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Original Article

Microwave-Assisted Extraction of Crude Pectin from Sitaya Citrus Processing Waste: Impact of Microwave Power on Yield and Characteristics

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Abstract

Citrus peels are produced in large quantities as a by-product of beverage production, leading to underutilization of waste. Sitaya agrihorti citrus is one of the citrus varieties used in the beverage industry because of its sweet taste. Wasted sitaya citrus peels contain components such as pectin. Microwave-assisted extraction (MAE) is a well-known innovative method, currently widely used in pectin extraction due to its efficiency and reduced processing time compared to conventional methods. This study used MAE at different power levels: 360, 450, 540, 630, and 720W, each applied for two minutes. The extracted pectin was evaluated for key properties, including equivalent weight, methoxyl content, galacturonic acid content, degree of esterification, and water content. This study aims to determine the effect of microwave power on pectin yield and quality. The results showed that microwave power significantly affected pectin yield ($p < 0.01$), with the highest yield of 12.103% obtained at 720W power. However, variations in microwave power did not significantly affect the physical or chemical characteristics of pectin extracted from Sitaya citrus peel. This study concluded that MAE is an effective extraction method for producing pectin from citrus peel waste, which offers a sustainable approach to agro-industrial waste management. The findings highlight the potential for increasing the value of orange peel through an efficient extraction process, contributing to economic and environmental sustainability while creating value-added products.

Keywords: citrus peel, extraction, microwave-assisted extraction, pectin
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Introduction

Pectin is a polysaccharide that is widely used in the food and pharmaceutical fields. Pectin is used as a thickener and stabilizer for food and drinks, as well as to bind tablets or capsules (Gurev et al. 2023). The degree of methylation of the galacturonic acid that produces pectin determines its functional properties. The demand for pectin has increased as a result of its expanding use and the growing popularity of natural and health-conscious products (Gawkowska et al. 2018). Citrus fruit peels (such as oranges and lemons) and apple pulp are the main sources of pectin.

Sitaya Agrihorti is a local variety of citrus originating from West Kalimantan, Indonesia. Sitaya Agrihorti citrus is used considerably in the beverage industry due to its unique sweet flavor. Waste citrus peel is produced during the processing of Sitaya Agrihorti citrus into processed beverages. Processing Sitaya Agrihorti in the beverage industry produces waste citrus peel. The citrus peel contains polysaccharide components such as pectin (Valdés et al. 2015; Zhang et al. 2016). Research on effective and eco-friendly extraction techniques to extract pectin from Sitaya Agrihorti citrus peel is encouraged by the fruit's potential as a source of pectin that has not been properly utilized.

Conventional techniques for extracting pectin include hot water extraction and acid solution extraction (Ilharco et al. 2016). Although this method is quite effective, it has several limitations, including a long processing time, a high temperature, and significant energy consumption. Furthermore, pectin produced using conventional methods frequently has low extraction yields and low purity levels. As a result, improvements in extraction technology are required to increase productivity while minimizing the negative impact that the extraction process causes on the environment (Picot-Allain et al. 2022).

Microwave-assisted extraction (MAE) is one of the methods that is being developed to overcome the limitations of conventional extraction methods. Applying MAE to pectin extraction can produce more pectin with better quality, making it an effective way to traditional extraction methods (Widiastuti 2015). Microwave-assisted extraction is an innovative method that has gained interest recently due to its capacity to extract bioactive chemicals from plant materials effectively (Rudke et al. 2022). Utilizing microwave energy in the extraction process enables expedited and homogeneous heating, leading to increased extraction yields and decreased extraction durations compared to conventional techniques. Moreover, MAE is renowned for its capacity to maintain the integrity of the extracted chemicals as a result of reduced extraction durations and decreased working temperatures (Widiastuti 2015; Abbas et al. 2021; Mali and Kumar 2023).

