

CHAPTER 2

Literature Reviews

2.1 Coffee and By-products of Coffee Industry

2.1.1 Coffee

Coffee is the world most popular beverage prepared by roasted and ground coffee beans. Most popular consumed coffee beverage is produced by two species; Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*). But, due to superior sensory property, Arabica coffee dominates the worldwide production (Sunarharum *et al.*, 2014). Coffee is not only known as a stimulant (mostly from caffeine), but also a functional drink due to various phenolic compounds (Bonita *et al.*, 2007).

The coffee fruit or coffee berry, depicted in Figure 2.1, consists of smooth and tough outer skin. The color of the skin is green when unripe, but turns red or yellow (depending on genotype) when ripe. The next yellowish fibrous layer called pulp is followed by the thin colorless viscous layer of mucilage that mostly consisting of pectin. This layer covers thin yellowish color parchment which covers the two hemispheres of coffee bean. In each hemisphere, there is a tough translucent layer of silver skin covering around the bean separating the two hemispheres.

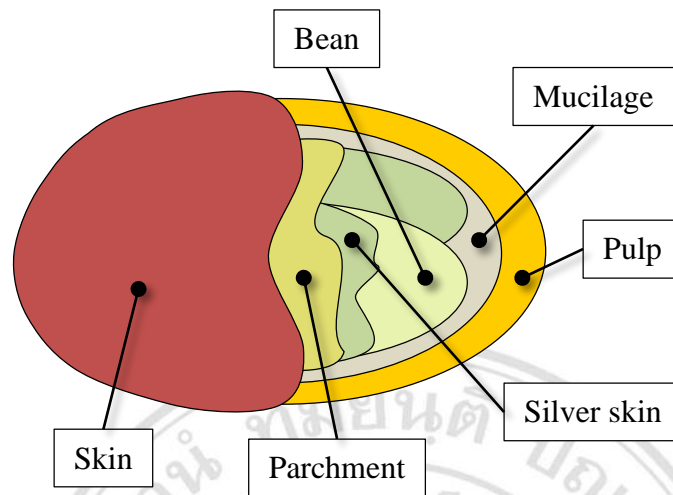


Figure 2.1 Constitution of coffee berry

2.1.2 Production of coffee bean

Coffee production begins from a manufacturing of green coffee bean from coffee berry. Then, the green coffee bean is heated to produce the roasted coffee bean, which is brewed to produce coffee. There are two basic methods in producing green coffee bean; wet process and dry process. Each process results in different flavor and quality of green coffee bean (Sunarharum *et al.*, 2014). Usually, the green coffee bean processed by wet method is called washed. On the other hand, the bean processed by dry method is called unwashed. It was also found that coffee bean produced by wet process has better sensory characteristics (Bytof *et al.*, 2005) and higher chlorogenic acid (CGA) content than that produced by dry method (Duarte *et al.*, 2010).

In wet process, the coffee pulp is removed from the bean by pulper supplied with clean water. Then, the bean is fermented and de-mucilaged. The purpose of fermentation is to digest the remaining mucilage layer and completely remove mucilage from the parchment cover. The complete removal of mucilage is required to produce good quality coffee without mustiness, but over-fermentation must be avoided to prevent loss of color and flavor from the resulting coffee bean (Sunarharum *et al.*, 2014). The mucilage free bean is sun-dried until its moisture content around 10%. Finally, the parchment and some of the silver skin are

removed by hulling resulting in green coffee bean. As a result, by-products of wet process are coffee pulp, parchment and mucilage (if no fermentation is used).

Dry method of producing coffee bean involves sun drying of the whole freshly collected ripe coffee berry. The cherry is dried for about 2 weeks. This method avoids an exposure of the cherry to humidity preventing a mold formation. A coffee husk is removed by hulling. The husk is an only by-product from green coffee bean production. It consists of coffee skin, pulp, mucilage, some of parchment and silver skin.

