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Pectin from Durian (*Durio zibethinus* Murray) Peel: Microwave-Assisted Extraction Followed by Solvent Extraction

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Abstract

The world market demand for pectin has been growing fast due to the expanding consumer base for low-calorie and low-fat food products. Thus, there was a need to explore other sources of pectin. This study extracted pectin from durian (*Durio zibethinus* Murray) peel cv. Long lab-lae. Before solvent extraction, microwave-assisted extraction was utilized to improve the pectin yield. The parameters during the pectin extraction process were investigated using acetic acid concentrations ranging from 10 to 40 % at pH 2, extraction temperatures ranging from 40 to 100 °C, and extraction times ranging from 2 to 6 h. The pectin extraction was carried out at pH 2.0 because a higher pH significantly reduced the yield. The results showed the parameters had a significant influence on the yield. It decreased at a higher acid concentration, extraction temperature and extraction time. It was noticed that the pectin turned into liquid at a higher temperature, 100 °C. Therefore, the optimum conditions for extracting the highest yield of pectin were 20 % acetic acid, an extraction temperature of 80 °C, and an extraction time of 2 h. The pectin yield under these optimum conditions was 1.91 %. The Fourier transform infrared spectroscopy (FT-IR) analysis confirmed the presence of functional groups in the fingerprint region of identification for polysaccharides in the extracted pectin. The FT-IR spectrum of the pectin in durian peel was extremely close to that of commercial pectin. There was limited published data on extracting and characterizing pectin from durian peel. Thus, this study could pave the way for using durian peel pectin, for instance, in food processing (i.e., gelling agent for weak-acid, low-calorie food) and pharmaceutical applications. Furthermore, using durian peel, which is agricultural waste, reduces the disposal and burning of waste to the environment, causing several pollutions and improving the economic value of durian peel.

Keywords: Durian peel, Fourier transform infrared spectroscopy, Gelling agent, Long lab-lae, Microwave-assisted extraction, Pectin, Solvent extraction

Introduction

Durian (*Durio zibethinus* Murray) is one of Southeast Asia's most highly valued and desired fruits due to its distinct flavor and unique taste. In Uttaradit Province, Durian cv. Long lab-lae is ovoid-oblong to nearly round shaped with an average weight between 0.5 and 3.5 kg. The peel is green to yellowish brown, thick and semi-woody, with sharply pointed pyramidal thorns. During the harvest season, approximately 65 to 70 % of the total weight is in the peel, which is typically discarded, leading to significant environmental waste [1]. However, this biomass can be utilized because durian peel is fertile with polysaccharides, a source of pectin, which is a potential value-added product for the local community [2]. Several previous studies have utilized pectin as a heavy metal adsorbent [3], dye adsorbent [4], biofertilizer [5] and bioplastic material for packaging applications [6,7]. Pectin is not only used as an additive for dietary fiber in foods [8], but also as a natural thickening agent [9], texturizing agent [10], stabilizing agent, emulsifying agent and gelling agent to increase the viscosity of various food products such as jellies, jams, marmalades, fruit juice, confectionary products, yogurt and daily desserts, which rely on this property [11]. It has been demonstrated that pectin contributes to lower cholesterol levels in the blood, binds lead and mercury in the gastrointestinal tract, and plays an anti-cancer role [12]. Up to 30 % of the dry mass of the primary cell wall is composed of pectin, the main macromolecule in the middle lamella (**Figure 1**). Multiple interactions occur among pectin, cellulose and hemicellulose [13].

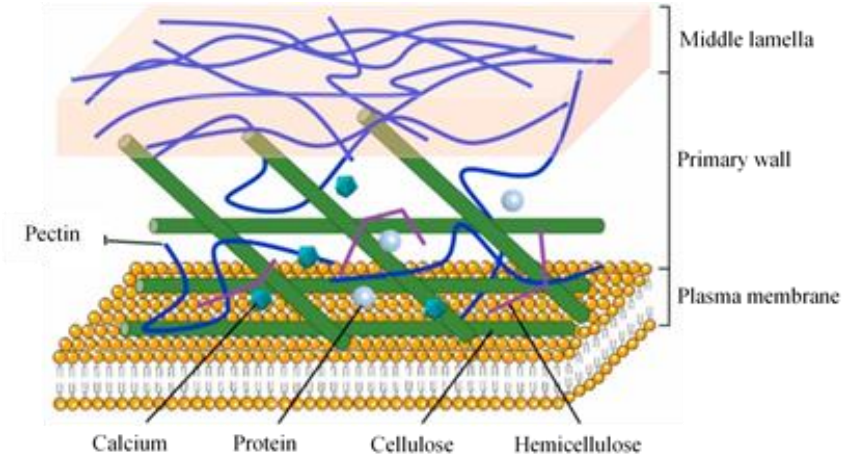

Figure 1 Existent form of pectin in the fruit cell wall [13].