Pomelo peel extracted with MAE at 560 W microwave power for 30 minutes produced a pectin yield of 26.70% (Zhang et al. 2024). Microwave-assisted pectin extraction of banana peel showed positive effects on pectin extraction for HGA and RG-I regions. The highest AIS yield of 12.5% was achieved at 70 ◦C, 15 min (Mao et al. 2024). The pectin produced by using MAE at 110 ◦C,

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pH 2.2, for 10 minutes with a 1:2 supernatant to ethanol ratio demonstrated higher purity than commercial citrus pectin and had an equivalent weight of 833 mg, a methoxyl content of 7.44%, a degree of esterification of 66.67%, and content of galacturonic acid of 63.15% (Duggal et al. 2024).

An important benefit of MAE is its capacity to improve the extraction of pectin from plant sources (Sahraoui et al. 2011; Angiolillo et al. 2015). Studies involving the extraction of pectin from fruit peels by the MAE method have shown promising results. Factors such as raw materials, extraction time, temperature, microwave radiation strength, and the type of solvent used can affect the properties of the resulting pectin (Benmebarek et al. 2024). This study aims to determine how different MAE strengths affect the properties of Sitaya Agrihorti orange pectin.

Methods

Material

Sitaya Agrihorti peel was collected from KPRI Citrus Industry, Batu City East Java. Sitaya Agrihorti peel was dried with a food dehydrator at a temperature 55^0C for 6 hours. Dried citrus peel, then ground with a blender and stored in a vacuum before further treatment. Chemical materials such as HCL (Merck) and NaOH (Merck) from Kridatama Persada, Malang.

Pectin extraction

The method for pectin extraction refers to research (Widiastuti 2015) with modification. The Sitaya Agrihorti peel powder that has been obtained is first weighed in the amount of 5 grams. Then put it in a 250 ml Erlenmeyer flask and add 0.5 N HCl solvent with a volume of 100 ml. Next, the sample is put into the microwave. The microwave is turned on and set to power according to the treatment: 360, 450, 540, 630, and 720W. After that, start the microwave and wait for 2 minutes. After 2 minutes, the sample was removed and cooled first. When cool, the sample was then centrifuged at 3000 rpm for 10 minutes. After that, the sample will fall into 2 phases, namely filtrate and residue. Then, the filtrate was taken and put into a 250 ml beaker. Next, 96% ethanol was added to the filtrate in a ratio of 1:1. The function of 96% ethanol is to precipitate pectin. Then, the sample was closed and left at 40^0C for 24 hours. The washed pectin was dried using a dehydrator at 50^0C for 3 hours. After obtaining dry pectin, the pectin is then crushed until it forms powder.

Pectin analysis

Pectin yield

The pectin yield is calculated by weighing the dry weight of the extracted pectin and entering it into the following formula (Benmebarek et al. 2024) :

$$Pectin\ yield: \frac{weight\ of\ dried\ pectin\ (g)}{initial\ weigth\ of\ sample\ (g)} x100$$

Moisture content

Moisture content analysis by preparing a cup as a container to place the pectin sample (Sulihono et al. 2012). Dry the cup in the oven at a temperature of 100-105℃ for 3 hours. Remove the cup and put it in a desiccator for 10 minutes. Weigh and record the weight of the cup. Add 0.25 grams of dry pectin sample. Reweigh the cup containing the sample. The cup containing the sample is put in the oven for 3 hours. Remove the cup and put it back in the desiccator for 10 minutes. Do the same process until a constant weight is obtained.

Equivalent weight

Equivalent weight was analyzed by weighing 0.5 grams of dry pectin (Sulihono et al. 2012). Moisten the dry pectin with 5 mL of 96% ethanol. Add 1 gram of NaCl to sharpen the titration point and add 100 mL of distilled water. The mixture is stirred until there are completely dissolved. The mixture is added with 6 drops of PP indicator and titrated with 0.1 N NaOH until the color changes to pink (constant) for approximately 30 seconds. Record the volume of titrant used to be included in the following formula:

$$Equivalent\ weight: \frac{weight\ of\ sample\ x\ 1000}{ml\ of\ alkali\ x\ concentration\ of\ alkali}$$

Methoxyl content (MeO)

