UMAE) pectin	21.5%	HMP (DE, 62.5%)	[22]
14	Potato	Pulp	Extracted with different acids and precipitated by ethanol	4.08–14.34%	LMP (DE, 21.51–37.45%)	[23]

APP, alcohol-precipitated pectin; MPP, metal ion-precipitated pectin; DPP, dialyzed precipitated pectin.

Table 1.
High methoxyl pectins (HMP) and low methoxyl pectins (LMP) from various horticultural crops.

2. Pectin structure

Pectin is a highly complex plant cell wall polysaccharide that plays a significant role in plant growth and development. It is predominantly present in fruits and vegetables and constitutes approximately 35–40% of the primary cell wall in all the dicot plants [24]. The composition and structure of pectin is influenced by the developmental stages of plants [25, 26]. Structural analysis of pectin revealed that it is a polymer comprised of chain-like configuration of approximately 100–1000 saccharide units; therefore, it does not possess a defined structure. In general, pectin is illustrated as a heteropolysaccharide of three components namely, homogalacturonan (HG), rhamnogalacturonan-I (RGI), and rhamnogalacturonan-II (RGII) [28, 29]. The Backbone structure may branch with other neutral sugar chains such as arabinan, xylogalacturonan (XGA), arabinogalactan I (AG-I), and arabinogalactan II (AG-II).

Homogalacturonan (HG) is a polymer of galacturonic acid (GalA), in which Gal A residues are linked together by α -1-4 glycosidic bond and the number of GalA residues in HG may vary from 72 to 100% depending on the source of pectin [30]. For instance, the HG backbone of cashew apple pectin, *C. maxima* pectin, sunflower pectin, citrus pectin, comprises of 69.9–85%, 71–75%, 77–85%, 80–95%, GalA residues, respectively. Amaranth pectin contains more than 80% GalA residues in HG backbone structure. Furthermore, it was also observed that HG may be methoxy-esterified at C-6 and/or O-acetylated at the O-2 and/or O-3. Some exception has also been reported in the detailed structural analysis of HG region of pectin such as C-3 substitution of the galacturonic acids of HG with xylose in pea, apple, carrot, duck weed, etc. [31], and C-2 or C-3 with apiose in duck weeds (*Lemna minor*) [32]. HG is susceptible to both mechanical and enzymatic deesterification and degradation.

Rhamnogalacturonan I represents approximately 20–35% of the pectin polysaccharides. It is the highly branched and heterogeneous polysaccharide which is characterized as repeating units of α -(1 \rightarrow 2)-linked rhamnose and α -(1 \rightarrow 4)-linked GalA residues. It can be O-acetylated at O-2 and/or O-3 positions of GalA residues

[33, 34]. Pectin from citrus peels, mung bean, kidney bean, apple fruit, and flax hypocotyls has been reported 100% methyl esterified in the RGI region [35, 36]. The composition of RGI varies in pectin extracted from different sources. In sugar beet pectin, 80 repeating units of $[\rightarrow 2] -\alpha\text{-L-Rha-(1-4)-}\alpha\text{-D-GalA-(1}\rightarrow\text{)}$ comprised the backbone of rhamnogalacturonan I (RG-I), whereas citrus pectin contains only 15–40 repeating units [37]. The polymeric side chains of galactans and arabinans are substituted at the O-4 position of RG-I backbone. Arabinogalactan I (AG-I) and arabinogalactan II (AG-II) are also reported to be present as polymeric side chains [38–40]. The side chains are often referred to as “hairs” and believed to play an important role in pectin functionality. The loss of side chains may increase the solubility of the pectin [41]. PGI is prone to enzymatic depolymerization. However, protease and acid-catalyzed cleavage of RGI has also been reported [28, 42, 43].