The resulting green coffee is composed of both volatile and non-volatile compounds. But, it is not usually consumed; the consumable form of coffee bean is a result of roasting and brewing processes. According to Wei and Tanokura (2015), the roasting process introduces green coffee bean to pyrolysis reaction of the organic constituents in the coffee bean including Maillard reaction of polyphenolic compounds, while brewing process transforms those chemicals into an emulsion. Thus, the characteristics flavor and aroma of coffee is achieved. The silver skin left on the green coffee bean is a by-product of this roasting process.

2.1.3 By-products of coffee bean production

As mentioned in the previous section, by-products of coffee bean varied by the process method. The wet method produces coffee pulp and parchment, while dry method leaves only coffee husk (a combination of coffee pulp, mucilage and parchment). Coffee silver skin is mostly produced during roasting process. Amount of by-products produced in each process, shown in Table 2.1, states that the major by-product from wet process is coffee pulp and the one from dry process is coffee husk.

Table 2.1 Amount of by-products from coffee bean production

Wet method		Dry method	
By-product	Amount (% dry weight)	By-product	Amount (% dry weight)
Coffee pulp	69	Coffee husk	92
Parchment	29	Silver skin	8
Silver skin	2		

Source: Murthy and Madhava Naidu (2012)

The compositions of major by-products are summarized in Table 2.2. Regarding to the chemical composition of each by-products, coffee pulp and husk rich in carbohydrates, proteins and appreciable amounts of tannins, polyphenols, chlorogenic acids and caffeine. On the other hand, coffee silver skin is mostly comprised of dietary fibers and possessed some antioxidant property from polyphenols.

Table 2.2 Chemical composition of coffee by-products

Composition (% dry weight)	Coffee pulp	Coffee husk	Silver skin
Cellulose	63	43	17.8
Hemicellulose	2.3	7	13.1
Protein	11.5	8	18.6
Fat	2	0.5	2.2
Total fiber	60.5	24	62.4
Total polyphenols	1.5	0.8	1
Total sugars	14.4	58	6.65
Pectic substance	6.5	1.6	0.02
Lignin	17.5	9	1
Tannins	3	5	0.02
Chlorogenic acid	2.4	2.5	3
Caffeine	1.5	1	0.03

Source: Murthy and Madhava Naidu (2012)

Coffee pulp (from wet process) and husk (from dry process) are traditionally utilized as fertilizer, compost and animal feed. But, due to a high amount of polyphenols (especially tannins), which are toxic to microorganisms and have anti-nutritional effect against livestock (Salinas-Rios *et al.*, 2015), the utilization

of the materials can be done only in a fraction of available quantity; thus, is not productively efficient. However, they can be used as a source of phytochemicals for food and pharmaceutical applications. The phytochemicals are phenolic compounds in 4 major groups including flavan-3-ols, hydroxycinnamic acids, flavonols and anthocyanidins; but, most phenolic compounds in fresh coffee pulp are chlorogenic acids (Ramirez-Coronel *et al.*, 2004). Regardless of toxicity of coffee pulp, there are recent attempts to use coffee pulp and husk as substrate in bioprocesses. For instance, the high amount of fermentable sugar and other organic substances make these by-products an appropriate substrate for cultivation of yeasts, molds (Pandey *et al.*, 2000) and mushroom (Salmones *et al.*, 2005). Contrastingly, in order to effectively utilize the pulps and husks in this way, it requires a pretreatment step to breakdown harmful compounds (Orozco *et al.*, 2008). This step makes the utilization of coffee pulp and husk in this regard hard to achieve in an industrial scale.

Coffee silver skin left from coffee roasting process contains a high amount of polyphenols and dietary fibers. The majority of them are chlorogenic acids and melanoidins generated during roasting (Martinez-Saez *et al.*, 2014). Thus, it is used as a source of polyphenols (Narita and Inouye, 2012). The content in the silver skin also marks it as a functional ingredient that can be used in food (Pourfarzad *et al.*, 2013) and beverages (Martinez-Saez *et al.*, 2014)

2.2 Pectin

Pectin is a hetero-polysaccharide found as structural component of plant cell wall. Considered as natural derived polymer, pectin is generally used as gelling stabilizing or thickening agents in food (de Mars and Ziegler, 2001) and pharmaceutical applications (Kim *et al.*, 2003; Sansone *et al.*, 2011). With the emerging trend in sustainability, pectin is used in coatings and packaging, as well. These applications utilize biodegradability, edibility, gelation and renewability of natural polymer as a key point in development (Espitia *et al.*, 2014). Fishman *et al.* (2000) showed that pectin and starch can be used in correspondent to produce biodegradable packaging by extrusion method, which has suitable properties to be used as packaging material of many

household products. Kang *et al.* (2007) also showed that with pectin based coating containing green tea extract was able to extend shelf life of pork patty. Thus, Pectin is not only able to provide physical stability to many products, but it also able to provide microbiological and chemical stabilities.