Methoxyl content analysis was carried out using a neutral solution from the equivalent weight analysis results (Sulihono et al. 2012). The solution is added with 25 mL of 0.25 N NaOH. The solution is stirred and left for 30 minutes in a closed state at room temperature. Add 25 mL of 0.25 N HCl solution and 5 drops of phenolphthalein indicator (PP). Titrate with 0.1 N NaOH until the color changes to pink (constant). Record the volume of titrant used to be included in the following formula:

$$MeO: \frac{ML\ OF\ NaOH\ Xconcrentation\ of\ alkali\ x\ 31}{weight\ of\ sample} x100$$

Galacturonic acid (GalA)

Calculation of galacturonic acid levels was carried out using titrant data from measurements of equivalent weight and methoxyl content (Devi et al. 2014). The titrant data is entered into the following formula:

$$GalA: \frac{176\ x\ 0.1\ z\ x\ 100}{weight\ of\ samplex1000} + \frac{176\ x\ 0.1\ y}{weight\ of\ samplex1000}$$

While : z = titrant (mL) of equivalent weight and y = titrant (mL) of methoxyl content

Degree of esterification (DE)

The analysis of the degree of esterification is carried out from the methoxyl and galacturonic acid content values into the following formula (Devi et al. 2014):

$$DE: \frac{176\ X\ \%\ metoxil}{31\ x\ \%\ GalA}$$

Statistical analysis

Characterization of the pectin obtained will be analyzed by Analysis of Variant (ANOVA) using the Minitab software. If a significant difference is shown, it will be continued with the Tukey test through a 5% confidence interval.

Result & Discussion

Pectin characteristics

The sample solution was separated into two distinct phases during the precipitation process. At the bottom of the bottle, pectin created a thick, sticky layer after purification. After purification, pectin turned into a gel-like substance, and after drying, pectin solidified into coarse granules. The isolated pectin is shown in Figure 1. Wet pectin in Figure 1(a) resembles a white gel in both its form and its consistency. A compact texture is produced when 96% ethanol is added to the filter during the washing procedure. Wet gel pectin is created when this ethanol is added because it affects the stability of the colloidal dispersion.

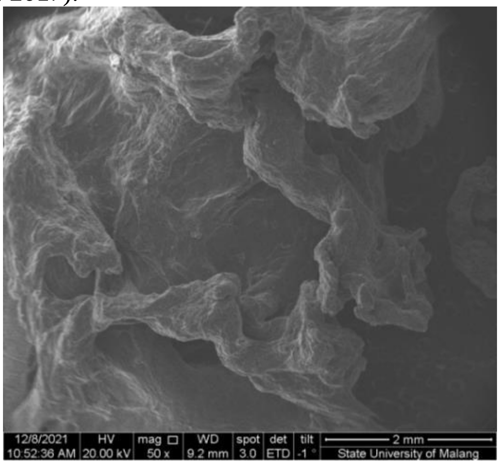
Pectin is a hydrophilic polysaccharide that can interact extensively with water molecules in a solution. The interaction between pectin and water occurs because the pectin chain can form a hydrogen bond with the molecule of water (Saadah Said 2023). Pectin molecules interact with one another as a result of reduced water activity, forming a three-dimensional helical structure that eventually gels. The dehydration properties of each organic solvent may be related to the density and compactness of the pectin gel structure that results from their addiction (Gawkowska et al. 2018). Dried pectin, as shown in Figure 1(b), has a hard color, flaky texture, and irregular shape. Pectin turns white color when washed, although it still contains organic materials, pigments, and sugars (mono-and disaccharides). After drying, ethanol is evaporated, reducing the volume of pectin and showing the mass composition of the mixture (Wang et al. 2023).

Dried pectin, as shown in Figure 1(b), has a hard color, flaky texture, and irregular shape. Pectin turns white color when washed, although it still contains organic materials, pigments, and sugars (mono-and disaccharides). After drying, ethanol is evaporated, reducing the volume of pectin and showing the mass composition of the mixture (Wang et al. 2023).