The highly conserved polysaccharide of pectin is rhamnogalacturonan II which constitutes about 10% of the pectin polymer [44]. This polysaccharide is made up of $(1 \rightarrow 4)\text{-linked-}\alpha\text{-D-GalA}$ units containing 12 monosaccharide such as apiose, acetic acid, 3-deoxy-manno-2-octulosonic acid (KDO), and 3-deoxy-lyxo-2-heptulosaric acid (DHA) as side chains [30, 39]. GalA present in backbone of rhamnogalacturonan II (RG-II) may be methyl esterified at the C-6 position. The percentage of esterified GalA and acetylated groups in HG chain is termed as the DE and DAC, respectively. It is proposed that in the early developmental stages of plants, highly esterified pectin is formed that undergoes some deesterification in the cell wall or middle lamella. In general, tissue pectin ranges from 60 to 90% DE [45]. Both the DE and the DAC of pectin may vary depending on the method of extraction and plant origin [30, 46]. The functional properties of the pectin are determined by the amount and the distribution of esterified GalA residues in the linear backbone. Presence and distribution of esterified and nonmethylated GalA in pectin define the charge on pectin molecules. Based on their degree of esterification (DE), pectins are classified as high methoxy pectins (HMP) or low methoxy pectins (LMP). DE values of HM pectin range from 60 to 75%, whereas pectin with 20–40% of DE is referred as LM pectin. It was also observed that solubility, viscosity, and gelation properties of pectin are correlated and highly dependent on structural features [47, 48]. Pectin and monovalent salts of pectins are generally soluble in water but di- and trivalent ions are insoluble. The solubility of pectin in water increases with decrease in polymer size and increase in methoxy contents. Pectin powder gets hydrated very fast in water and forms clumps. The solubility of these clumps is very slow. As the pectin molecules come in contact with water, deesterification and depolymerization of pectins start spontaneously. The rate of decomposition of pectin depends on pH and temperature of the solution. As the pH of the solution decreased, with elevated temperature, ionization of carboxylate groups also reduced, which suppresses the hydration and repulsion between the polysaccharide molecules and results in the association of molecules in the form of gels. During thermal processing, solubilization of pectin is affected by β -elimination which depolymerized the pectin molecule and reduced its chain length. Small polymers have poor affinity with cell wall framework and solubilize easily. However, preheating, as well as reduced moisture contents in thermal processing, adversely affects the solubility of pectin in water [49, 50].

3. Pectin as food emulsifier

Food additives that are used in food processing to blend two immiscible liquids to produce a desirable product are known as food emulsifier or emulgent. These additives act as surface-active agents on the border of immiscible layers and reduce

oil crystallization and prevent water separation. Emulsifiers are used in large number of food products such as ice creams, low-fat spreads, yoghurts, margarine, salad dressings, salty spreads, bakery products, and many other creamy sauces, to keep them in stable emulsion [27]. Emulsifiers increase the whip-ability of batters, enhance mouthfeel of the products, and improve texture and shape of the dough. Moreover, emulsions also help to encapsulate the bioactives [51]. Based on the disperse phase, there are two types of emulsion: oil in water (O/W) and water in oil (W/O). Milk, mayonnaise, dressings, and various beverages are some examples of O/W emulsion, whereas butter and margarine are the typical examples of W/O emulsion. Progress in hydrocolloid chemistry has resulted in the development of multitype emulsion such as O/W/O and O/W/O type emulsion (**Figure 1**). These emulsions are very important for fat reduction or encapsulation of bioactives and are used in preparation and stabilization of various low-fat creams, seasoning, and flavoring of sauces [52].

Commonly used emulsifiers in food processing are (i) small-molecular surfactant such as lectithins, derivatives of mono- and diglycerides prepared by mixing edible oils with glycerin or ethylene oxide, fatty acid derivatives such as glycol esters, sorbitan esters, polysorbates and (ii) macromolecular emulsifiers that include proteins and plant-based polymers such as soy polysaccharide, guar gum, modified starch, pectin, etc. [53]. As far as the properties of food emulsifier are concern, a good emulsifier should be low in molecular weight, capable to reduce the surface tension rapidly at interface, and should be soluble in continuous phase [54]. Research on food additives revealed the adverse effect of synthetic food additives on human being. Chassaing et al. found that polysorbate 80 (P80) or carboxy methyl cellulose (CMC) had adverse effects on gut microbiota and their continuous use triggered the weight gain and metabolic syndrome after 12 weeks of administration in mouse [55]. A recent research carried out on mice shows that regular use of P80 and CMC triggers low-grade intestinal inflammation which may ultimately lead to the development of colon cancer [56]. Therefore, safety issues with the synthetic