2.2.1 Structure and property of pectin

Pectin is mainly consisted of poly-D-galacturonic acid (Figure 2.2) bounded with glycoside linkage and attached with neutral sugars. A ratio of esterified galacturonic acid groups to total galacturonic acid groups is called degree of esterification (DE). DE is used to classified pectin into high methoxyl pectin (HMP) and low methoxyl pectin (LMP). HMP has over 50 percent of their carboxyl groups esterified ($DE > 50$), while LMP has less than 50 percent of esterified carboxyl groups ($DE < 50$). Because DE affects gelling properties and film properties, it is usually investigated along with other parameters in pectin related studies (Espitia *et al.*, 2014). Different sources of raw material reveal different DE of pectin (Mollea *et al.*, 2008; Pagán *et al.*, 2001). Moreover, DE can be, affected by extracting parameters; for instance, at higher extraction temperature, longer extraction time and more acidic environment, pectin is partially degraded (Minjares-Fuentes *et al.*, 2014; Prakash Maran *et al.*, 2013; Wai *et al.*, 2010).

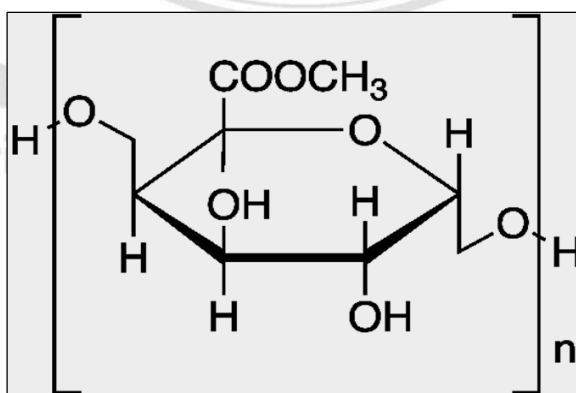


Figure 2.2 Chemical structure of poly-D-galacturonic acid esterified with methoxyl group

Source: <http://commons.wikimedia.org>

LMP is gelled by electrostatic interactions of de-esterified carboxyl chained with the presence of Ca^{2+} . The structure is stabilized by Van der Waals interactions and hydrogen bonding of the neighboring chains (Gilsenan *et al.*, 2003a, 2003b, 2003c). On the other hand, HMP gelation takes place in conditions with less ionic interaction, a presence of co-solutes and low pH (Paramita *et al.*). Moreover, when LMP react with ammonia, it becomes amidated pectin which required less Ca^{2+} to gel, less sensitive to precipitation and having thermo-reversible gel (Taubner *et al.*, 2015).

2.2.2 Pectin extraction

Pectin is conventionally extracted by water at high temperature and with the present of strong mineral acid, for instance hydrochloric acid and sulfuric acid. However, those acids are very toxic. Therefore, Minjares-Fuentes *et al.* (2014) had showed an alternative approach by using organic acids as the replacement. The factors affecting the pectin extraction include pH, temperature, time and type of acid. Pectin yield usually increases with lower pH, higher temperature and time, but the change in those factors would degrade more pectin (Kulkarni and Vijayanand, 2010; Mollea *et al.*, 2008; Wai *et al.*, 2010). Some of the optimum conditions for extracting pectin are summarized in Table 2.3. The studies showed that different raw material requires different extracting conditions. In addition, there are two extraction methods with relatively high yield, but shorter time, which are the using of microwave (Prakash Maran *et al.*, 2013) and ultrasonic (Minjares-Fuentes *et al.*, 2014).