Pectin constitutes the linear backbone of α-1,4-linked-galacturonic acids, which is partially methyl-esterified and contains a small amount of rhamnose in the main chain, and arabinose, galactose and xylose in the side chain (**Figure 2**) [2,14]. It is connected to other components in the cell walls that inhibit the release of pectin from the cell matrix. Therefore, the extraction process must be sufficient to allow selective extraction of pectin. Moreover, these processes should be able to protect the integrity of the molecular structure by limiting the degradation of pectin [15].

Pectin extraction is a multi-stage physico-chemical process in which the hydrolysis and extraction of pectin from plant tissue and its solubilization into a suitable solvent takes place under the influence of various factors including temperature, pH, solvent properties and duration of extraction [11]. Pectin can be classified into 2 types according to the degree of esterification (DE), which are high methoxyl pectin (HMP) (DE > 50 %) and low methoxyl pectin (LMP) (DE < 50 %). HMP forms a gel at high sugar levels (concentration > 55 %) and acidic conditions (pH ≤ 3.5). Conversely, LMP forms a gel in the presence of calcium ions at wider pH ranges (pH 2.0 - 6.0) [16]. Pectin can be extracted from plants through enzymatic treatment or chemical hydrolysis. However, enzymatic treatment is costly due to its complex production processes. Chemical extraction of pectin is preferred to avoid enzyme degradation and loss of gelling properties [8].

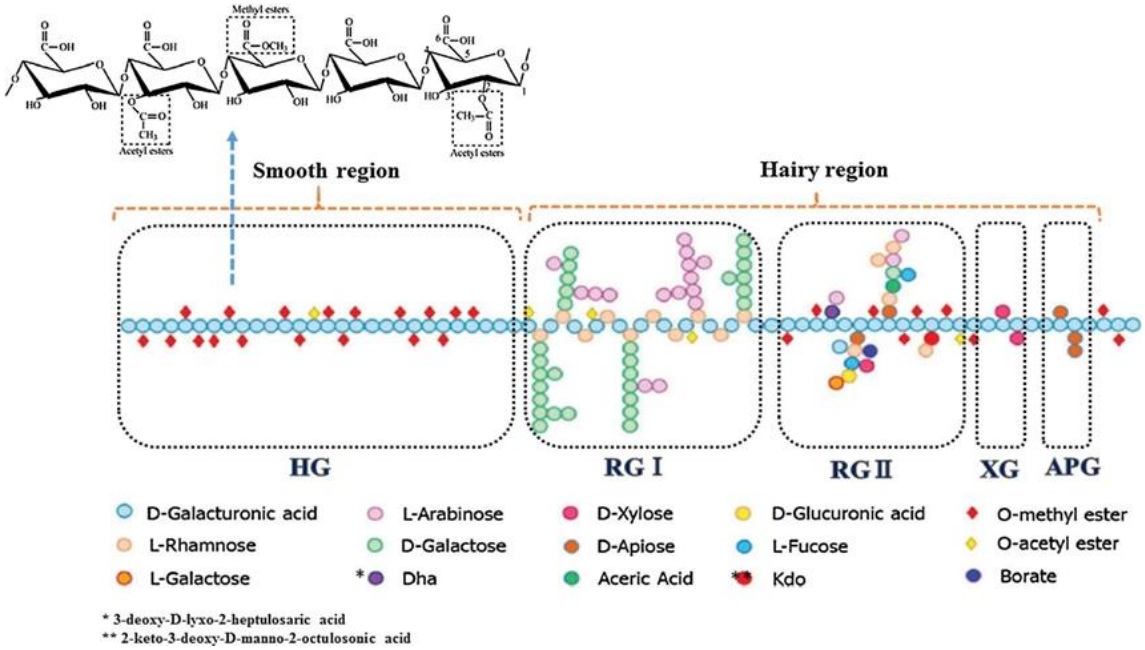

Figure 2 Structure diagram of pectin showing galacturonic acid backbone, homogalacturonan (HG); rhamnogalacturonan-I (RGI); rhamnogalacturonan-II (RGII); xylogalacturonan (APG) [14].