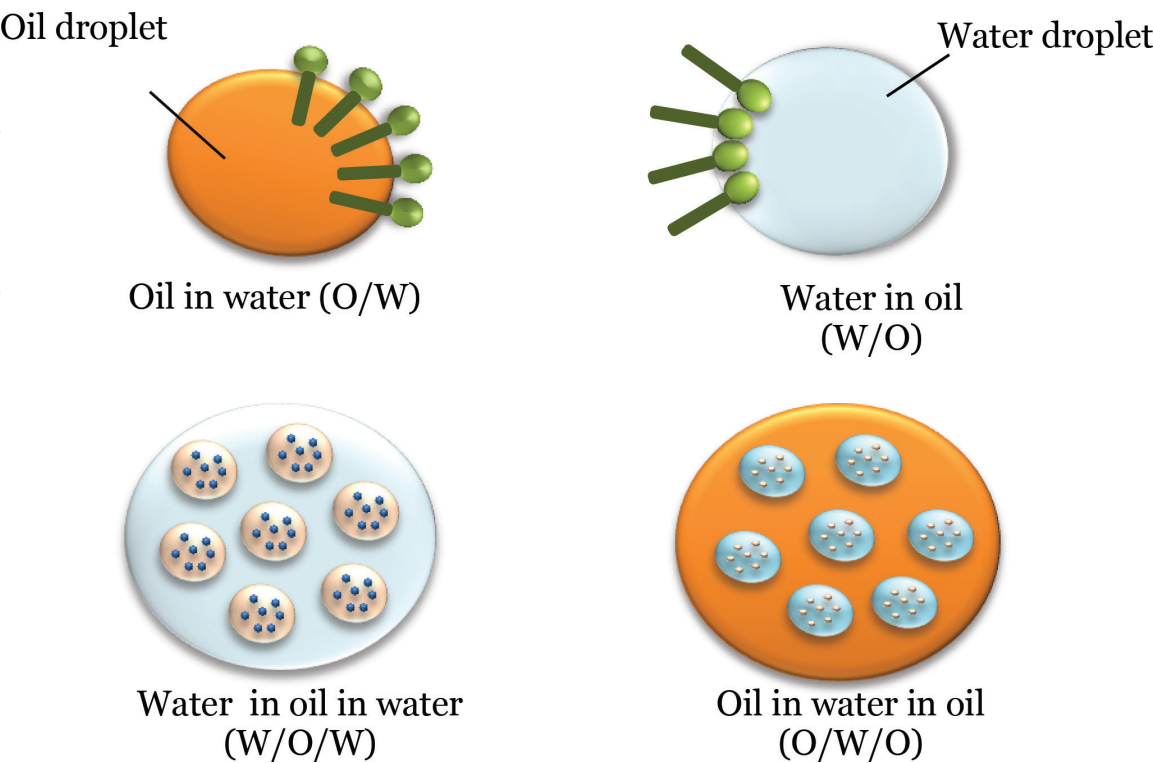


Figure 1.
Types of emulsions.

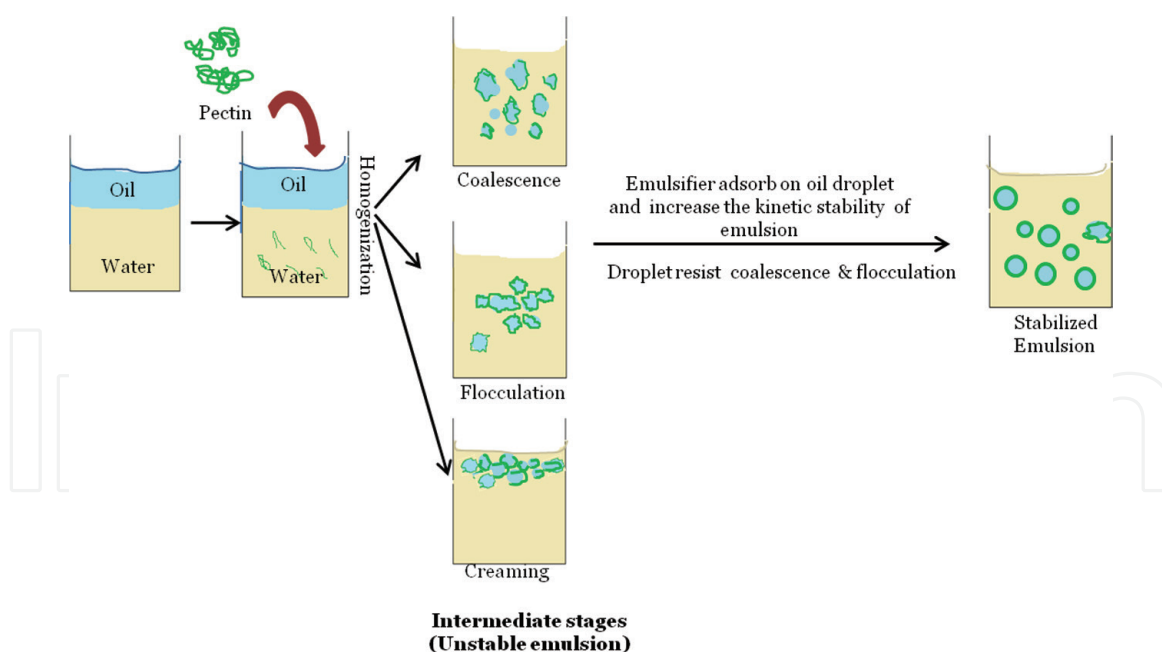


Figure 2.
Emulsion formation and stabilization using polymer as emulsifier.

food additives and consumer's demand for all natural food ingredients have necessitated the use of plant-based emulsifiers and stabilizers in food.

