CHAPTER III
LITERATURE REVIEW

3.1 Gum and mucilage

Plant gums are generally exudates from bark or soft stems of trees. The main component of gum is usually polysaccharides. The polysaccharide gums are synthesized by transformation of glucose and other sugars. Fractionation process shows discontinuities in structure and properties of gum and other complex heteroglycans which may be different among molecules by attaching of peripheral sugar units in core structure (18). The major composition of gum is polysaccharide substituted with arabinogalactan, galacturonan or glucuronomannoglycan (19). Thus, variation of aggregation (molecular weight) or peripheral unit ratio depends on plant species. The conservative structure of gum is glycosidic linkage between composing sugar units from a single species, so this structure affects on its functional properties. The component units compose of carboxylic acid, D- GlcA and D-GalA which is more than 40% of molecule GlcA proportions. Not only hydroxyl is substituted by acetate ester group but also hydroxyl with methyl of L-Rham, L-fructose, and 4-*O*- methyl-D-glucuronic acid are replaced by acetate ester (20). Gum is rich in L-arabinose under promoting hydrolysis condition decreased splitting of furanosidic linkages (21).

In conclusion, plant gums are polyhydroxylic. Monosaccharide units linked as glycosides are built by position attachment and anomeric configuration of hydrophilic and high, variable molecular weight compounds. Changing pH in spread medium (invariably water) affects binding mono- or divalent cation ability of gum, variation in solubility, viscosity and gel-forming ability. Thus, they may be hydrocolloids (22). The exuded materials are called gum (tacky) or mucilage (slimy). They are not only adhesive but also mucilaginous. Exudates from tree surfaces are defined as seed extractives or substances from bark or soft stems. Examples include okra (*Hibiscus esculentus*), psyllium (*Plantago* spp; Plantaginaceae, Scrophulariales), linseed (*Linum usitatissimum*; Linaceae, Geraniales) and ruredzo (*Dicerocaryum*

zanquebarium). All of these are acidic polysaccharides and a few are used in food preparations (23).

Food industry has used okra (gum or mucilage from pods of *Hibiscus* (*Abelmoschus*) *esculentus* Linn.) for a long time. Partial acid hydrolysis to give D-galactobiose and biouronic acid showed the pectic character of polysaccharide component (6). Before and after carboxyl reduction, a minor fraction from gas liquid chromatography analysis contains Rham, Gal and GalA in ratio of molar 1:3:1. GlcA was not detected. Moreover, the solubility and rheological properties depends on the DAc of the neutral sugar units in the polysaccharide (23).

3.1.1 Rheology and solution properties

When gum dissolved or dispersed in water it provides gel or viscous dispersions. Hence, the hydrophilic gums are efficient in food functionality or other applications. Factors which affect the property of gum solution are molecular interactions with water and other solutes. Moreover, the main structure of gum comprises the large molecular size, specific configurations and conformations, the density and distribution of charges and of polar groups capable of forming hydrogen bonds. All of these factors affect on inmobilization of water. Besides, the large molecule shape of gum exudates depends on degree of branching, hydrogen bonding site including hydroxyl group distribution on structure and polyelectrolyte character which identified specific charged groups on uronic acid residue (23).

The viscosity of gum is the important function of gum in food products when used as stabilizer and fat replacer (24). The factors affecting its viscosity are temperature, pH, the concentration of hydrocolloid and other solutes and interaction of electrolytes and other hydrocolloids which control the intermolecular interactions. Furthermore, some gum solutions are Newtonian systems of which viscosity does not depend on shear rate. Most gum solutions show pseudoplasticity or shear thinning i.e. when increasing shear rate, viscosity decreases. The degree of Newtonian behavior of gum solution relates to type of mouthfeel as slimy or sticky (coating the mouth). Moreover, gum helps perception of flavor and aroma because of increasing vapor pressure of volatile constituents in food from water immobilization. Not only gum provides the viscosity it also forms gel in food systems giving chewy (weak gels) to

brittle (hard gel) texture. Besides, when swallowing, the hydrocolloid helps rough-textured foods to be smoother (23).

In Africa and Asian countries, acidic mucilage is used to provide slimy consistency to soups and stews (5). The interesting raw material is okra pods. Okra mucilage solutions give viscosity at concentrations as low as 0.5%. Even though it is slightly shear-thinning, okra solution was determined as Newtonian systems under these conditions related to their slimy mouthfeel (25). When the concentration increases to 1% the viscosity increases rapidly and at higher concentration when okra mucilage is dissolved in water at room temperature, it needs maceration. However, about 80% of native mucilage may be solubilized in $NaBH_4$ solution. Solubility improvement can be achieved by heating but viscosity of solution is irreversibly lost. The solution with 0.5% concentration of native mucilage provides a maximal viscosity at pH 6-9 (26).