Among the extracting solvents, acid extraction is advantageous because it produces a higher yield of pectin, and the extracted pectin is generally enriched in galacturonic acid, reflecting a greater purity. The acid types commonly utilized are acetic (AA or CH_3COOH), citric (CA or $C_6H_8O_7$), tartaric (TA or $C_4H_6O_6$) (organic) acids, hydrochloric (HCl), nitric (HNO_3), phosphoric (H_3PO_4) and sulfuric (H_2SO_4) (mineral) acids [17,18]. Mineral acids were reported to be effective extractants in terms of yield; however, they were also reported to have environmental consequences and increased costs Organic acids, on the other hand, were famous for their lower degradation effect or reduced hydrolyzing and depolymerization capacity during extraction in generating pectin with better gelling properties. In addition, Luo *et al*. [19] revealed the yield, molecular weight, galacturonic acid content and DE of the AA-extracted pectin were higher than mineral acid-extracted pectin, except neutral sugars were lower. Additionally, the pectin extracted using AA showcased a greater viscosity as the shear rate increased and displayed a higher G" modulus when compared to the pectin obtained through mineral acid extraction and commercial pectin. This could be due to a greater interaction between polymer chains, which is reflected in the textural properties of the gel. Regarding the developing concept of "green chemistry and technology" and the disadvantages related to using mineral acids (e.g., HCl), the focal point is the utilization of organic acids (e.g., CH_3COOH) for pectin extraction [20]. Jong *et al.* [2] reported the yield of pectin extracted in durian peels with organic acids (CA, TA and AA), ranging from 6.98 to 10.23 %. Chamyuang *et al*. [6] extracted pectin from arabica coffee pulp with citric acid by boiling, and obtained a pectin yield of 15.9 ± 0.4 % (g/100 g dried weight). Tanaid and Lauzon [21] extracted pectin from unripe banana by using citric acid, and obtained a yield of 13.25 % pectin on a dry basis (88 min, 95 °C, 1:28 Peel:Solvent ratio). The influence of acid extractant type and concentration on the durian peel pectin properties, especially yield, DE and purity, pave the way for using durian peel as a pectin source. Generally, pectin extraction in acidic conditions involves 2 reactions overlapping 1 another, which are the solubilization of insoluble protopectin from the cell wall in the first reaction (R1) and the hydrolysis of the soluble pectin in the extraction medium to degraded products in the second reaction (R2) [22]. The R1 predominates until all the pectin is extracted from the plant cell wall, following the predominant of R2, a decrease in pectin yield is observed due to the degradation of soluble pectin. These reactions are believed to be affected by the acid type and concentration.

The pH was an important factor and had different effects on pectin extraction. The higher pH significantly reduced the yield and quality of the extracted pectin. Low pH may promote quick disruption of hydrogen bonds and ester linkages between pectin and cell wall, which increase the rate of diffusion of pectin and pectin extraction. It has been reported that the lower pH favored higher pectin yield from passion fruit peel, banana peel and pomegranate peel, respectively. Mamiru and Gonfa [23] reported the yield of pectin increases as pH increases from 1.0 to 2.0. However, a further increase in pH reduces the yield. A maximum yield of 18.1 % was observed at a pH of 2.0 and the value was reduced to 0.74 % at a pH of 5.0. Colodel and Petkowicz [24] reported the highest pectin yield (15.6 %) from cubiu fruit peel was obtained at pH 2 and the lowest (4.5 %) at pH 1 under the influence of the extraction conditions, boiled in nitric acid for 4 h. Colodel *et al*. [25] obtained the maximum pectin yield of 11.1 % under the optimized conditions (pH 2.08 for 135.23 min with a liquid-to-solid ratio (LS) of 35.11 mL/g) from Chardonnay grape pomace.

The anhydrouronic acid (AUA) content indicates the purity of the extracted pectin. The AUA content of commercial pectin must be not less than 65 % to ensure pectin purity in meeting the legislative requirement of the Food and Agriculture Organization (FAO) and Food Chemical Codex 1996 (FCC) for food application [16]. An AUA content of less than 65 % may indicate impurities due to the presence of proteins, starch and sugars in the precipitated pectin [21]. The quality of the pectin obtained depends on the source of pectin and the conditions of its extraction. These conditions include the type of acid used, solution pH, extraction time, temperature, purification method and alcohol precipitation procedure. Alcohol precipitation is a highly effective method for removing protein salts, free sugars, mono- and disaccharides and acid compounds that are soluble in alcohol, and it helps in obtaining purer pectin [16,23,26,27]. The glycosidic bonds in the pectin chain have varying resistance to acid hydrolysis: Linkages between galacturonic acid are more resistant, followed by linkages between galacturonic acid and rhamnose, and linkages between neutral sugars. Acids are essential in catalyzing the hydrolysis of linkages between the neutral sugars in pectin molecules, which are more acid sensitive, giving pectin a significantly higher AUA content than the control. Mineral acids are more effective in breaking down pectin's neutral sugar side chains because of their greater strength when compared to weak organic acids. This results in higher ratios of AUA in the pectin. According to Jong *et al*. [2] the pectin obtained from mineral acid extractions has a higher purity of AUA, with most samples being over 65 % and ranging from 62.18 to 80.58 %. While pectin obtained from organic acids was below 65 %, ranging from 41.64 to 64.89 %. Among the organic acids, AA-extracted pectin had an average AUA content lower than CA and TA, while the AUA contents of CA and TA pectin were similar. The protic nature of organic acids also appeared to affect pectin's purity. AA

(monoprotic acid), a weaker acid than TA (diprotic) and CA (triprotic), seemed to be less effective in removing the neutral sugar side chains of pectin during extraction, producing pectin with lesser AUA content. However, the extraction yield of pectin was not related to the AUA content of pectin. High uronic content in pectin does not necessarily represent a good yield. A good balance should be achieved in pectin extraction to acquire pectin with optimum yield and purity.