Pectin is a natural hydrocolloid which exhibits wide spectrum of functional properties. Because of the gelling ability of pectin, it is used as viscosity enhancer. During emulsification process, pectin molecules adsorb at the fine oil droplets from at O/W interface and protect the droplet from coalescing with adjacent drops (short-term stability). The quality of emulsifier is defined by its ability to provide long-term stability against flocculation and coalescence [27]. **Figure 2** depicts the stages in long-term emulsion formation using pectin as emulsifier. When the viscosity of the continuous phase is increased, the movements of oil droplets become restricted which improves the shelf life of emulsion [57]. In the past decade, some pectin has also been reported to exhibit surface active behavior in oil-water interface and thereby stabilizing the fine oil droplets in emulsion [42, 58]. These functions of pectin are determined by its source, structural modification during processing, distribution of functional groups in pectin backbone, and also by various extrinsic factors such as pH, temperature, ionic strength, cosolute concentration, etc. The emulsification or surface active properties of pectin, i.e., formation of fine oil droplets, are mainly contributed due to the high hydrophobicity of protein residue present in pectin [46, 59] and also by hydrophobic nature of acetyl, methyl, and feruloyl esters [42, 60], whereas emulsion-stabilizing ability is attributed to the carbohydrate moieties and their conformational features [61].

3.1 Mechanism of emulsion formation and stabilization

The mechanism of emulsion formation is shown in **Figure 3**. Different models explain the emulsion formation as covalently bound protein moieties in pectin are adsorbed onto the oil-water interface [46], form anchor points at the interface, and reduce the interfacial tension while the charged carbohydrate units extend into the aqueous phase [62] and stabilize by steric and viscosity effects in the aqueous phase (**Figure 3a**). Now, it is a well-established fact that pectin from different source shows variability in structure and protein contents. Leroux et al. identified many anchor points in sugar beet pectin (SBP) molecules [46], and proposed a loop-and-tail model (**Figure 3b**). According to the authors, only a limited amount of protein

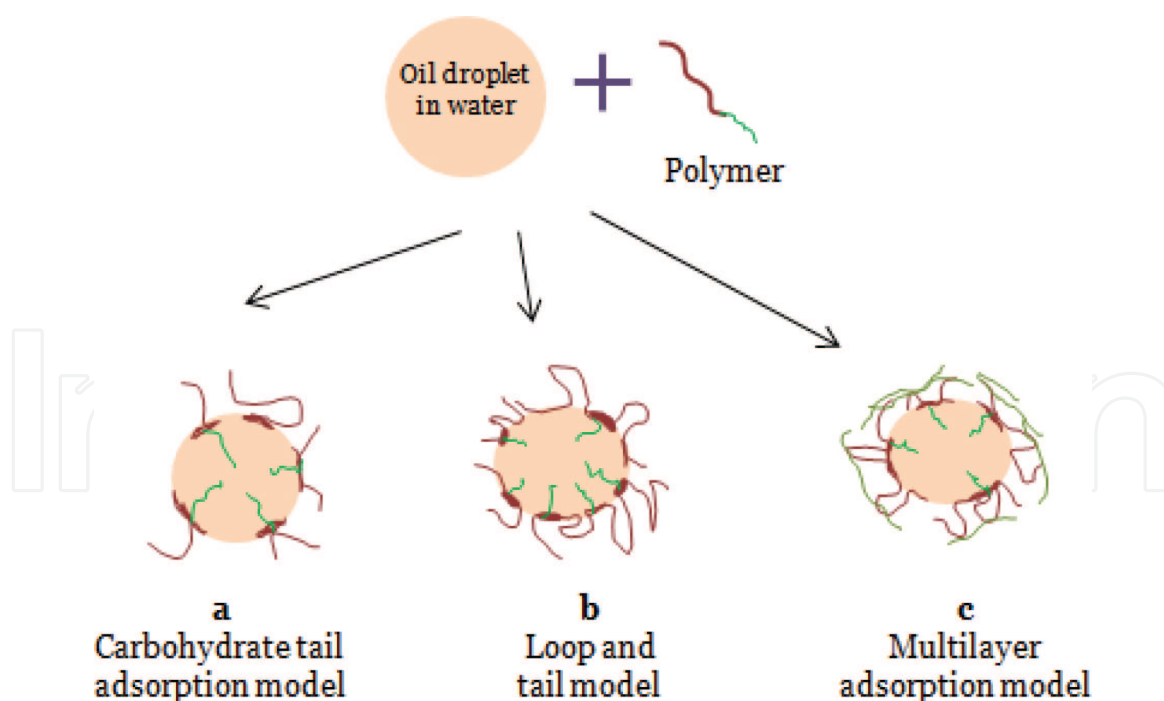


Figure 3.
 Different models showing pectin adsorption at oil/water interface during emulsion formation.

is adsorbed at the oil surface and acts as main moiety in the stabilization of the emulsion. This model was further confirmed by Siew and others [62]. The study was carried out to measure the thickness of the adsorbed SBP on oil-water interface layer, proposed a multilayer adsorption model (**Figure 3c**). Electrostatic interactions between the positively charged protein moiety and the negatively charged carbohydrate moiety were also reported.