3.1.2 Food application

Mucilage is used as a thickening agent to give a perceived texture in food products. Furthermore, an interesting function of gum solution is stabilization of two-phase dispersions. Stabilization relates to solid particles sedimentation or suspended droplets, rise of gas bubbles, and encounter between particles, droplets, or bubbles which causes flocculation of coalescence. Gum promotes maintenance of immiscible phase. Moreover, stabilizing of emulsions, suspension and foams function happen when increasing viscosity of aqueous phase (23). Thus, dispersed globules or particles inhibit coalescence, flocculation or sedimentation. Notably, a low concentration of gum is the most efficient of viscous dispersions. Besides, in fruit drinks and pie fillings gum is added as a suspending agent for insoluble solids (27). Some products such as milk shakes and whipped toppings use gum in stabilization of foams whereby surface tension of liquid phase is decreased and viscosity is increased by gum.

3.2 Pectin

Pectin is a polysaccharide located in the primary cell walls and intercellular regions of higher plants as shown in Figure 3.1 (28). The important role of pectin in the middle lamellae of primary cell walls is cementing material (29). Pectin composes of polysaccharides rich in GalA units and various neutral sugars. Moreover, it is present in many fruits and vegetables such as orange, lemon, apple and sugar beet. Its contents and qualities depend on the types of plant, fruit maturity and method of extraction. In food processing industry pectin has been used as a gelling agent and a thickening agent (30).

3.2.1 Chemical structure of pectin

The pectin structure is mainly α (1→4) linked D- GalA units which are different in the proportions of the acid groups. The acid groups in pectin are partially replaced with methyl esterification of the carboxyl groups. Besides, other components include neutral sugars such as arabinose, Gal, Rham and xylose (31, 32). The types of neutral sugar in pectin depend on the types of plant. Pectin from apple, citrus, cherry, strawberry, carrot, pumpkin, sugar beet, potato, onion and cabbage shows similar neutral sugar composition (33).

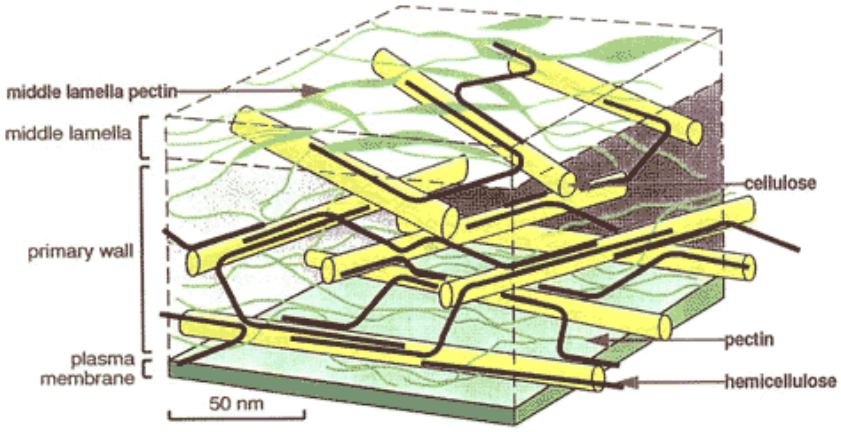

Figure 3.1 Plant cell wall structure (34)

In contrast to pectin from mountain pine pollen, Japanese kidney beans and duckweed, which contains large amounts of xylose or apiose (33). The structure of pectin comprises 2 regions which are smooth region and hairy region. The smooth region or backbone is α-(1→4)-linked D- GalA acid units called homogalacturonan (HGA). Some HGA interrupted by (1→2)-linked L-rhamnopyranosyl residues are also found in the backbone. The hairy region composes of neutral sugar side chains such as D-Gal, L-arabinose and D-xylose. Moreover, the hairy region contains both rhamnogalacturonan I (RG-I) and rhamnogalacturonanII (RG-II) structure. (Figure 3.2) (30).

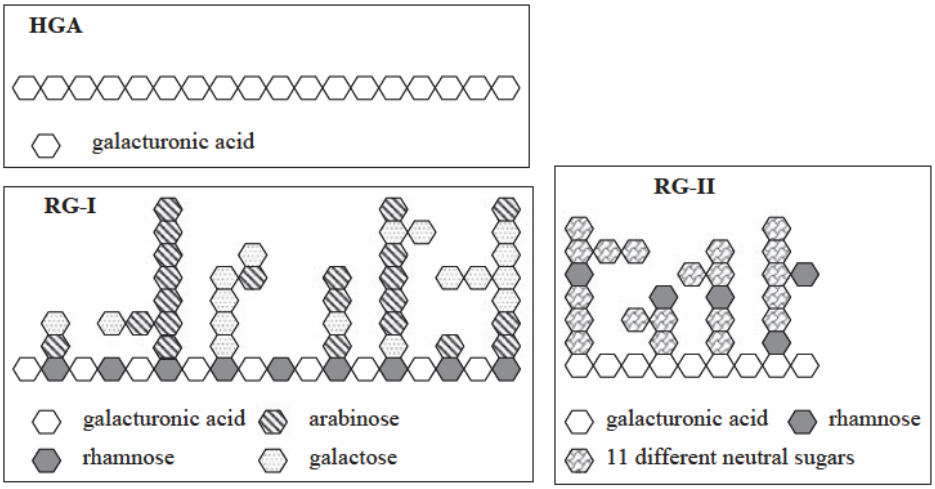

Figure 3.2 The homogalacturonan (HGA), rhamnogalacturonan I (RG-I) and rhamnogalacturonan II (RG-II) (30)