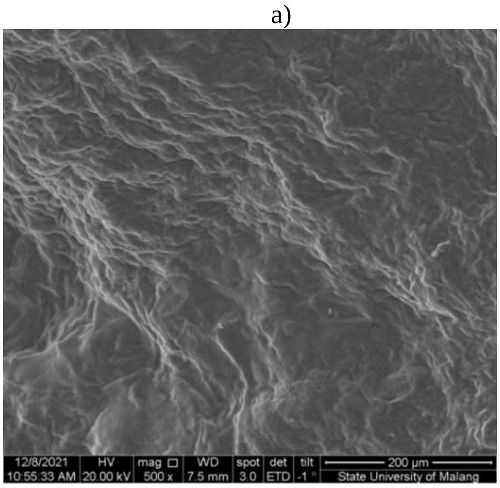
a) b)

Figure 1. a) wet pectin; b) dry pectin

Figure 2 is a micrograph of SEM results at different magnifications. The purpose of SEM analysis is to visually determine the characteristics of the morphological structure on the surface of dry pectin particles from extraction. The extracted pectin has a large and flaky particle size. Liew et al., (2014) explained that mound-shaped pellets appeared on the pectin surface when the extracted pectin was dried, suggesting that drying had certain detrimental and swelling effects on the pectin structure. The source of raw materials and extraction methods can affect the morphology of the resulting pectin. Pectin particles with a porous structure have better solubility than particles with a rigid structure and lower porosity. This is because the surface area is larger so that it can absorb and retain more water (Begum et al. 2017).



a)



b)

Figure 2. SEM of dry pectin at 50x and 500x magnification

Characteristics yield, moisture content, and galacturonic acid

Using various microwave power levels had a statistically significant impact on pectin yield. Table 1 displays the mean pectin yield obtained using the MAE technique. The pectin output from Sitaya Agrihorti citrus peel varies between 7.798% and 12.103%. The highest yield was obtained in extraction with a power of 720W, and the lowest yield was obtained in an extraction with a power of 360W. The greater the microwave power used, the higher the pectin yield produced. At high power, the temperature increases, causing a decrease in viscosity and surface tension, which facilitates the solvent to dissolve the sample and increase wetting and penetration into the medium (Assous et al. 2007).

Table 1. The Characteristics of yield, moisture content, and galacturonic acid of Citrus Pectin

No.	Power (W)	Yield (%)	Moisture content (%)	Galacturonic acid (%)
1.	360	7.798[a]	18.6[a]	48.88[a]
2.	450	9,168[ab]	17.5[a]	47.39[a]
3.	540	9,462[ab]	19[a]	55.04[a]
4.	630	10,660[bc]	16.8[a]	50.86[a]
5.	720	12,103[c]	19.8[a]	46.46[a]

The power on the microwave provides local heating within the sample, which acts as a driving force for the microwave to destroy the medium. The interaction of molecules with electromagnetic fields causes rapid energy transfer and can destroy matrix components. HCL, as a solvent, can absorb microwave energy well and produce heat efficiently. In addition, microwave irradiation accelerates cell rupture with a sudden increase in temperature. It increases the internal pressure inside plant cells, which promotes the destruction of the surface of the medium. Therefore, the solute can diffuse out and dissolve in the solvent quickly (Tongkham et al. 2017).

The use of different microwave power did not have a significantly different effect on the moisture content of pectin. The moisture content of pectin produced from Sitaya Agrihorti citrus peel ranges from 16.8-19.8%. The highest water content was obtained in extraction with a power of 720W and the lowest water content was obtained in an extraction with a power of 630W. An increase in temperature and extraction duration increases the volume of water evaporated during the extraction process, consequently facilitating the drying process and resulting in a reduced pectin water content. High temperatures can hydrolyze pectin polymers, resulting in the reduction of molecular chain length. The shorter the pectin polymer chain, the more facile the drying process due to reduced water retention (Injilauddin et al., 2015).