Pectin O/W emulsion is generally stabilized through steric and electrostatic interaction. The carbohydrate moieties and neutral sugar side chains of RG I region of pectin confer the stability to the pectin emulsions through steric properties of the adsorbed polymers, when pectin is used as monoemulsifiers. In addition, pectin reversible association with galactan/arabinogalactan prior to emulsification also improves the emulsion stability [42, 63]. Electrostatic stabilization of emulsion is ascribed to sugar moieties and structural features of the HG units of pectin. If the pH of dispersion medium is above 3.5, nonmethylated carboxylic group of HG region gets ionized and confers charge on the pectin surface. Interaction of an ionic surfactant with oil droplets results in electrostatic stabilization [64]. Pectin viscosity also plays an important role in controlling the emulsion stability. HG region-rich pectin shows higher intrinsic viscosity ($[\eta]$); therefore, HG and RG ratio of pectin and molecular interactions that improve the intrinsic viscosity ($[\eta]$) of pectin solution also contributes in shelf life of emulsion [65, 66]. It has also observed that structural features of pectin such as pectin protein content, molecular mass, and presence of ferulic acid, and acetyl group in carbohydrate moieties of pectin also affect pectin's emulsifying and emulsion stabilization properties [15]. Williams et al. showed that ferulic acid-rich pectin did not show significant difference in emulsifying ability of pectin when compared with pectin poor in ferulic acid [67]. Digestion of sugar beet pectin (SBP) with acidic proteases resulted in formation of larger size of oil droplet, lower creaming stability, and loss of emulsifying activity of SBP which confirms that protein contents of SBP play an important role in emulsifying ability of the polymer [42]. Nevertheless, in other research, it was also found that protein-rich fractions of SBP did not necessarily displayed better emulsifying ability; therefore, it was concluded that both protein with carbohydrate

moiety together help in controlling emulsifying ability of SBP. Castellani et al. further suggest that both the carbohydrate and protein moieties function together as unit and affect the hydrophilic-hydrophobic equilibrium of the SBP molecule [68]. Therefore, when SBP is digested with proteases or other enzyme, a single moiety may function differently. Furthermore, it was also proposed that protein folding may also mask the hydrophobic effect of protein and thus affect the overall properties of the polymers [69].

Molecular weight of pectin has also been reported to affect the emulsifying capacity of pectin. Pectin with low molecular weight was more efficient in stabilizing small emulsion droplets than high-molecular weight pectin. However, very small size of citrus pectin had negative effect on emulsion-stabilizing ability of pectin. It could be due to the poor steric stabilization of depolymerized polymer [59].

3.2 Pectin-containing emulsion-based food

Emulsion-based food products can be defined as a network of pectin-protein molecules entrapping the oil droplet in between. Nowadays, a large number of pectin- and polysaccharide-based emulsified low-fat dairy products, meat products, spreads or desserts, bakery products, sauces, etc., are available in market. Low-fat and low-cholesterol mayonnaise, low-fat cottage cheese, low-fat drinking yogurt, and flavored oil-containing acidified milk drinks are the few examples of pectin-based emulsified products. These products are prepared by replacing full-fat milk from skimmed milk, emulsified oil, and whey proteins [70, 71]. A low-fat cheese was prepared using skimmed milk and water-in-oil-in-water ($W_1/O/W_2$) emulsified canola oil. Different emulsifiers such as amidated low-methoxyl pectins (LMP), gum arabic (GA), carboxymethylcellulose (CMC), and combinations of GA-CMC or GA-LMP were used to stabilize the emulsion. Textural characteristics and sensory evaluation of low-fat cheese show that polymers used to stabilize the emulsion affected both microcrystalline structure and organoleptic properties. The cheese prepared using GA and LMP was almost similar in textural characteristics to the full-fat milk cheese [72]. In another study, Liu et al. compared the textural and structural features and sensory quality of full-fat and low-fat cheese analogs prepared with or without the incorporation of pectin [71]. Microstructure analysis using scanning electron microscopy revealed that full-fat cheese was denser and contained higher concentration of fat globules than low-fat cheese made with or without pectin. Comparison within the low-fat cheese analogs showed clear difference in their hardness, gumminess, chewiness, and adhesiveness. Addition of pectin had positive effect on textural and sensory attribute and scored better in mouthfeel also.