In addition pectin also contains non-sugar substituents such as methanol, acetic acid, phenolic acid and amide groups. Some carboxyl groups on GalA units may also be esterified at the O-2 or O-3 position with acetic acid, and with methyl group at C-6 of GalA (Figure 3.3). The ratio of methyl esterified galacturonic acid groups to total GalA groups is termed the DM. The DM is a very important structural characteristic of pectic substances. In plant the more ruptured the cell wall and the more mature the plant, the lower DM (30, 32).

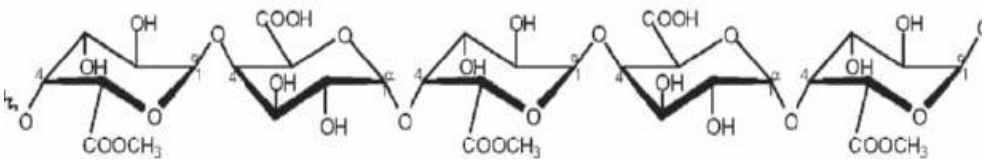

Figure 3.3 A partly methyl-esterified galacturonic acid unit (30)

Furthermore, the GalA units can be *O*-acetylated at C-3 and occasionally at C-2. The percentage of galacturonosyl residue esterified with one acetyl group represents the DAc. Acetylation is found in some plants such as potato tubers (35) and sugar beet roots (36).

3.2.2 Commercial pectin

Commercial pectins contain at least 65% by weight of GalA-based units. They are water-soluble pectin which has high molecular weight and specified DM and DAc for gelling at specified condition. In an extraction with hot acidic condition for commercial pectin, RG-I and RG-II domains are removed and the neutral sugars are hydrolyzed. Thus, the commercial pectin mainly composes of the homogalacturonic backbone with 75% of galacturonan groups being methyl esterified (32). There are two types of commercial pectin which are high methyl ester (HM) and low methyl ester (LM). HM has the DM greater than 50%. Normally, most of HM has DM about 55–75% and LM has DM less than 50%. In addition, treating pectin with ammonia to convert some of the C-6 methyl ester groups to amide groups results in amidated LM pectin. The degree of amidation (DA) is defined as the ratio of amidated galacturonic acid groups to total galacturonan units.

a) Raw material for pectin production

Raw materials for pectin production are chosen with consideration regarding sufficient quantity and quality. Normally, by-products such as dry apple pomace obtained from apple juice manufacture, wet or dry citrus pomace obtained after the extraction of citrus juice and sugar beet pulp from the refined sugar industry are used in pectin production. Moreover, new interesting sources are such as sunflower pectin (37), potato fiber and the residue of starch production. Besides, in the third world countries potential raw materials including onion skins, tobacco leaves, the

residues of mango, guava, papaya, coffee, okra and cocoa processing, are being investigated (38, 39, 40).

b) The extraction

Pectin extraction methods have been developed to get conditions which suit the raw material. Almost all procedures of extraction relate to physical and chemical processes to get a concentration of high molecular weight pectin. The common method is extraction with hot aqueous acid followed by filtration and precipitation in alcohol (Figure3.4). The acid extraction helps pectin to be released from the cell wall matrix and the high temperature reduces viscosity to ease filtration. Low pH, high temperature and long period of treatment lead to the high yield of pectin. However, these conditions cause de-polymerization and methyl de-esterification of the pectin. Thus, many factors such as extraction time, temperature, pH and the ratio of raw material to aqueous acid should be optimized to get the high yield, gelling capacity and desired DM. Typical extraction conditions are in the range of 50–90 °C for 3–12 h at pH 1–3 (30). Dried apple pomace and citrus pomace are extracted at the ratio of pomace to water being 1:15 and 1:35, respectively. The extraction conditions are pH 1.5-3, 60 – 100 ° C and 0.5 – 6 hours. Rapid set pectins (DM>70%) are essentially extracted at pH 2.5 and 100 °C for 45 min. On the contrary, slow set pectins (DM 60-70%) are extracted at lower temperatures and longer time of extraction because de-esterification occurs faster than de-polymerization at lower temperatures. The finally products usually have 0.3 and 0.5% pectin (32) and the color of pectin is white (citrus) to light brown (apple).