The use of different microwave power had an effect that was not significantly different at the level of $p<0.05$ on pectin galacturonic acid levels. The galacturonic acid pectin content produced from Sitaya orange peel ranges from 46.46-55.04%. The highest galacturonic acid levels were obtained in extraction with 540W power, and the lowest galacturonic acid levels were obtained in extraction with 720W power. The galacturonic content of pectin increases with increasing extraction temperature due to the hydrolysis reaction of protopectin into pectin, the basic component of which is D-galacturonic acid. High temperatures break the glycosidic bonds of the methyl ester group to produce galacturonic acid, which causes glucuronate levels to increase. Pectin is composed of galacturonic acid molecules linked by α-(1 -4)-glycoside bonds to form polygalacturonic acid. The carboxyl group is partly certified with methanol, and the secondary alcohol group is acetylated (Musita 2021).

Characteristics degree of esterification, equivalent weight, and methoxyl content

(Lara-Espinoza et al. 2018). Low methoxy pectin is suitable when applied to food products such as low-calorie

The degree of esterification (DE) is used to classify pectin because the degree of esterification will determine the gelling properties of the pectin. Pectin can be divided into 2 groups based on its DE. High methoxyl pectin (HMP) has an esterification degree value of greater than 50%, that is, more than half of the carboxyl groups are in the form of methyl esters and low methoxyl pectin (LMP), namely pectin that has an esterification degree value of less than 50%. HMP and LMP have different gelation mechanisms (Picot-Allain et al. 2022).

DE pectin produced from Sitaya citrus peel ranges from 42.50% -52.17%. The highest DE was obtained in extraction with 540W power and galacturonic acid content the lowest was obtained at extraction with a power of 630W. DE pectin shows the percentage of carbonyl groups esterified with methanol. DE pectin will decrease with increasing temperature. High temperatures in the extraction process can cause degradation of the methyl ester groups in pectin into carboxyl acids due to the presence of acid. The acid used in pectin extraction will hydrolyze hydrogen bonds. The glycosidic bonds of the methyl ester groups of pectin tend to be hydrolyzed to produce galacturonic acid (Chandel et al. 2022).

Table 2 shows that the methoxyl content of Sitaya citrus peel pectin ranged between 3.526% and 5.022%, with all results remaining below 7%. This indicates that the extracted pectin is included in the category of low methoxyl pectin (Low Methoxyl Pectin), indicating that the methoxyl content is low (Devi et al. 2014). The 540W microwave power produced the highest methoxyl content of 5.022%, while the 450W and 720W microwave powers produced the lowest methoxyl content of 3.534% and 3.526%, respectively. The statistical results showed that the microwave power treatment did not affect the methoxyl content of pectin.

Table 2. The Characteristics degree of esterification, equivalent weight, and methoxyl level of citrus pectin

No.	Power (W)	Degree of esterification (%)	Equivalent weight (mg)	Methoxyl level (%)
1.	360	45.38[a]	696.2[a]	3.891[a]
2.	450	43.35[a]	700[a]	3.534[a]
3.	540	52.17[a]	715[a]	5.022[a]
4.	630	42.50[a]	635,7[a]	3.743[a]
5.	720	43.03[a]	707,5[a]	3.526[a]

Previous research that conducted pomelo pectin extraction using the subcritical water extraction method produced low methoxyl pectin with a yield of 19.6% (Liew et al. 2018). The final texture of a food is greatly influenced by the gel formation of pectin. The addition of sugar at a concentration of 10–20 percent can reduce syneresis and improve texture in pectins with low methoxyl content by changing the calcium to pectin ratio. High pectin content with relatively little calcium will produce an elastic gel, while the use of more calcium with less pectin will produce a much more fragile product

jam and dairy products such as ice cream and yogurt (Singhal and Swami Hulle 2022).