Low-fat (Lf) mayonnaise was prepared by partial replacement of egg yolk and incorporation of pectin as emulsifier [73, 74]. Pectin weak gel, pectin micro-encapsulation, and whey protein isolate were used in preparation of low-fat (Lf) mayonnaise. Physicochemical and sensory properties of Lf mayonnaise were compared with full-fat (Ff) mayonnaise; Lf mayonnaise had low energy and more water contents than Ff. Textural features and rheological properties of the Lf and Ff mayonnaise were similar and both displayed thixotropic shear thinning behavior and categorized as weak gels. Moreover, Lf mayonnaise prepared using pectin had better acceptability than whey protein incorporation [75]. Emulsified oil is used as an effective delivery system of active compound in functional foods, and also serves as milk fat replacer in fat-free dairy products. To improve the nutritional value of food, low-fat dairy products are produced, whereas saturated milk fat is generally replaced with emulsified-unsaturated vegetable oils [76].

In recent year, pectin in combination with inulin has been reported to prepare low-fat meat batter. Méndez-Zamora et al. studied the effect of substitution of

animal fat with different formulations of pectin and inulin on chemical composition, textural, and sensory properties of frankfurter sausages [77]. Finding of the research showed that fracturability, gumminess, and chewiness of the low-fat sauces were slightly lower than those of the control. However, addition of 15% inulin improves the sensory properties. In a similar work, replacement of pork back fat with 15% pectin and 15% inulin was found effective in maintaining the physico-chemical properties and emulsion stability of the low-fat meat batter [78].

4. Pectin as gelling agent

The use of pectin in food products as a gelling agent is a long tradition. Later on, it was discovered that pectin forms different types of viscoelastic solution under suitable conditions. This property of pectin is commercially exploited in preparation of jams, jellies, and marmalades. Rheological behaviors of pectin depend on pectin source, its degree of methylation, distribution of nonmethylated GalA unit on pectin backbone, and degree of acetylation, and also on various extrinsic factors such as temperature, pH, concentration, and presence of divalent ions. At a constant pH, the setting time of pectin increases with decreasing DM and degree of blockiness (DB) in the absence of bivalent ions [79]. Therefore, on the basis of gelling process, pectin is classified as rapid, medium, and slow set pectin [80].

Gelling process of pectin and its stabilization follows different mechanisms for different types of pectin. HMP form gels in a narrow pH range (2.0–3.5) in the presence of sucrose at a concentration higher than 55% w/v in medium. During the gelatin process of HMP, junction zones are formed due to the cross-linking of two or more pectin molecules. These junctions are stabilized by weak molecular interaction such as hydrogen and hydrophobic bonds between polar and nonpolar methyl-esterified groups and require high sugar concentration and low pH [81]. These gels are thermally reversible. LMP can form gel over a wide pH range (2.0–6.0) independent of sucrose, but requires divalent ion, such as calcium [82, 83]. LMP follow the eggbox model for its gelation, where positively charged calcium ions (Ca^{2+}) are entrapped in between the negatively charged carboxylic group of pectin. The zigzag network of Ca^{2+} ion and GalA molecules looks like eggbox, and therefore, model is named as eggbox model [80]. These gels are stabilized by electrostatic bonds. In the presence of Ca^{2+} , calcium bridges are formed with pectin molecules that make the solution more viscous. At the higher pH, the ionic strength of the solution is increased and thus more Ca^{2+} is needed for gelation. In case of highly acetylated pectin such as sugar beet, acetyl groups cause steric hindrances and interfere with the Ca^{2+} ion and GalA bond formation, thus preventing gel formation. Kuuva et al. [84] reported that enzymatic modification in pectin structure, i.e., removal of acetyl groups using α -arabinofuranosidase (α -Afaes) and acetyl esterase enzymes, can improve the gelling property of acetylated pectin.

HMP are generally used in preparation of standard jams where sugar contents are above 55%, high-quality, tender confectionary jellies, fruit pastes, etc. LMP do not require sugar for its gelatin and therefore preferred choice for the production of low-calorie food products such as milk desserts, jams, jellies, and preserves, [28, 85]. LM pectins are more stable in low pH and high temperature conditions as compare to HM pectins and can be stored for more than a year.

5. Pectin in food packaging

Food packaging is one of the fastest growing segments of food industry. Traditionally, packaging system was limited to the containers and packaging

material to transport the food items from manufacturer to the retail market and then to the consumers. Such type of packaging was unable to contribute in the extension of the shelf life and maintenance of the quality of the products. Due to the globalization of food market and increasing demand of shelf-stable processed food that retains the natural properties of food, the need of functional/active packaging material is increasing. To meet the industrial demand, a number of polymers are being synthesized and used in food packaging because of their flexibility, versatility, and cost effectiveness. Although, synthetic materials are able to fulfill all the industrial needs and keep food fresh and safe by protecting them from abiotic factors such as moisture, heat, oxygen, unpleasant odor, and biotic components such as micro- and macroorganisms. But, disposal of nonbiodegradable packaging material is a serious problem which poses a threat to the environment. Therefore, more research has been focused on the development of biodegradable packaging for food packaging applications using poly(lactic acid) (PLA), poly(hydroxyalkanoates) (PHAs), starch, etc. [86]. Among all the natural polymers, polysaccharides are gaining more attention as they are versatile in nature and easily available in relatively low cost.