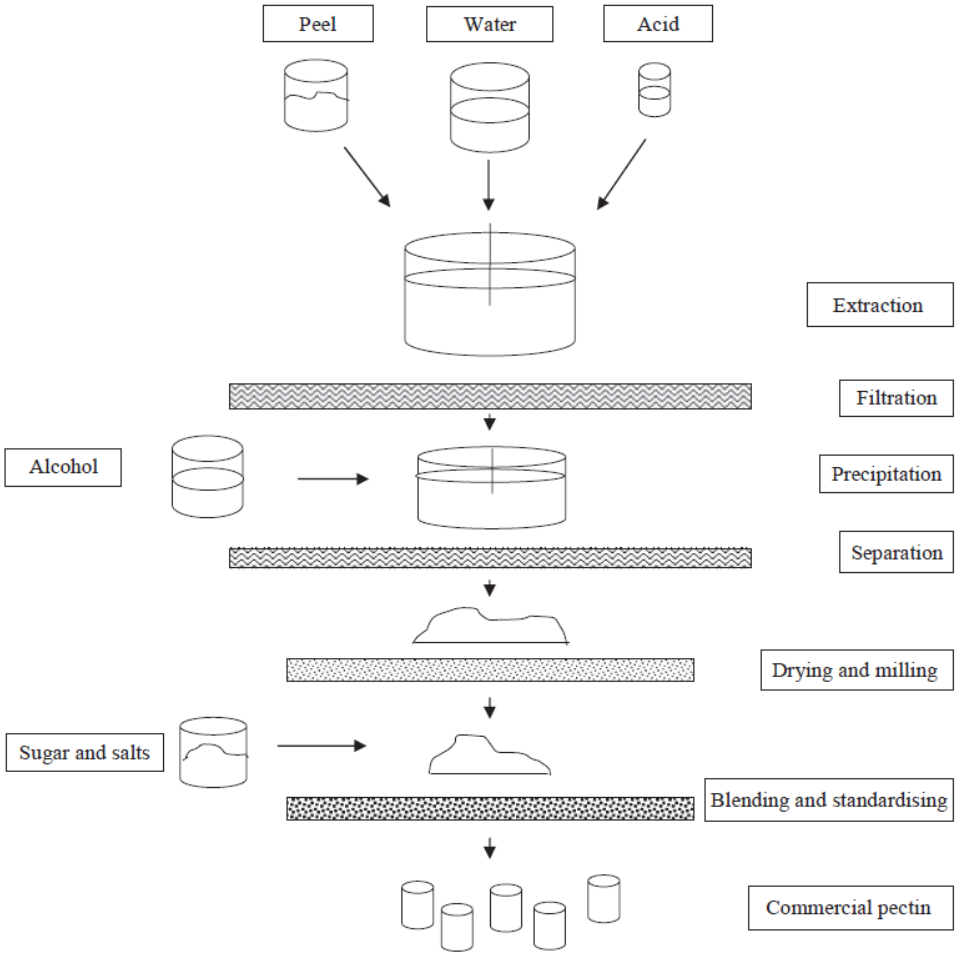

Figure 3.4 Typical production process for commercial pectin (30)

3.2.3 Chemical properties of pectin

a.) Acid properties

In general pectin presents negative charge at neutral pH and when pH decreases, the charge approaches zero. Its property is a weak acid with polyelectrolyte behavior. p*K*a of pectin depends on degree of dissociation of the carboxylic groups on the homogalacturonic backbone. Normally p*K*a is obtained in the range of 2.9–3.3, close to the p*K*a for GalA which is 3.5 (32,41). Pectin is used in acidified milk drinks because its negative charge reacts with positively charged polymer of proteins.

b.) Stability

De-esterification and de-polymerization of pectin may rapidly occur when it is kept in unsuitable conditions of pH and temperature**.** The optimal stability of pectin is obtained at pH 3.5–4.0 and it is degraded outside this range and at high temperatures. The β-elimination happens in neutral and alkaline conditions where homogalacturonic backbone is de-polymerized. As a result of *β*-elimination at glycosidic bonds of C-4, the methylated galacturonic acid units are separated resulting in reducing of the molecular weight (Figure3.5).

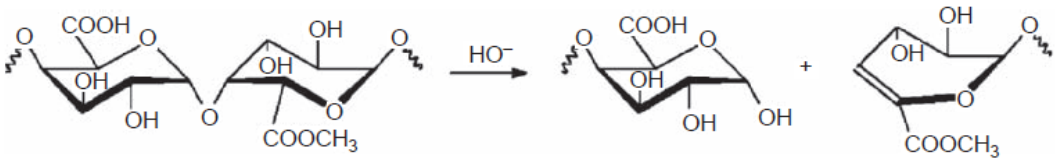

Figure 3.5 De-polymerization of homogalacturonic backbone (30)

De-polymerization of the pectin backbone occurs at pH 5 and β-elimination is found in HM pectin more than LM pectin. Splitting of methyl ester and acetyl groups by saponification and hydrolyzing neutral sugars occur in acidic condition. Moreover, elimination of glycosidic bonds in the pectin backbone occurs quickly when the temperature increases. In general pectin solutions are stable at 20 °C. At higher temperature the stability of pectin depends on pH. Nevertheless, both pH and temperature affect the stability of pectin as shown in Figure 3.6 which shows that the molecular weight of HM pectin decreases at higher pH and temperature (30).