Conclusion

Sitaya citrus peel waste can be utilized and increase its economic value by extracting the natural pectin content in orange peels. Pectin is extracted using the Microwave Assisted Extraction method with power treatment. The microwave power used affects the pectin yield produced. The highest yield was obtained from extraction with 720W power treatment for 2 minutes, namely 12.103%. The pectin is then analyzed for its characteristics which include equivalent weight, methoxyl content, galacturonic acid content, degree of esterification, and water content. It is known that microwave power treatment has no significant effect on the pectin characteristics of sitaya orange peel.

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Reference

Abbas M, Ahmed D, Qamar MT, et al (2021) Optimization of ultrasound-assisted, microwave-assisted and Soxhlet extraction of bioactive compounds from Lagenaria siceraria: A comparative analysis. Bioresour Technol Reports 15:100746. https://doi.org/10.1016/j.biteb.2021.100746

Angiolillo L, Nobile MA Del, Conte A (2015) The extraction of bioactive compounds from food residues using microwaves. Curr Opin Food Sci

Arimpi A, Pandia S (2019) Pembuatan Pektin dari Limbah Kulit Jeruk (Citrus Sinensis) dengan Metode Ekstraksi Gelombang Ultrasonik menggunakan Pelarut Asam Sulfat (H2so4). J Tek Kim USU 8:18–24

Assous M, Abd El-Wahab E, El-Waseif K (2007) Effect of Microwave Power on Quality Parameters of Pectin Extracted From Mango Peel. Arab Univ J Agric Sci 15:395–403. https://doi.org/10.21608/ajs.2007.14950

Begum R, Yusof YA, Aziz MG, Uddin MB (2017) Structural and functional properties of pectin extracted from jackfruit (Artocarpus heterophyllus) waste: Effects of drying. Int J Food Prop 20:S190–S201. https://doi.org/10.1080/10942912.2017.1295054

Benmebarek IE, Gonzalez-Serrano DJ, Aghababaei F, et al (2024) Optimizing the microwave-assisted hydrothermal extraction of pectin from tangerine by-product and its physicochemical, structural, and functional properties. Food Chem X 23:. https://doi.org/10.1016/j.fochx.2024.101615

Chandel V, Biswas D, Roy S, et al (2022) Current Advancements in Pectin: Extraction, Properties and Multifunctional Applications. Foods 11:1–30. https://doi.org/10.3390/foods11172683

Devi WE, Shukla RN, Bala KL, et al (2014) Extraction of Pectin from Citrus Fruit Peel and Its Utilization in Preparation of Jelly. Int J Eng Res Technol 3:1925–1932

Duggal M, Singh DP, Singh S, et al (2024) Microwave-assisted acid extraction of high-methoxyl kinnow (Citrus reticulata) peels pectin: Process, techno-functionality, characterization and life cycle assessment. Food Chem Mol Sci 9:. https://doi.org/10.1016/j.fochms.2024.100213

Gawkowska D, Cybulska J, Zdunek A (2018) Structure-related gelling of pectins and linking with other natural compounds: A review. Polymers (Basel) 10:. https://doi.org/10.3390/polym10070762

Gurev A, Cesko T, Dragancea V, et al (2023) Ultrasound- and Microwave-Assisted Extraction of Pectin from Apple Pomace and Its Effect on the Quality of Fruit Bars. Foods 12:1–20. https://doi.org/10.3390/foods12142773

Ilharco LM, Pagliaro M, Fidalgo A, et al (2016) Eco-Friendly Extraction of Pectin and Essential Oils from Orange and Lemon Peels. https://doi.org/10.1021/acssuschemeng.5b01716

Injilauddin AS, Lutfi M, Nugroho A (2015) Pengaruh suhu dan waktu pada proses ekstraksi pektin dari kulit buah nangka (Artocarpus heterophyllus). J Keteknikan Pertan Trop dan Biosist 3:280–286

Lara-Espinoza C, Carvajal-Millán E, Balandrán-Quintana R, et al (2018) Pectin and pectin-based composite materials: Beyond food texture. Molecules 23:. https://doi.org/10.3390/molecules23040942

Liew SQ, Chin NL, Yusof YA (2014) Extraction and Characterization of Pectin from Passion Fruit Peels. Agric Agric Sci Procedia 2:231–236. https://doi.org/10.1016/j.aaspro.2014.11.033

