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Physicochemical Characteristics and Molecular Structure of Pectin Extract from Rambutan (Nephelium lappaceum) Peel Waste as a Thickening and Gelling Agent: A Narrative Literature Review

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Abstract : *Rambutan peel (Nephelium lappaceum L.) is an agricultural waste product with potential as an alternative source of pectin, offering opportunities to increase the value of fruit by-products. This study aims to examine the relationship between extraction conditions, physicochemical characteristics, and molecular structure of rambutan peel pectin, particularly in relation to its potential food applications. A Narrative Literature Review was conducted by examining studies on conventional acid extraction, pulsed electric field-assisted extraction, and pectin characterization. The reviewed studies were compared based on extraction methods, solvent types, temperature, extraction time, yield, moisture content, ash content, methoxyl content, galacturonic acid content, and degree of esterification. The findings indicate that conventional acid extraction of rambutan peel has produced pectin yields of approximately 6.5–8%, with reported values varying according to extraction conditions. Alternative extraction methods, including pulsed electric field-assisted extraction, have also demonstrated potential for producing pectin with different physicochemical characteristics. These findings indicate that extraction conditions influence pectin yield and chemical composition. Although galacturonic acid content, methoxyl content, and degree of esterification provide information about pectin quality and functional potential, they do not directly establish its viscosity or gel-forming ability. Therefore, further rheological and gel-strength testing is required to confirm its performance as a thickening and gelling agent. Rambutan peel consequently represents a promising alternative pectin source and supports the valorization of agricultural waste..*

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Introduction

Rambutan (Nephelium lappaceum L.) is a tropical fruit widely cultivated and consumed in Indonesia. High rambutan consumption results in large amounts of fruit peel waste that has not been optimally utilized. However, rambutan peel has the potential to be a source of value-added compounds, including pectin, which can be utilized in the food industry. Utilizing rambutan peel waste as a raw material for pectin is an alternative to increase the utility value of agricultural by-products while reducing the amount of organic waste. Furthermore, rambutan peel contains bioactive compounds, including anthocyanins, which have the potential to provide added value when used as a functional raw material (Albuquerque et al., 2023).

Pectin is a natural polysaccharide found in the cell walls of plants, particularly fruits and vegetables. In the food industry, pectin is widely used as a thickener, gelling agent, and stabilizer due to its ability to influence product texture and consistency. Pectin is used in various products, such as jams, jellies, and other food products that require specific textural characteristics. The functional properties of pectin are related to its physicochemical characteristics and chemical composition, including methoxyl content, galacturonic acid content, and degree of esterification. Differences in these characteristics can affect pectin's gelling ability and determine its suitability for specific food applications (Chandel et al., 2022).

The characteristics of pectin are closely related to its molecular structure. Pectin is a complex polysaccharide whose primary structure consists of galacturonic acid units, with some carboxyl groups subject to esterification by methyl groups. Differences in the degree of esterification affect pectin's properties, particularly its gel formation. Based on the degree of esterification, pectin is generally divided into high-methoxyl pectin and low-methoxyl pectin, which have different gel formation mechanisms. An understanding of molecular structure is necessary to explain the relationship between pectin's chemical composition and its potential in food applications (Chandel et al., 2022).

The physicochemical characteristics of pectin are important aspects that need to be studied to determine its quality and potential use as a food additive. Several parameters that can be used to characterize pectin include yield, water content, ash content, equivalent weight, methoxyl content, galacturonic acid content, and degree of esterification. Galacturonic acid content is related to pectin purity, while methoxyl content and degree of esterification are related to its functional properties, especially gel-forming ability. Pectin with low and high methoxyl content has different gel-forming characteristics, allowing it to be used according to the needs of food product formulations. Therefore, testing the physicochemical characteristics is necessary to evaluate the quality of extracted pectin and estimate its potential applications (Aziz et al., 2018; Chandel et al., 2022).

The physicochemical properties of pectin can be determined through several parameters, such as yield, water content, ash content, equivalent weight, methoxyl content, galacturonic acid content, and degree of esterification. Yield indicates the amount of pectin obtained from the extraction process, while water and ash content describe the characteristics of the extracted material. Meanwhile, methoxyl content, galacturonic acid content, and degree of esterification are related to the composition and chemical characteristics of pectin. These parameters are important for evaluating pectin quality and estimating its suitability as a food additive (Chandel et al., 2022).