Table 2.3 Optimal conditions for pectin extraction

Raw material	Optimal extraction condition			Source
	pH	Temp (°C)	Time (minutes)	
Coco husk	2.5	95	60	Mollea <i>et al.</i> (2008)
Orange peel	1.4	80	60	Pagán <i>et al.</i> (2001)
Passion fruit peel	2.5	98.7	60	Kulkarni and Vijayanand (2010)

2.3 Chlorogenic Acids

Chlorogenic acids are major polyphenols in coffee (both in pulp and bean) (Esquivel and Jiménez, 2012). Chlorogenic acids are negatively charged phenolic acid that attach to plant cell wall. Thus, they have to be free from plant cell wall before they are extracted or absorbed (Padayachee *et al.*, 2012b).

2.3.1 Structures and property of chlorogenic acids

Chlorogenic acids are a sub-group of phenolic acids formed by the esterification of certain hydroxycinnamic acids (such as caffeic and ferulic acids) with quinic acid. Figure 2.3 shows some of the molecular structures of chlorogenic acids.

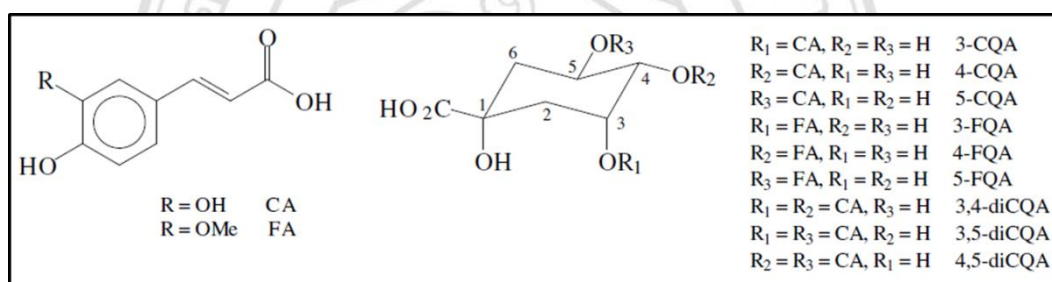


Figure 2.3 Chemical structures of chlorogenic acids

Source: Marques and Farah (2009)

Chlorogenic acids have many benefits including antioxidant (Xiang and Ning, 2008), antimicrobial (Lee and Sung, 2008; Lou *et al.*, 2011), reducing risk of cardiovascular diseases and anti-obesity (Bonita *et al.*, 2007; Cho *et al.*, 2010). Antioxidant activity of chlorogenic acids is gained from extended conjugation of phenolic acid group that enabling their molecules to absorb electron from free radicals (Xiang and Ning, 2008). On the other hand, antimicrobial activity of chlorogenic acids are come from membrane disruption effect on the microbes resulting in loss of cell content and eventually death as proposed by Lou *et al.* (2011). The authors also identified the minimum inhibition concentration (MIC) of many bacteria including: 1) *Streptococcus pneumonia* (20 µg/mL); 2) *Staphylococcus aureus* (40 µg/mL); 3) *Bacillus subtilis* (40 µg/mL); 4) *Escherichia coli* (80 µg/mL); 5) *Shigella dysenteriae* (20 µg/mL) and 6) *Salmonella typhimurium* (40 µg/mL).

2.3.2 Extraction of chlorogenic acids

Chlorogenic acids are water soluble compound and can be extracted by many polar solvents. The best solvent for extraction of the compounds is still remained in contradiction; for instance, Upadhyay *et al.* (2012) concluded that water is most suitable, while Mazvimba *et al.* (2012) recommended the use of 80% methanol as extracting solvent. But, most study still used water for extraction (as summarized in Table 2.4). In general, chlorogenic acid is extracted under neutral solvent with mild heating. The heating method determine the extraction time. Conventional extraction (heat reflux) required long time and high heat for extraction while ultrasonic extraction can be performed in cold solvent with less time (Mazvimba *et al.*, 2012). However, when using microwave, chlorogenic acids can be rapidly extracted with moderate heat (Upadhyay *et al.*, 2012; Zhang *et al.*, 2008). Moreover, Li *et al.* (2011) showed that the yield of chlorogenic acids can be improved with slightly decrease in pH (to 5), but more acidic condition resulted in the degradation of chlorogenic acids. Increasing in temperature can also improve the yield as suggested by Upadhyay *et al.* (2012), but too much heat can degrade the compound (more than 50°C), as well.