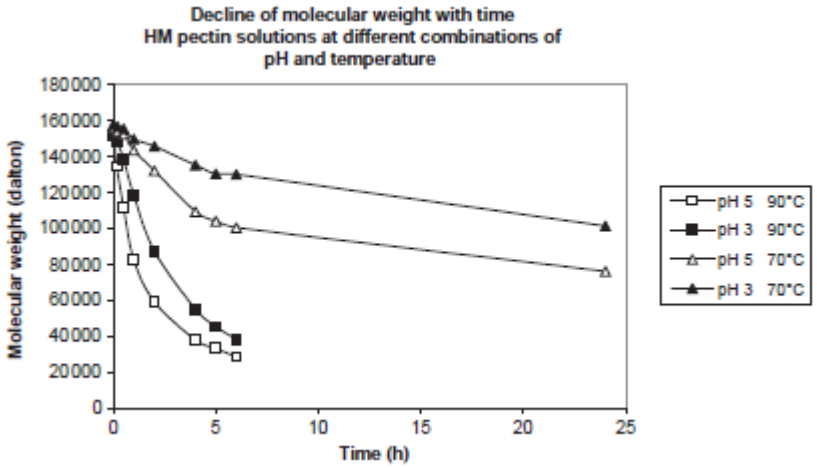

Figure 3.6 Effect of pH and temperature on the stability of high methyl-esterified pectin solutions (30)

c.) Solubility

There are many factors affecting the solubility of pectin such as soluble solids, types of counter ion, ionic strength, pH and temperature. Pectin is a hydrophilic compound, so it is soluble in water. It is not able to dissolve in alcohol and non-polar solvent. However, pectin forms lump when it is added into water making it difficult to be dispersed in a solution. For example, pectin solution with concentrations above 3-4% could be made homogeneous by a high-speed mixer because dispersion is hindered by higher viscosity. Viscosity of concentrated pectin solution is decreased when shear rate increases which shows the non- Newtonian behavior. LM pectin backbone bound electrostatically with monovalent ions such as sodium and potassium but gelling of LM pectin in the egg-box model relates to divalent cations. In addition, pectin can be soluble in high levels of soluble solids condition and small amount of salts (30).

d.) Rheology

Pectin provides viscosity to solution as other water-soluble polymers. The concentration of pectin influences viscosity. Thinning and non-Newtonian properties are found in concentrated pectin solution but at lower concentrations (<0.5%), pectin exhibits Newtonian behavior. Moreover, pectin solution recovers its viscosity after stopping or reducing the shear rate. The viscosity of pectin solution also depends on type of pectin, solvent, pH, temperature and the

presence of salts. Pectin which has a high molecular weight and rigid molecules gives the higher viscosity than lower molecular weight and compact molecules. In tertiary structure, ionic strength influences viscosity. Increasing ionic strength lowers viscosity of pectin by charge shielding of pectin chain (32, 41).

3.2.3 Gelation

Another interesting property of pectin is gel forming and gel strength which increases with higher molecular weight. Pectin gelling depends on DM. LM pectin forms gel at a low soluble solid content with the presence of calcium, while HM pectin gels in a high sugar and acidic condition.

a.) HM pectin gelling mechanism

Optimal gelling condition of HM pectin is low pH and low water activity. In general, the soluble solids content should be in the range of 55% - 85% and the pH has to be between 2.5 and 3.8 (acidic condition). In this mechanism pectin-pectin interactions are promoted by high content of soluble solids i.e. low water activity condition than pectin-solvent interactions. Moreover, dissociation of carboxyl groups decreases at low pH, so electrostatic repulsion is decreased. HM pectin gelling bases on hydrogen bonding which comprises bonding between non-dissociated carboxyl groups and secondary alcohol groups (42) and interactions of hydrophobic molecule with methyl ester group (43). If the degree of esterification is increased and pH is reduced, gel forming is promoted by this condition. The gelling mechanism occurs on hydrogen bonding between non-dissociated carboxyl groups and secondary alcohol groups together with hydrophobic interactions between methyl ester groups. Junction zone (highlighted in boxes) is the area where the interactions between the pectin polymers occur as shown in Figure 3.7.