New applications of pectin continue to emerge, making pectin extraction and commercialization an attractive investment. Commercially available pectin is extracted from citrus peels and apple pomace worldwide. However, several durian peels represent potential sources of pectin, which can also be capitalized. It is to be noted that conventional extraction of pectin requires a lot of energy and involves the use of mineral acids or organic acids. In alignment with sustainable development goals, researchers have evaluated the efficacy of non-traditional green extraction methods, such as microwave-assisted extraction (MAE) and ultrasound-assisted extraction (UAE), on the yield and characteristics of pectin extracted from durian peel [28]. Accordingly, these modern techniques, compared to acid extraction, are more environmentally friendly because of the low consumption of solvents and energy at a short extraction time. MAE is an advanced technique to extract polysaccharides from plant sources. This method can increase the extraction efficiency of bioactive compounds in the reaction mixtures through the molecular interactions between the electric component of the microwave field with the dipolar molecules and ionic species. Nonionizing radiation in a broad spectral frequency owing to the molecular friction produces volumetrically distributed heating energy. It increases the mass transfer coefficient of the target constituted by the inner parts of solid materials. Compared to other advanced extraction technologies, MAE has several advantages, such as relatively higher extraction yield and reproducibility in a shorter time, more improved selectivity, easier manipulation and lower solvent consumption. Also, this extraction system with controlled processing conditions can maintain physicochemical and structural features and bioactivities (such as antioxidant, antiradical and antimicrobial effects) of extracted polysaccharides. Using an optimization method in the MAE process would be very interesting owing to the quality and quantity improvement of extracted [29]. The processing parameters, such as microwave power, pH, extraction time or irradiation time and solid-to-liquid ratio on the pectin yield, were employed to optimize MAE. Kamal *et al*. [30] reported the optimal conditions were obtained at microwave power 495.48 W, pH 1.99, irradiation time 8.93 min and solid-to-liquid ratio of 1:20.59, which resulted in a pectin yield of > 20 % with satisfactory quality in terms of equivalent weight (EV), methoxyl content (MC), anhydrouronic acid (AUA) content and esterification degree (DE).

This study aims to investigate the optimum conditions for pectin extraction from durian peels using microwave-assisted extraction followed by solvent extraction. The results will help further develop a potential commercial product for the market, which is superior to the existing pectin production considering the value added to by-products in local durian commerce. Durian peels yield a high volume of raw material, and the contribution also decreases waste in the community.

Materials and methods

Materials

All of the chemicals used were of analytical grade. Acetic acid and concentrated hydrochloric acid were purchased from Merck (Darmstadt, Germany). Sodium hydroxide was obtained from Ajax Finechem (Ajax, Australia), and 95% pure ethanol was obtained from Apex Alco (Bang Khun Thian, Bangkok, Thailand). The Fourier transform infrared spectroscopy (FTIR) spectra of pectin were examined using an FTIR spectrophotometer (Thermo Fisher Scientific, Waltham, USA), and by employing the Attenuated Total Reflection (ATR) method.

Collection of durian peels

Durian peels were collected on the same day as the disposal from a local durian wholesaler store in a fruit market in Uttaradit province, Thailand. They were available from mid-May to early July. Upon collection, the durian peel was checked to ensure it was free from defects, for example, wet and watery rinds, rotten patches, an outgrowth of mold, visible holes by pests and browning on the peel.

Sample preparation

Durian peel cv. Long lab-lae was obtained from a local fruit market in Mueang district, Uttaradit province, Thailand. The peels were washed and dried under sunlight. Afterwards, they were chopped into 2 - 3 cm-sized pieces with a sharp stainless-steel knife and ground into a coarse powder (**Figure 3**) using a blender (Philips, HR2115; Samut Prakan, Thailand. The powder of durian peel was oven-dried (Memmert,

Model 400; Schwabach, Germany) at 70 °C for 24 h, sieved (60-mesh) to retrieve the fine powder (**Figure 4**), sealed in a high-density polyethylene bag, and stored in desiccators.

Figure 3 Coarse powder.

Figure 4 Fine powder.