Table 2.4 Optimum methods and conditions for chlorogenic acid extraction by water

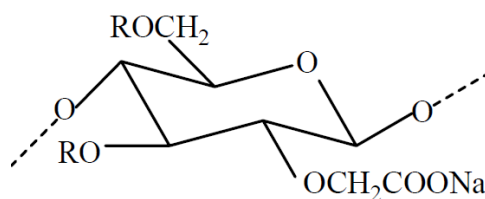
Raw material	Extraction method	Optimal extraction condition			Source
		pH	Temp (°C)	Time (minutes)	
Tobacco leaves	Heat reflux	7	70	210	Mazvimba <i>et al.</i> (2012)
Tobacco leaves	Ultrasonic	7	20	45	Mazvimba <i>et al.</i> (2012)
Flower buds of <i>Lonicera japonica Thunb</i>	Microwave	7	60	5	Zhang <i>et al.</i> (2008)
Sweet potato leaves	Microwave	5	25	Not available	Li <i>et al.</i> (2011)
Green coffee bean	Microwave	7	50	5	Upadhyay <i>et al.</i> (2012)

2.4 Carboxymethyl Cellulose

2.4.1 Structure and property

Carboxymethyl cellulose (CMC) is an ionic polysaccharide synthesized from the most abundant natural polymer as cellulose. The structure of CMC is shown in Figure 2.4. Usually, synthesized CMC is existed in the form of copolymer between β -D-glucose (monomer of cellulose) and β -D-glucopyranose-2-O-(carboxymethyl)-monosodium salt (β -D-glucose with carboxymethyl added to its hydroxyl group). The substitution of carboxymethyl molecule cellulose can occur at C2, C3 or C6 of the anhydroglucose unit but predominant at C2 position (Toğrul and Arslan, 2003). Degree of substitution (DS) is the measurement for how much the hydroxyl group in glucose units of the cellulose chain are substituted by carboxymethyl group. DS is generally in the range of 0.65-0.95 but the legal limit is 1. The higher DS results in more solubility and stability of the CMC solution (Arinaitwe and Pawlik, 2014).

CMC provides viscosity, water binding properties and solution clarity to products. With its abundance and easy to synthesize, it is widely used in many food, pharmaceutical, textile, paper and paint industry (Pushpamalar *et al.*, 2006). Moreover, Rachtanapun *et al.* (2012) showed that CMC had excellent film forming properties; however, the resulting films had weak mechanical properties. The mechanical properties of CMC films can be improved by blending with other polymers; for instance, Muppalla *et al.* (2014) showed that CMC blended with polyvinyl alcohol (PVA) had mechanical properties rivaling the synthetic one while still retaining biodegradability of CMC.



sodium carboxymethyl cellulose

R = H or CH₂ COONa

according to DS_{CMC}

Figure 2.4 Chemical structure of CMC

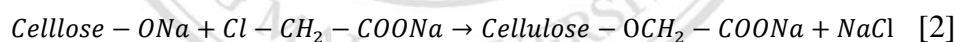
Source: Heinz & Pfeiffer (1999)

2.4.2 Synthesis of carboxymethyl cellulose

CMC is produced by etherification of the hydroxyl groups with sodium monochloroacetate or monochloroacetic acid in the presence of aqueous alkaline (Toğrul and Arslan, 2004). The first step in CMC synthesis is an equilibrium reaction between NaOH and the hydroxyl groups of the cellulose; Equation [1].



The second step is etherification of the carboxymethyl group by the substitution of sodium monochloroacetate; Equation [2].



In this second step there is a competitive reaction (Equation [3]) of sodium monochloroacetate with NaOH to form sodium glycolate.