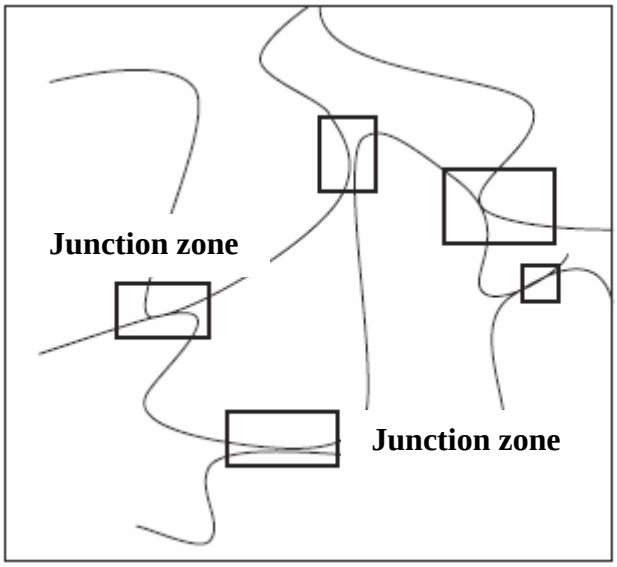

Figure 3.7 Gelling mechanism of high methyl-esterified pectin (30)

Furthermore, commercial HM pectin is divided to 5 types depending on setting time and temperature. There are ultra rapid set, rapid set, medium rapid set, slow set and extra slow set pectin. The degree of esterification of ultra rapid set pectin is between 74%-77%, while that of extra slow set pectin is 58%-60%.

b.) LM pectin gelling mechanism

Gelling condition of LM pectin is different from HM pectin. It gels in the presence of calcium which can be explained by the egg-box model (44) in Figure 3.8. In the egg-box model, the main chain of pectin has two-fold symmetry, thus series of electronegative gaps are formed by different affinities between divalent cations and pectin molecule. Dimers of polygalcturonic chains are formed by ionic interaction between cations and free carboxylic groups on pectin structure. The lower degree of methyl esterification helps to promote gel forming. However, pectin gel is sensitive to higher calcium content (45).

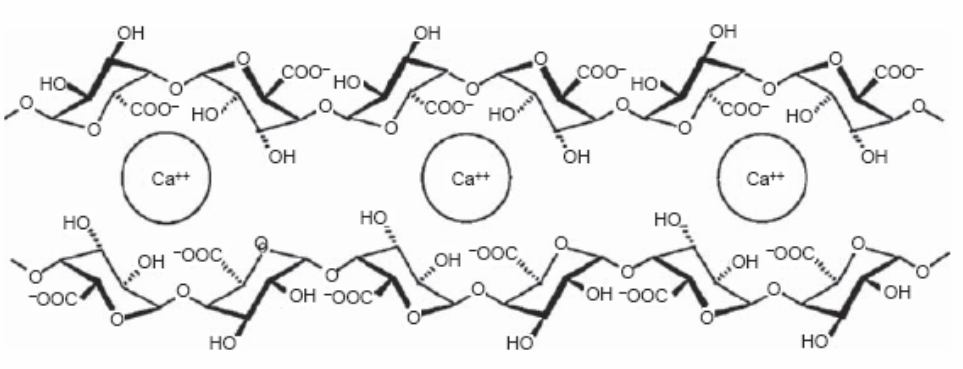

Figure 3.8 The 'egg-box' model illustrating the gelling mechanism for low methyl-esterified pectin (30)

Besides, LM pectin gelling mechanism depends on the distribution of esterified carboxylic groups. Differing in arrangement of non-esterified carboxylic acid molecule gives pectin with differences in gelling properties and setting temperature (45).

3.3 Determination of galacturonic acid

The cell wall of fruits and vegetables contains GlcA and 4-*O*-methylglucuronic acid. Polysaccharide rhamnogalacturonan has GalA in the form of uronic acid. Colorimetric procedures are employed for the quantitative measurement of total uronic acid by the carbazole reaction. Yield products react with carbazole resulted from sugars heated with concentrated sulfuric or hydrochloric acid. For example, Dische (46) reported the determination of uronic in sulfuric acid using carbazole but it was interfered with the presence of neutral sugars. In the modified method by Gregory (47) and Bitter and Muir (48), borate was added in the sulfuric acid mixture in heating step to increase color production. However, the results were still interfered by neutral sugars. In 1967, Galambos (49) further modified the heating step with addition of sulfamate before heating. Sugar interference problem was solved by sulfamate but precipitation tended to occur. Adding of sodium tetraborate in sulfuric acid was tested in the modified method of Blumenkrantz and Asboe-Hansen (50) in which the color reagent used was *m*-hydroxydiphenyl instead of carbazole. The result was still interfered by neutral sugars. Filisetti-Cozzi and Carpita (51) improved

the determination of uronic acid by using sodium tetraborate in sulfuric acid and *m*-hydroxydiphenyl. Sulfamate was incorporated into the mixture. Nowadays, this colorimetric method is the method of choice because it can measure uronic acids in the presence of up to 10 times the weight of neutral sugars. Furthermore, precipitation of neutral sugars was inhibited by sulfamate and the sensitivity of the reaction was increased by tetraborate (52).