Sample extraction

Three g of the sample were added to 20 mL of acetic acid at concentrations of 10, 15, 20, 30 and 40 %. After standing for 10 min at room temperature, the sample was adjusted to pH 2.0 with 1 M of hydrochloric acid. Preliminarily, the sample was heated in a microwave (Samsung, ME711K; Shah Alam, Malaysia) using an input power of 300 W for 5 min, followed by solvent extraction using a hot plate (C-MAG, HS 7; IKA, Malaysia). The extraction temperature was varied at 40, 60, 80, 90 and 100 °C, while the extraction time was varied at 2, 4 and 6 h. The resulting slurries were filtered through cheesecloth and cooled at room temperature. Subsequently, acidified ethanol (4 % hydrochloric acid in 95 % ethanol) was added at a ratio of 1:4 (v/v) and left for 1 h. The solution was then centrifuged at 2,400 rpm for 20 min in a centrifuge (Ugaiya Bio-Sciences, TD 3; Japan). The gel-like precipitate was collected and re-suspended in distilled water at a ratio of 1:4 (w/v) (**Figure 5**). Then, the solution was twice rewashed with 95 % ethanol (1:2, v/v) and centrifuged at 2,400 rpm for 20 min. The extracted wet pectin was collected (**Figure 6**) and oven-dried at 70 °C for 4 h. The pectin was milled (Kala Outlet, Porcelain mortar pestle 5 cm; Lampang, Thailand) and sieved (60-mesh) to powdered form. Each experiment was run 3 times according to the design, and the average results were reported. The percentage yield of pectin was calculated using Eq. (1);

$$Y = \frac{W_A}{W_B} \times 100 \quad (1)$$

where Y is the percentage yield of pectin (%), W_A is the weight of extracted pectin (g), and W_B is the weight of dried durian peel (g).

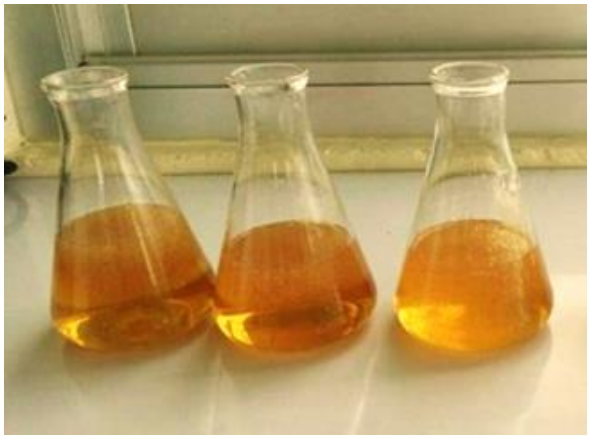

Figure 5 Precipitated pectin.

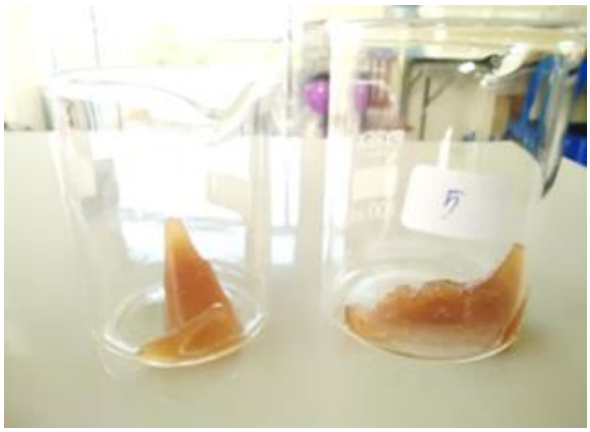

Figure 6 Extracted wet pectin.

Results and discussion

Concentration of acetic acid

The acetic acid (AA) concentration was investigated at 10, 15, 20, 30 and 40 %, respectively. The yield of pectin increased when the concentration of AA increased from 10 to 20 %. The highest yield (5.03×10^{-2} g) was obtained when the concentration of AA was increased to 20 %. After that, the concentration level of the pectin yield decreased. The result was similar to Jong *et al*. [2] who illustrated the trend of AA-extracted pectin yield in durian peel increased from 0.00001 to 0.01 M and a gradual decrease from 0.01 to 1.0 M or a gradual decline in pectin yield of AA extraction at increasing concentration. Moreover, the result agreed with Luo *et al*. [19] where the pectin yield from apple pomace increased with increasing AA concentration (5 - 10 % w/w) until a plateau was reached at higher concentrations (20 - 40 % w/w).

Acid extraction facilitated the extraction of insoluble pectin tightly bound to the cell matrix of the durian peel [31]. However, excessive use of acetic acid can cause the production of smaller, highly soluble pectin molecules due to the partial destruction of glycosidic bond and ester bond at a higher concentration of acetic acid, thus resulting in a lower pectin yield. Acetic acid (AA) extraction was optimized at 20 % concentration, yielding 5.03×10^{-2} g (**Figure 7**).

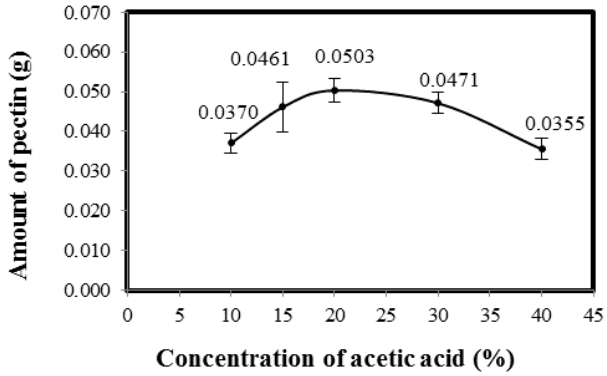

Figure 7 Effect of concentration of acetic acid on pectin yield at pH 2 with extraction temperature at 80 °C for 90 min.