Liew SQ, Teoh WH, Tan CK, et al (2018) Subcritical water extraction of low methoxyl pectin from pomelo (Citrus grandis (L.) Osbeck) peels. Int J Biol Macromol 116:128–135. https://doi.org/10.1016/j.ijbiomac.2018.05.013

Mali PS, Kumar P (2023) Optimization of microwave assisted extraction of bioactive compounds from black bean waste and evaluation of its antioxidant and antidiabetic potential in vitro. Food Chem Adv 3:100543. https://doi.org/10.1016/j.focha.2023.100543

Mao Y, Dewi SR, Harding SE, Binner E (2024) Influence of ripening stage on the microwave-assisted pectin extraction from banana peels: A feasibility study targeting both the Homogalacturonan and Rhamnogalacturonan-I region. Food Chem 460:. https://doi.org/10.1016/j.foodchem.2024.140549

Musita N- (2021) Characteristics of Pectin Extracted from Cocoa Pod Husks. Pelita Perkeb (a Coffee Cocoa Res Journal) 37:62–75. https://doi.org/10.22302/iccri.jur.pelitaperkebunan.v37i1.428

Picot-Allain MCN, Ramasawmy B, Emmambux MN (2022) Extraction, Characterisation, and Application of Pectin from Tropical and Sub-Tropical Fruits: A Review. Food Rev Int 38:282–312. https://doi.org/10.1080/87559129.2020.1733008

Rudke AR, da Silva M, Andrade CJ de, et al (2022) Green extraction of phenolic compounds and carrageenan from the red alga Kappaphycus alvarezii. Algal Res 67:. https://doi.org/10.1016/j.algal.2022.102866

Saadah Said NI young lee (2023) Pectin Hydrogels: Gel-Forming Behaviors, Mechanisms, and Food Applications. 1–28

Sahraoui N, Vian MA, El Maataoui M, et al (2011) Valorization of citrus by-products using Microwave Steam Distillation (MSD). Innov Food Sci Emerg Technol 12:163–170. https://doi.org/10.1016/j.ifset.2011.02.002

Singhal S, Swami Hulle NR (2022) Citrus pectins: Structural properties, extraction methods, modifications and applications in food systems – A review. Appl Food Res 2:. https://doi.org/10.1016/j.afres.2022.100215

Sulihono A, Tarihoran B, Agustina TE (2012) JENIS PELARUT TERHADAP EKSTRAKSI PEKTIN DARI KULIT JERUK BALI (CITRUS MAXIMA). 18:1–8

Tongkham N, Juntasalay B, Lasunon P, Sengkhamparn N (2017) Dragon fruit peel pectin: Microwave-assisted extraction and fuzzy assessment. Agric Nat Resour 51:262–267. https://doi.org/10.1016/j.anres.2017.04.004

Valdés A, Burgos N, Jiménez A, Garrigós MC (2015) Natural pectin polysaccharides as edible coatings. Coatings 5:865–886. https://doi.org/10.3390/coatings5040865

Wang H, Zhu Y, Li D, Zhu C (2023) Characterization of hawthorn pectin gained via different ethanol concentrations. Food Sci Nutr 11:2663–2676. https://doi.org/10.1002/fsn3.3321

Widiastuti DR (2015) Ekstraksi Pektin Kulit Jeruk Bali Dengan Microwave Assisted Extraction Dan Aplikasinya Sebagai Edible Film. Universitas Negeri Semarang

Zhang T, Lan Y, Zheng Y, et al (2016) Identification of the bioactive components from pH-modified citrus pectin and their inhibitory effects on galectin-3 function. Food …

Zhang X, Zhuang X, Chen M, et al (2024) An environmentally friendly production method: The pectin and essential oil from the waste peel of juvenile pomelo (Citrus maxima ‘Shatian Yu’) were extracted simultaneously in one step with an acid-based deep eutectic solvent. Lwt 206:. https://doi.org/10.1016/j.lwt.2024.116622