3.4 Average molecular weight determination and intrinsic viscosity

Molecular weight is one of the most important characteristics in determining the functional behavior of pectin. Pectin is highly heterogeneous with respect to molecular weight. The factors affecting molecular weight distribution of pectin include plant source, ripening stage and condition of extraction. In addition, most plant gum polysaccharides are identified as polydisperse, so molecule size and composition are determined in form of an average value. Besides, the rheological properties affect the molecular weight of gum polysaccharides and pectin. Thus, gums and pectin study usually involves determination of an average molecular weight. Different methods give different types of the average value obtained. Osmometry gives number-average molecular weights ($\overline{M}_n$) while isothermal give $\overline{M}_n$ < 20,000. Furthermore, a light-scattering or sedimentation-equilibrium technique determines weight averages ($\overline{M}_w$). In addition, the preferred methods are viscosity measurements. These methods are used to estimate average molecular weights. If molecular weight is independent of the methods and polysaccharides are homogeneous fractions, the Mark Houwink-Sakurada equation relates intrinsic viscosity [η] to average molecular weight ($\overline{M}$). Intrinsic viscosity determines viscosity at a low concentration of solute using a relationship derived by Kravtchenko and Pilnik (53).

3.5 Determination of substituents

3.5.1 Methoxyl content

The DM of pectin can be calculated from the methoxyl and GalA contents. The DM is most commonly determined by the titration or copper-binding method that is also used for analysis of GalA. In addition, IR and ^{13}C-NMR spectroscopy have been used for determining DM. These methods are simple and fast. However, most gum and pectin have high viscosity of their solution in water (D_2O) making it difficult to apply (54, 55).

3.5.2. Acetyl content

Acetyl content can be determined conveniently by GLC (56), HPLC (57), or distillation and titration after alkaline saponification and acidification (58).

3.5.3 Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy is used to monitor chemical changes in pectic substance, especially degree of esterification (DE). The method is simple, fast, using smaller amounts of samples and non-destructive to samples. The determination of DE was developed by various authors. Attenuated total reflectance spectroscopy (ATR) was used in the methods of Barros *et al*. (59). While diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) technique was used by Gnanasambandam and Proctor (60) and Monsoor *et al*. (61). However, both methods could not determine mixture or unpurified pectin samples. They are used for pure samples because many overlapping peaks may occur in spectral region (1750–1600 cm^{-1}). These peaks are identified as the degree of esterification, so this spectral region is deconvoluted. In addition, both methods determine degree of esterification in the limited range between DE 28.5 - 93.0% and 26.2 - 76.2%, respectively. Recently, FTIR becomes a preferred technique for determining the DE due to its ease of use (62, 63). Furthermore, the absorption of the different types of functional groups involved (i.e. the methyl ester carboxylic group and the carboxylate group) are located at different wave numbers.

Table 3.1 FT-IR spectrum of pectin: wave numbers and intensities of functional groups

Wave number (cm^{-1})	Functional groups	Intensity	Appearance	Vibration mode
3600–2500	O–H	Strong	Broad	Stretching
3000–2800	C–H, Symmetric, Asymmetric	Sharp	Occasionally double overlapping with O–H,	Stretching
1760-1730	C=O, Esterified	Strong		Stretching
1630–1600	COO-	Strong		Stretching
1400	COO	Weak		Stretching
1380	C–H	Weak		Bending
1300 - 1000	C=O	Weak		Stretching

Adapted from Gnanasambandam and Proctor (60) and Filippov (62).

3.6 Applications in food systems

Pectin has many beneficial properties in food industries. It is used as a gelling agent in jams and jellies. One important property of pectin is gel forming which depends on DM. HM pectin forms gel at low pH and high sugar condition by combination between hydrogen bonding and hydrophobicity which is irreversible upon heating. Gelling of LM pectin occurs at low sugar levels in the presence of calcium resulting in a heat-reversible gel. LM pectin is used for glazing in jams and jellies and retorting, microwaving, sterilization or pasteurization. Pectin is added to form gel in concentrations within the range of 0.5 to 2.5% (38). In acid products low concentration of pectin is used while higher concentration is used in nonacid products with calcium-sequestering salts. In addition, another application of pectin is as a thickening agent. HM pectin has a thixotropic behavior to give the mouthfeel in food system such as freshly squeezed orange. Besides, HM pectin inhibits aggregation of casein on heating in dairy products such as acidified milk products, drinkable yoghurts, blends of milk and fruit juice and acidified soybean milk products.