Extraction temperature

Initially, the sample was extracted by microwave extraction followed by solvent extraction. Microwave radiation accelerated the cell rupture due to the sudden rise in temperature and the internal pressure inside the cells of durian peel. This promoted the destruction of the sample surface, and the pectin within the cells of the durian peels was released into the solution [32]. In the process of solvent extraction, the pectin yield increased with increased extraction temperature from 40 to 80 °C, obtaining the highest yield at 80 °C, closely similar to what Jong *et al*. [2] reported at about 83 °C, pectin yield reaches the peak. Above that, the yield decreased at 90 °C due to pectin degradation [23,33], and pectin was slowly turned into liquid at 100 °C. When the extraction temperature is too low, dissolving the pectin from the plant cell wall is difficult. When extracting pectin, using a higher temperature can cause damage to the molecules that form the pectin chain, resulting in a decrease in yield and a reduction in pectin quality. This is because the high temperature can cause the pectin to crack or degrade, leading to a lower molecular weight and viscosity of the pectin. As a result, the rate and effectiveness of pectin extraction may also be affected [27,34]. Based on the highest yield (5.20×10^{-2} g) obtained, 80 °C was the optimum temperature for extraction (**Figure 8**).

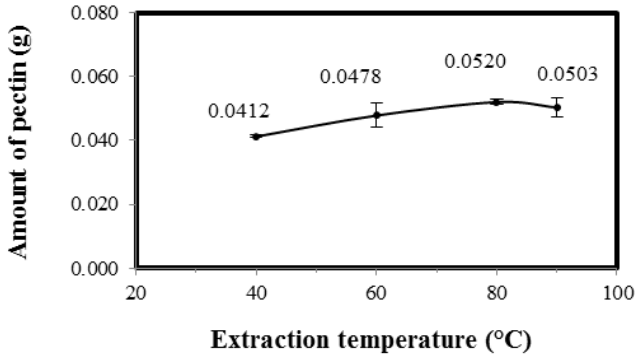

Figure 8 Effect of extraction temperature on pectin yield at pH 2 with 20 % of acetic acid for 90 min.

Extraction time

The extraction time was investigated at 2, 4 and 6 h. The decreasing results in pectin yield were obtained as the extraction time increased. The highest yield (5.72×10^{-2} g) was obtained when the extraction time was 2 h (**Figure 9**). The result was agreed with Jong *et al*. [2] who reported the extraction time should be between 60 and 70 min, in which pectin can be completely extracted and the gelling property can be retained. The results indicated a longer extraction time increased the free pectin hydrolysis, decreasing pectin yield. The pectin extraction rate may be impacted by lengthy extraction times since they may cause pectin chain molecules to degrade, affecting the degree of methylation, water binding capacity and viscosity [27,30,35-37].

In addition, in the process of pectin production, the time between adding acid and being precipitated by ethanol should be as short as possible. The acid can destroy glycoside bonds and ester bonds. The destructive augment with the increase of extraction time. The consequence is that the molecule weight of pectin deteriorates, and the quality for possible applications in food product formulations (e.g., gelling property) declines. Besides that, considering energy consumption, long-time extraction goes against saving energy. Based on the highest yield (5.72×10^{-2} g) obtained, 2 h was the optimum time for extraction.

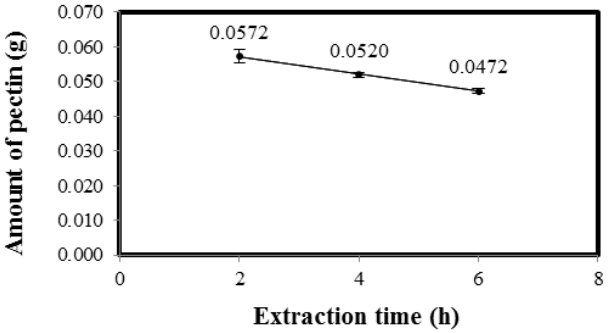

Figure 9 Effect of extraction time on pectin yield at pH 2 with 20 % of acetic acid at 80 °C.