A variety of natural polysaccharides, such as pectin, chitosan derivatives, alginate, cellulose, seaweed extract, and starch are usually used in the preparation of edible films and coatings [87]. Pectin is one of the most significant renewable natural polymers which are the main component of all the biomass and ubiquitous in nature. Being flexible in nature, pectin and its derivatives are used in many biodegradable packaging materials that serve as moisture, oil, and aroma barrier, reduce respiration rate and oxidation of food [88]. Pectin along with food grade emulsifiers is also used in the preparation of edible films. These films are used in fresh and minimally processed, fruits and vegetables, foods and food products as pectin is the main component of the omnivorous diet and can be metabolized. Edible coating protects the nutritional properties of the food and also saves highly perishable food from the enzymatic browning, off-flavor development, aroma loss, retards lipid migration, and reduces pathogen attack during storage.

At low pH, LM pectins are cross-linked with calcium cations and form hard gels. These gels have highly stable structure and act as water barriers. Because of these properties, LM pectin films are used as edible coatings [88, 89]. Extension of shelf life of avocado fruits was also reported to over a month at 10°C by using edible pectin films. It was found that when avocados were coated with edible pectin films and stored at 10°C, rate of oxygen absorption and rate of respiration decreased which results in delaying of texture and color change of fruits [90]. Oms-Oliu et al. used calcium chloride and sunflower oil cross-linked with LM pectin films onto fresh-cut melon to see the effect on extension of shelf life of cut fruits [91]. It was observed that edible pectin films maintained the initial firmness, decrease the wounding stress of fresh-cut fruits, and prevent the dehydration during storage up to 15 days at 4°C but could not reduce the microbial growth onto the fresh melon. It has been observed that to reduce the respiration rate and to prevent the off-flavor development, different pectin and emulsifier formations are required for different fruits. Edible coating film formulation consisted on pectin, sorbitol, and bee wax was successfully used by Moalemiyan et al. to keep the fresh-cut mangoes in original state for over 2 weeks [92]. Whereas in a similar study, pectin coating containing sucrose and calcium lactate was able to prevent the fruits' respiration rate and maintain sensory properties in fresh melon fruits for up to 14 days storage at 5°C. In a similar study [93], pectin edible coating solution containing pectin (3%), glycerol (2.5%), polyvinyl alcohol (1.25%), and citric acid (1%) was prepared and applied on sapota fruits by dipping method and uncoated sapota fruits were used as control. Both the treated and control fruits were stored at $30 \pm 3^\circ\text{C}$. Physicochemical parameters namely, weight, color, firmness, acidity, TSS, pH, and ascorbic acid contents of

both the coated and control fruits were measured at regular interval up to 11th day of the storage at $30 \pm 3^\circ\text{C}$. Reduced rate of change in weight loss and other parameters were reported in pectin-coated sapota as compared to control fruits and it was observed that pectin film formulation was able to maintain good quality attributes and extend the shelf life of pectin-coated sapota fruits up to 11 days of storage at room temperature, whereas control fruits were edible up to 6 days. Furthermore, it was also observed that sapota fruits dipped in sodium alginate containing 2% pectin solution for 2 min were more effective in maintaining the organoleptic properties up to 30 days of refrigerated storage as compared to sapota fruits dipped for 4 min and untreated sapota fruits [94]. Bayarri et al. developed antimicrobial films using lysozyme and LM pectin complex. The main purpose of the study was to control the release of lysozyme in packaged food and to target lysozyme-sensitive bacteria such as *Bacillus* and *Clostridium*. It was observed that in the presence of fungal pectinase, due to the dissociation of pectin linkage, lysozyme activity of films increased remarkably. Many food-contaminating bacteria are pectinase producing and such type of films may be used to control food contaminants. These results have opened new avenues for custom-made biodegradable film [95].