Furthermore, stabilizing properties of pectin is useful in multiphase systems for stabilization of emulsions, suspensions and foams. HM and LM pectins have both thickening and stabilizing properties. They are used in mayonnaise, salad cream, tomato ketchup, protein foams, cloudy juices and beverages and in ice cream (39). Moreover, pectin is used as an emulsifying agent by formation of protein-polysaccharides complexes because protein alone is not able to give stable emulsion. In addition, pectin is a dietary fiber which does not provide energy, so it is used in low-calorie products with high nutritional value. Furthermore, pectin having acetyl groups inhibits pectin gelling. This property is useful in an emulsifier and a stabilizer because hydrophobic molecule is improved by acetyl groups. Thus, pectin not only provides viscosity but also acts as an interfacial agent in oil/water and air/water systems (64). For example, sugar beet pectin has low gelling properties but it has high water-holding capacity and low viscosity. Low methoxyl pectin from sunflower head is efficient in water-holding capacity and high viscosity.

3.7 Okra (*Abelmoschus esculentus* L. (Moench))

Okra *Abelmoschus esculentus* L. (Moench), is a vegetable which is grown in many parts of the world, especially in Africa. The okra plant grows well in warm climate areas such as Asia, Middle East and Western Africa. The appearance of okra pod is about 5-10 cm in length with long curve shape. The immature pods of okra are harvested for eaten as a vegetable. There are many ways to cook okra fruit. In Middle, Western and part of Eastern Mediterranean, okra is widely used as a thickening agent in stews. Moreover, okra is popular in South India. It is added to gravy-based preparations. In Japan, it is brought into Japanese cuisine since the end of the 20th century and it is eaten as tempura and served with soy sauce and katsuobushi. In the southern United States , okra is cooked by breaded and deep fried (65). Very commonly, blanched okra pod is eaten with chill paste in Thailand.

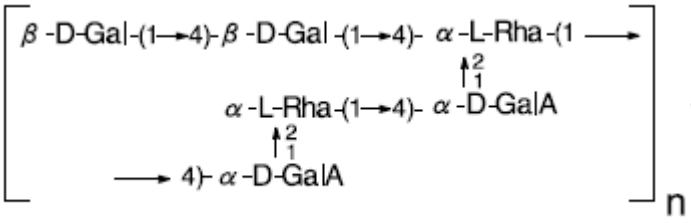

Figure 3.9 Structure of okra polysaccharide (66)

Okra contains many necessary nutrients such as calcium, potassium and other minerals which are found lacking in certain population of developing countries (67). The composition of edible portion of okra is given in Table 3.2. Medicinal benefits of okra have also been recorded. It was used against genito-urinary disorders, spermatorrhoea and chronic dysentery (68). Moreover, it was used in curing ulcers and relief from hemorrhoids (69). In addition, the main component of okra is dietary fiber which was reported to demonstrate medical benefits in controlling blood pressure and reducing the risk of cardiovascular disease.

Okra mucilage contains mostly polysaccharide and protein. The polysaccharide from okra mucilage composes of approximately 40% Gal, 27% Rham, and 24% GalA and protein is less than 4% (70). It has the repeating structure of (1→4)-*O*-α-(D-galactopyranosyluronic acid)-(1→2)- *O*-α-L-rhamnopyranose ((α1→4) GalA)-(α 1→2) Rha) in its hexasaccharide repeating unit of its main chain as shown in Figure 3.9 (71). A repeating unit of α –(1,2)-linked rhamnosyl and α-(1,4)-linked galacturonosyl residues and dimeric β-(1,4)-linked galactan side chains which was substituted to O-4 of half of the rhamnosyl residues was obtained in okra polysaccharide extracted with cold water and purified by 10% chelating agent solution (72).

Table 3.2 Composition per 100 g of edible portion of okra

Moisture	89.6 g	Minerals	0.7 g
Protein	1.9 g	Carbohydrates	6.4 g
Fat	0.2 g	Calcium	66 mg
Fibre	1.2 g	Iron	0.35 mg
Calories	35	Potassium	103 mg
Phosphorus	56 mg	Thiamine	0.07 mg
Sodium	6.9 mg	Nicotinic acid	0.6 mg
Sulfur	30 mg	Vitamin C	13 mg
Riboflavin	0.1 mg	Magnesium	53 mg
Oxalic acid	8 mg	Copper	0.19 mg

Adapted from Gopalan *et al.*, 2007 (73)

Okra mucilage extracted with water by using heat at 80 ºC for 10 min gave the higher yield than without using heat. Moreover, okra mucilage powder was reported to be very hygroscopic due to rapid moisture pick-up from the environment (74). Rheological property of okra polysaccharides is given as pseudoplastic and viscoelastic behavior (5). The highest viscosity of okra polysaccharide extracted with water was found in the range of pH 4-6 (75). Besides, okra polysaccharide solution heated to 90 ºC showed the decreased viscosity. However, cooling the solution increased back the viscosity (12).

Okra mucilage was applied in food products as a fat replacer and a thickening agent. For example, okra gum was used as fat-ingredient substitute in a fat-free chocolate bar cookies, chocolate frozen dairy with accepted sensory characteristics (76) and okra mucilage powder was used as a fat replacer in chocolate brownies to obtain a softer and tendered texture (74).