In summary, in this study, pectin was extracted from Thai durian peel by microwave-assisted extraction (300 W, 5 min) followed by solvent extraction with acetic acid (AA) at pH 2 (solid to liquid ratio of 1:7, m/v). The extraction was performed at 80 °C for 2 h in a water bath. The pectin yield was 1.91 %. However, Hui *et al*. [16] reported the pectin yield from the white inner part of Malaysia durian peel (W-I) and the whole Malaysia durian peel (W-H) were 9.62 and 7.76 %, respectively, in a mildly acidic aqueous solution adjusted to pH 4.5 using citric acid (CA) (solid to liquid ratio of 1:10, m/v) at 95 °C for 20 min in a shaking water bath. Durian peel is rich in cell wall material such as α-cellulose, hemicellulose and lignin. This feature causes the peel in the durian rind sample to have decreased pectin yield, as the thorns could add to the total weight of the sample powder. To increase the amount of pectin extracted from durian peels (currently at 1.91 %), it is necessary to investigate different factors such as the solid-to-liquid ratio, type of acid extraction and parameter of MAE. Additionally, the concentration of AA, extraction temperature and extraction time should also be considered, according to Belkheiri *et al*. [38] the solid-to-liquid ratio typically falls between 1:10 and 1:50 for pectin extraction. When this ratio is less than 1:10, it leads to low pectin yields because the solvent is insufficient to dissolve and extract the pectin. An increase in the solid-to-liquid ratio (up to 1:30, m/v) increments regarding the pectin yield due to the rise in dissolution capacity. Pectin extraction yield increases following an increase in the solid-to-liquid ratio through an increase in the dissolution capacity [39]. Jong *et al*. [2] reported that the nature of organic acid AA (monoprotic acid) was weaker than CA (triprotic acid). Furthermore, the amount of pectin could differ depending on plant species, plant variety, plant tissues and growth stage. In addition, Chamyuang *et al*. [6] reported the pectin yield obtained by using MAE (900 W, 15 min) and not using (boiling at 90 °C, 90 min) were 9.3 ± 0.6 and 15.9 ± 0.4 %, respectively. It was noticed that the extracted yield with MAE was lesser than the expected yield. However, the conventional extraction of pectin required a lot of energy and involved using acids. In line with sustainable development goals, studies have been undertaken to assess the efficiency of non-conventional green extraction methods, such as MAE, on the yield and characteristics of pectin extracted from durian peel. In addition, the microwave power and irradiation time intervals should be investigated to ensure the highest yield.

Fourier transform infrared spectroscopy (FTIR) analysis

FTIR spectra of pectin were recorded using an FTIR spectrometer (Thermo Fisher Scientific, Waltham, USA) with a wavenumber ranging from 500 to 4,000.0 cm^{-1} in the attenuated total reflection (ATR) mode. The strong and broad absorption peak at 3,317.0 cm^{-1} was attributed to O-H stretching vibration due to the galacturonic acid backbone's intra- and intermolecular hydrogen bonding [23,44]. The band at 2,923.6 cm^{-1} indicated a characteristic of C-H stretching vibration from -CH, $-CH_2$ and $-CH_3$, methyl esters of galacturonic acid in polysaccharide components [35,45]. The strong band at 1,727.9 cm^{-1} corresponded to the carbonyl (C=O) in the methyl-esterified group ($-COOCH_3$). Meanwhile, the strong band at 1,635.5 cm^{-1} and the weaker band at 1,328.7 cm^{-1} represented the asymmetrical and symmetric

stretching vibration of carboxylate ion (COO^-), respectively [4,46]. The intensities of the 1,727.9 and 1,635.5 cm^{-1} absorption bands strongly suggested the high degree of esterification in pectin. The region below 1,300 cm^{-1} displayed the fingerprint region, which is unique and specific for each polysaccharide [47], while the spectra observed between 1,300 and 900 cm^{-1} corresponded to the ether R-O-R and cyclic C-C ring linkages of the pectin structure. The absorption bands for extracted pectin were in agreement with the known bands for commercial pectin (**Figure 10**).