As a result, amount of NaOH in the synthesis of CMC is the most important parameter to control during the synthesis; since, it opens up cellulose molecules for synthesis and determines the etherification reactions. Other parameters affecting CMC synthesis are synthesis medium, amount of reactant, temperature and time. Pushpamalar *et al.* (2006) studied all process parameters and concluded that the optimum condition for CMC synthesis from sago waste was using isopropyl alcohol as the medium with 6 grams of sodium monochloroacetate per 5 grams of cellulose at 45°C for 3 hours and using 25% NaOH concentration. They

stated that NaOH concentration affected the accessibility of the reactant. The more NaOH concentration, the easier the reactant could reach the cellulose molecule. However, high concentration of NaOH promoted the formation of sodium glycolate. Therefore, the amount of NaOH must be controlled to increase DS and limited the side reaction. Increasing reaction temperature and time increased DS and the yield; nevertheless, too high temperature and too long reaction time, CMC was degraded. Rachtanapun *et al.* (2012) was also used the same condition except reaction temperature and NaOH concentration for CMC synthesis from durian rind. They used reaction temperature of 55°C to study the effect of NaOH concentration on the CMC. Based on the study, the optimum NaOH concentration was 30%.

2.5 Chitosan

Chitosan is a positively-charged polysaccharide derived from chitin. It was mostly synthesized from an outer shell of crustaceans (Sagheer *et al.*, 2009). The strong point of chitosan is that it possesses biocompatibility and biodegradability as it is a natural derived polymer. More importantly, chitosan shows a strong antimicrobial activity against both bacteria and fungi (Gómez-Estaca *et al.*, 2010; Jiang *et al.*, 2011; Martínez-Camacho *et al.*, 2010; Pereda *et al.*, 2011; Sébastien *et al.*, 2006). According to the review by Kong *et al.* (2010), antimicrobial mechanism of chitosan was still undetermined, but it was speculated to come from the three mechanisms including: 1) positively charged chitosan molecules interfere with cell membrane of microorganism obstructing its activity, causing the leakage of cellular material and following by cell death; 2) chitosan molecules act as chelating agent absorbing the essential metals from microorganisms preventing it from growth and reproduction and 3) low molecular weight of chitosan can enter the microorganism cell and interfere with the messenger RNA; thus, stop the cell from protein synthesis. In addition, chitosan film possesses mechanical properties rivaling the commercial polymer (Liu *et al.*, 2014). As a result, coupled with its antimicrobial activity, chitosan had been used as food coatings and packaging for extending shelf life of many food products (de S. Medeiros *et al.*, 2012; Gómez-Estaca *et al.*, 2010; Jiang *et al.*, 2011; Schreiber *et al.*, 2013). Moreover, natural

chitosan with cationic nature has been used to improve properties of many films; For instance, Sébastien *et al.* (2006) used chitosan to improve biodegradability of the polylactic acid film. While Chen *et al.* (2010) used chitosan to form polyelectrolyte complex to improve mechanical properties and prevent water solubility of the film based on gelatin.

2.6 Bioplastics

Bioplastics are polymers that can be derived from renewable resources. According to Yu *et al.* (2006), the trend of bioplastic has gained a lot of attention due to increasing environmental concern and limited amount of petroleum. They also stated that bioplastics can be classified into three categories based on derivations: 1) natural polymers such as starch, protein, cellulose, chitosan and pectin; 2) polymers synthesized from natural monomers such as polylactic acid and 3) polymers produced from biotechnology such as polyhydroxybutyrate. A triumph bioplastics against petroleum based polymers is their biodegradability. However, this benefit comes with a difficulty. It is very important to control many factors to prevent the polymers from prematurely degraded (Guilbert and Gontard, 2005). In addition, many natural polymers are water soluble, which raise concern for most applications of polymer that require water resistance. Besides, mechanical, physical and chemical stability of bioplastics are still outmatched by inertness of petroleum based polymers (Tharanathan, 2003). But, like many materials, the properties of bioplastic can be improved by blending with other polymers and composite formation. For example, water barrier properties and film strength are usually improved by film compositing. Savadekar and Mhaske (2012) utilized water resistance nature of nanoscale cellulose fibers to improve both the strength and water resistance of the starch base film. However, the use of the material was very limited due to its difficulty in production and relatively small yield. Recently, there are researches related to the use of polyelectrolyte complex to improve the properties of the film (Chen *et al.*, 2010; Farris *et al.*, 2011; Farris *et al.*, 2009; Gómez-Estaca *et al.*, 2010; Kołodziejska and Piotrowska, 2007; Silva *et al.*, 2008). The structure utilizes the ionic interaction and hydrogel structure to form a strong polymer network that can enhance mechanical properties of the film and provide a possibility to