In last few years, some researchers have focused on pectin-based coating containing edible essential to improve the antimicrobial properties and to enhance the efficiency of the pectin films. Edible coating formulation containing sodium alginate and pectin (PE) enriched with eugenol (Eug) and citral (Cit) essential oil at different concentrations was used to increase the shelf life of strawberries. Physical and organoleptic parameters of coated fruits stored at 10°C for 14 days show that formulation containing PE 2% + Eug 0.1%; PE 2% + Cit 0.15% was more suitable than sodium alginate-based formulations [96]. Pectin coating containing lemon and orange peel essential oils was reported to increase the shelf life and quality attributes of the strawberry fruits up to 12 days when stored at 5°C . It was also observed that fruits coated with pectin + 1% orange essence showed less weight loss and soluble solids as compare to their control during the storage [97]. Sanchís et al. studied the combined effect of edible pectin coating with active modified atmospheric packaging on fresh-cut “Rojo Brillante” persimmon. Persimmon fruit slices were coated by dipping in the pectin-based emulsion or in water as control. Both the treated and control slices were packed under 5 kPa O_2 (MAP) or under ambient atmosphere for up to 9 days at 5°C . Various parameters, such as package gas composition, color and firmness of slice, polyphenol oxidase activity, were measured during storage. It was observed that edible coating along with MAP significantly reduced the CO_2 emission and O_2 consumption in the packaged fruits. Furthermore, coating was also effective in controlling microbial growth and reducing enzymatic browning and maintains good sensory parameters up to 10 days on storage [98].

Drying is the traditional and oldest method of fruit and vegetable preservation. It decreases the enzymatic activity, reduces the moisture contents, and protects the food from microbial attack. However, drying results in loss of nutrients, vitamins, heat-labile enzymes, modifies the texture, color, and organoleptic quality of dried fruits and vegetables and therefore diminishes the market value also. Pretreatment of food products with pectin coatings containing other bioactive compound such as ascorbic acid, CaCl_2 , edible gum, etc., before drying or blanching has been proposed as an effective method to preserve the nutritional as well as organoleptic quality of dried food [99]. Recent researches have shown that application of pectin coating could protect the moisture and vitamin C loss in pretreated papaya slice and osmotic dehydrated pineapple. In one of the research [100], pineapple slice was pretreated with pectin coating formulation containing (50%)/calcium lactate (4%)/ascorbic acid (2%) solutions and then dried by hot-air-drying method. Physicochemical analysis of dried product showed less reduction in vitamin C

contents as compared to untreated pineapple slice. In a similar work, pectin coating supplement with vitamin C (1%) was used for precoating of papaya slice. It was found that incorporation of vitamin C did not affect the drying process. However, significant increase in vitamin C content was observed in final product [101].

Frying is a method of cooking that causes changes in chemical and physical parameters of food and enhances the taste. However, high temperature vaporizes the water of food and affects the nutritional properties due to protein denaturation and starch gelatinization. The oil uptake during frying is affected by various parameters such as type of oil used, frying temperature and duration, product moisture content, shape, porosity, prefrying treatment, etc. [102]. Surface area and pretreatment of products are the major factors that determine the oil absorbed. Edible coating has also been used successfully, to reduce the oil uptake during frying in various deep-fried products. Reduction in oil uptake and improvement of texture and quality of potato slices was reported by Daraei Garmakhany et al. in 2008. Authors found that coating of potato slices with pectin, guar, and CMC solutions can reduce the oil uptake when compared with nontreated potato chips [103]. Similar results were also obtained by Khalil, where a combination of pectin or sodium alginate with calcium chlorides significantly reduces the oil uptake of French fries. Coating formulation of 0.5% calcium chloride and 5% pectin was most effective in reducing the oil uptake [104]. Kizito et al. used different edible coatings (pectin, carboxy methyl cellulose, agar, and chitosan) at a concentration of 1–2% for pretreatment of potato chips, followed by deep frying of chips. Fried chips were analyzed biochemically and organoleptically to investigate the quality attributes of the products. It was revealed that all the coating polymers were successful in reducing the oil uptake but pectin was most effective and reduced oil uptake up to 12.93%, followed by CMC (11.71%), chitosan (8.28%), and agar (5.25%) and significantly improved moisture retention of strips ($p < 0.05$) [105].

6. Conclusion

The application of natural polymers in food industry is increasing day by day. Researchers are focusing more and more toward the pectin because of the ease-of-availability, structural flexibility, and versatile composition. Pectin can be sourced from a number of easily available horticulture crops (**Table 1**). Pectin is a hydro-colloid which is used as a food emulsifier, gelling agent, thickener, and stabilizer. It is the preferred choice of most of the food processors as fat or sugar replacer in low-calorie foods. In the recent years, increasing demand of ready-to-serve foods, fresh-cut fruits, and vegetable has opened a new market for edible films. Being biodegradable and recyclable, a lot of research is being done on pectin-based edible film formulations. These films reduce the exchange of moisture, gases, lipids, and volatiles between food and environment, and also serve as protective barrier for microorganisms.

Even though a lot of information is available regarding pectin structure and many pectin-based products are available in market, role of many carbohydrate moieties and their effect on various function of pectin are not yet well defined. Therefore, it is necessary to understand the structural-function relationship of pectin and its interactions for developing functional food products.

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Conflict of interest

The authors declare no conflict of interest.

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