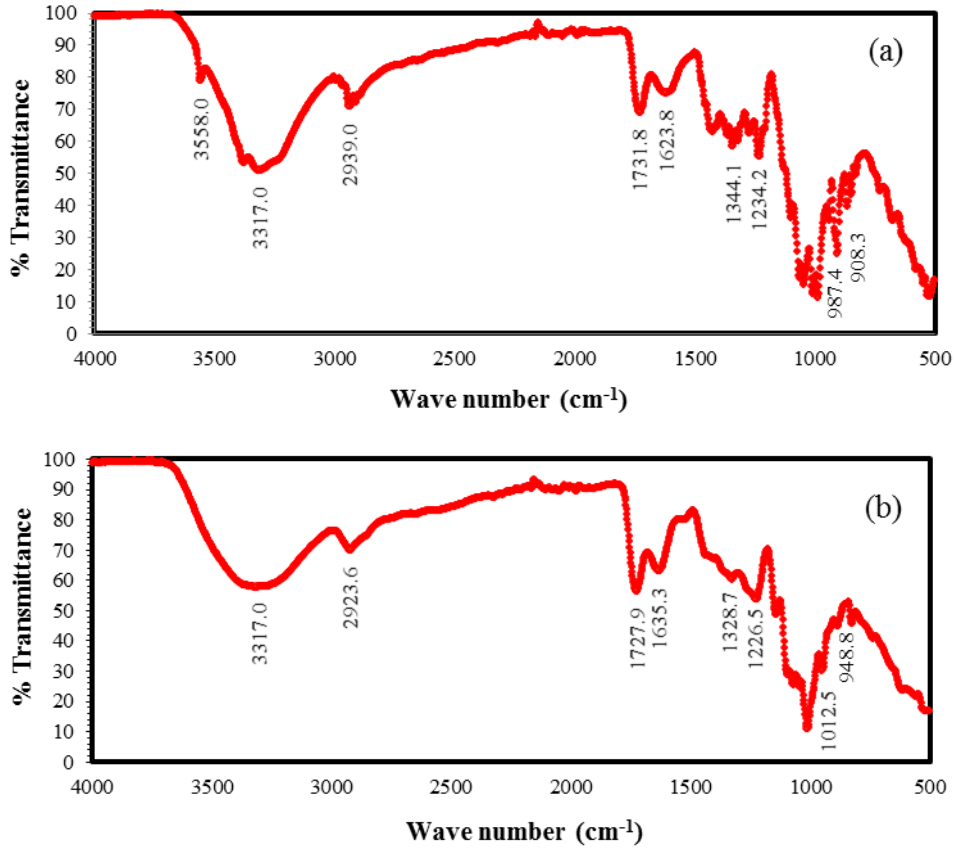

Figure 10 FTIR spectra for (a) commercial pectin and (b) durian peels pectin.

It is worth mentioning that the pectin extracted from durian peels has better thermal stability than commercial pectin, which is favorable for high-temperature food processing, e.g., baking cakes, bread and pastries [35]. It also exhibited greater gel strength than commercial pectin under the same gelling condition. It could be a suitable gelling and thickening agent for weak-acid-low-calorie food and pharmaceutical applications under a broad temperature range [40].

Economic and environmental benefits of extracting pectin from durian peels

Extracting pectin from durian peel has a few economic and environmental benefits. Firstly, durian peel is a natural source of pectin, which has become more valuable in recent years. Hence, pectin from a natural source is cheaper and safer, ensuring better pectin quality. Furthermore, using agricultural waste, durian peel, can reduce waste disposal and burning that causes several environmental pollutants and, at the same time, improve the economic value of durian peels [2]. The world's market demand for pectin has been growing quickly (> 7 % annual growth rate) due to the expanding consumer base for low-calorie and low-fat food products [41]. Moreover, the market size of pectin is expected to expand more rapidly than gelatin and starch [42]. Thus, there is a need to explore other sources of pectin. To date, few plant sources are used for pectin production, mainly citrus peel (85.5 %), apple pomace (14.0 %) and sugar beet pulp (0.5 %) [2]. Durian peels are a potential source of pectin. There are limited published data on the extraction and characterization of pectin from durian peel [16]. In response to the growing demand for pectin, other plant sources, such as durian rinds, could be explored as a potential alternative pectin resource. Moreover, the pectin precipitation and purification ethanol can be recycled or recovered by distillation, avoiding massive hazardous effluent disposal. Implementing a continuous ethanol recovery by distillation can be

advantageous from both operational and economic points of view, leading to a decrease in ethanol consumption by approximately 76 % [43].

However, studies on extracting and characterizing pectin from durian peels are limited. In future research, a comparison of different extraction methods or different types of acid extraction could be done. The extraction with deionized water should be the control for optimizing extraction steps, and pectin should be extracted for 1 h in a variation of extraction time. In addition, a more detailed characterization of durian rind pectin can be done. For instance, physicochemical properties (ash content, jelly grade, setting time and acetyl value) and rheological properties are important characteristics needed for application in various industries, such as the food industry.

Conclusions

The pectin was extracted from durian (*Durio zibethinus* Murray) peel cv. Long lab-lae by microwave-assisted extraction followed by solvent extraction. The optimum conditions for obtaining a pectin yield of 1.91 % were achieved when the concentration of acetic acid was 20 %, the extraction temperature was 80 °C, and the extraction time was 2 h. The pectin extraction was carried out at pH 2.0 because a higher pH significantly reduced the yield. The parameters during the pectin extraction process were investigated using acetic acid concentrations (10 - 40 %), extraction temperatures (40 - 100 °C) and extraction times (2 - 6 h). The parameters significantly influenced the yield, which decreased at a higher acid concentration, extraction temperature, and especially extraction time when the pectin turned into liquid at a higher temperature (100 °C). The FT-IR analysis confirmed the presence of functional groups in the fingerprint region of identification for polysaccharides in the extracted pectin. The FT-IR spectrum of the extracted durian peel pectin was extremely close to that of commercial pectin, which could pave the way for the utilization of pectin for food processing, for instance, gelling agent for weak-acid-low-calorie food and pharmaceutical applications. Furthermore, using agricultural waste, durian peels, can reduce the disposal and burning of waste to the environment, causing several pollutants, and at the same time, improve the economic value of durian peel.

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