incorporate active compounds into the packaging (Farris *et al.*, 2009). Moreover, to improve the flexibility of the film, bioplastics usually employ the use of plasticizer due to their ability to reduce intermolecular forces between polymer chains; thus, their mobility is increased. Glycerol is usually used as a plasticizer in formation of hydrophilic polymers. It can improve film extensibility but reduce its elasticity and water resistance (Bergo *et al.*, 2013).

2.6.1 Plastic composite by polyelectrolyte complex structure

Polyelectrolyte complex is a hydrogel structure forming by polymers with opposing charges. The electrostatic interaction between polymers with opposite charge generates a reversible continuous physical co-gel, which has higher performance; both strength and water resistance, than individual polymer (Farris *et al.*, 2011). According to Farris *et al.* (2009), in order to achieve suitable structure, composition of the plastic must have a major and a minor polymers. The major component acts as a matrix; while, the minor component acts as reinforcing agent that electrostatically interact with the polymer. Figure 2.5 illustrates the probable polyelectrolyte complex structure. They also stated that there were two process conditions (pH and net charge) that must be controlled during polyelectrolyte complex generation. Firstly, pH must be adjusted to a level that could ionize both polymers. Too high or too low pH level would result in phased separation or precipitation of the polymers. Besides, at the very low pH level, degradation of polymer molecules might occur as well. Another condition was net charge. The net charge in the system must be predominated by one type of charge so that the polyelectrolyte complex structure could be formed while having enough charges to stay dissolved (Gilsenan *et al.*, 2003b). Net charge could be controlled by adjusting amount of the polymers of known properties. In case of gelatin-pectin film studied by Farris *et al.* (2011), the optimum film formulation contained 62% gelatin, 5% pectin and 33% glycerol and the film was casted at pH of 4.2.

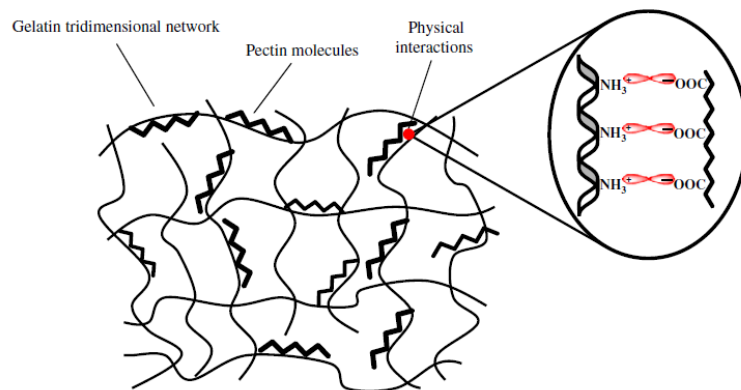


Figure 2.5 Polyelectrolyte complex structure

Source: Farris *et al.* (2009)

2.6.2 Active packaging

In food industry, active packaging is packaging that can respond with external or internal stimuli (Chen and Gu, 2013) as well as carry and release variety of active compounds including antioxidant, flavoring and antimicrobial compounds (Espitia *et al.*, 2014). Active packaging used in food is mostly produced using edible films, which can provide suitable control release system without excessively increasing the amount of additive in food (Alvarez *et al.*, 2015). Antimicrobial films are the major research subject for edible films targeted as food packaging. By utilizing a control diffusion of antimicrobial agent to the food surface or modified an inside atmosphere (María Alejandra Rojas-Graü *et al.*, 2009), this packaging have system successfully extended shelf life of many food products (Gómez-Estaca *et al.*, 2010; Jiang *et al.*, 2011; Muppalla *et al.*, 2014; Maria A. Rojas-Graü *et al.*, 2007a; María A. Rojas-Graü *et al.*, 2007b). According to Espitia *et al.* (2014), there are three classes of compound that used in as antimicrobial agent in modern research. The three classes of compounds are generally recognized as safe (GRAS). The first group is bacteriosins, which are peptides that bacteria synthesize to kill competitor bacteria. These compounds have advantage from the strong activity against targeted bacterial species; however, they are ineffective against organism that produces them. The second class is essential oils. Essential oils are compounds that plant produce to compete against microbes in nature; thus, not only it can be used as flavoring agent, but also a natural antimicrobial agent. However, the compounds have a limitation as

food packaging as they introduce unwanted sensory characteristics to the food (María A. Rojas-Graü *et al.*, 2007b). Lastly, polyphenols are the groups of compound that possess not only antimicrobial activity, but also a strong antioxidant activity. However the use of such compounds is still limited due to their stability in the packaging system (Wang *et al.*, 2013)

2.6.3 Biodegradability

According to Mohee and Unmar (2007) biodegradability is “ the degree of the changes in physical and chemical characteristics of molecular structure of organic substances under degradation by microorganisms”. For bioplastics, the degradability is the basic requirement and a major advantage against conventional packaging system. The most probable way in disposing the biodegradable plastic involves the uses in composting and organic recovery, which require three characteristics for utilization: 1) biodegradation; 2) disintegration and 3) no effect on the compost quality (Mohee and Unmar, 2007). Biodegradability of the plastic is usually determined by either measuring disintegratability or biodegradability under controlled aerobic or anaerobic composting condition. Disintegratability or degree of disintegration is measured by comparing the initial weight of the sample with the recovered fraction after composting (Mohee and Unmar, 2007). On the other hand, biodegradability is determined by the rate of CO₂ production or O₂ intake of the composting organisms (Gómez and Michel Jr, 2013; Pagga *et al.*, 1995). Biodegradability of the plastic depends on the type of the plastic and composting condition including temperature, type of inoculum, aeration and humidity (Gómez and Michel Jr, 2013).

2.7 Fresh Cut Carrot

Modern consumers have become more dependent on convenience and health benefits of food product. In response to the emerging trend, fresh cut fruits and vegetables are new market segment that shows promising growth (Mastromatteo *et al.*, 2012). The required characteristics of fresh cut products include convenience while retaining freshness and nutritional value; but, the production processes usually results in a destruction of tissue integrity enhancing deterioration process. In case of carrot

(*Daucus carota* ssp. *sativus*), fresh cut process often removes epidermal barrier which increase moisture and sugar content on the surface accelerating deterioration processes. Usually, deterioration processes of fresh cut carrot include oxidative browning, moisture loss, and microbial spoilage that product yield may loss in texture, color and nutritional values (Mastromatteo *et al.*, 2012). Those processes limit the shelf life of fresh cut carrots which, in turn, will limit the marketing opportunity of the product. Therefore, to overcome the hurdles, pretreatment process is usually used in a combination of packaging system. According to Alegria *et al.* (2012), conventional pretreatment of fresh cut carrots is performed by either heat shock process, or chlorine treatment which shows effectiveness in reducing initial microbial load of the product. Moreover, heat shock process showed superiority in inhibits the enzymes (such as polyphenols oxidase, peroxidase and pectinase) that responsible for deterioration processes as well. However, chlorine treatment was more effective in reducing microbial load than heat shock process. They also compared the new pretreatment process that used UV-C irradiation treatment. The process showed comparable microbial reduction as chlorine treatment with similar enzyme inhibition effect as heat shock process. The major role of packaging in the fresh cut product is to prevent the moisture loss and limit the growth of microorganisms and other deterioration processes, which are usually achieved by maintaining appropriate amount of CO₂ and O₂ (Mastromatteo *et al.*, 2012). In addition, some active compounds such as antimicrobials or antioxidants could be added into the film system to enhance its effectiveness in extending shelf life of the product (Gómez-López *et al.*, 2007; María Alejandra Rojas-Graü *et al.*, 2009).

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