In addition to its physicochemical characteristics, the molecular structure of pectin is also an important aspect in understanding its properties and functions. Pectin is composed primarily of galacturonic acid units forming polysaccharide chains, with carboxyl groups partially esterified by methyl groups. The degree of esterification and the presence of methoxyl groups are related to the chemical characteristics of pectin and its behavior in gel formation. These structural changes can occur during the extraction process, primarily due to the effects of temperature, time, and solvent acidity. Extraction under inappropriate conditions can cause hydrolysis or degradation of the pectin chains, thus affecting the characteristics of the resulting product. Therefore, studies on molecular structure are necessary to complete the understanding of the relationship between pectin's chemical composition and its functional properties (Chandel et al., 2022; Suwoto et al., 2017).

The gelling ability of pectin is influenced by its chemical characteristics and the conditions of the food system. High-methoxyl pectin generally forms gels under high sugar content and acidic pH

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conditions, while low-methoxyl pectin can gel with the aid of calcium ions. In addition to its gelling properties, pectin is also used to increase viscosity and help maintain the stability of food products. These differences in characteristics make testing the physicochemical properties of pectin crucial for determining its potential use in various food formulations (Chandel et al., 2022).

The extraction process is one of the factors that determine the characteristics of pectin obtained from rambutan peel waste. Istrada et al. (2026) reported that temperature and extraction time significantly affect the yield, water content, ash content, equivalent weight, methoxyl content, galacturonic acid content, and degree of esterification of rambutan peel pectin. In this study, extraction using an acid solvent at 80 °C for 120 minutes resulted in a yield of 7.34%. The obtained pectin had a water content of 9.51%, ash content of 2.59%, methoxyl content of 6.42%, galacturonic acid content of 59.93%, and degree of esterification of 55.75%. These results indicate that adjusting the extraction conditions plays a role in producing pectin with characteristics suitable for further study as a functional ingredient. The research of Laiya et al. (2021) also discussed the physicochemical characteristics of pectin from rambutan peel waste, so that it can be a comparative source to understand the variations in pectin characteristics based on extraction conditions.

Based on the above description, a study of the physicochemical characteristics and molecular structure of pectin extracted from rambutan peel waste is important to understand its potential use in the food industry. This article was compiled using a narrative literature review method to examine information from previous studies regarding the chemical composition, physicochemical characteristics, molecular structure, and the relationship between these characteristics and the ability of pectin as a thickening and gelling agent. This study is expected to provide an overview of the potential of rambutan peel waste as an alternative pectin source and serve as a basis for evaluating opportunities for its use in food product development.

Research methods

This study uses a literature review method with a descriptive approach to examine the characteristics of pectin extraction from rambutan peel waste (Nephelium lappaceum L.). The study was conducted by reviewing scientific journals that discuss the pectin extraction process, factors that influence the extraction process, and the physicochemical characteristics of the resulting pectin. The main source used is the study by Istrada et al. (2026) entitled The Effect of Temperature and Extraction Time on the Physicochemical Properties of Pectin Extracted from Rambutan Peel Waste (Nephelium lappaceum L.). Information from the journal was used as a basis for understanding the effect of temperature and extraction time on the yield and quality of pectin obtained from rambutan peel waste.

Data collection was conducted through a documentation study of scientific articles relevant to the research topic. The data reviewed included the pectin extraction method, the type of solvent used, variations in temperature and extraction time, the pectin precipitation process, and physicochemical characteristics parameters including yield, water content, ash content, equivalent weight, methoxyl content, galacturonic acid content, and degree of esterification. The data were then grouped based on extraction process variables and pectin characterization results to facilitate the analysis and comparison of information.

Data analysis was conducted descriptively by identifying the relationship between extraction conditions and the characteristics of the resulting pectin. Research results in major journals were compared based on variations in extraction temperatures of 70, 80, and 90 °C and extraction times of 60, 90, and 120 minutes. Furthermore, the study results were interpreted to determine the extraction conditions that provide optimal results and changes in pectin characteristics due to different treatments. Based on research by Istrada et al. (2026), extraction using 0.1 N HCl solution at 80 °C for 120 minutes resulted in a pectin yield of 7.34%. These results form the basis for discussing the potential use of rambutan peel waste as an alternative pectin source.

Results and Discussion

Rambutan (Nephelium lappaceum L.) peel is an agricultural byproduct with the potential to be used as an alternative pectin source for the food industry. Utilizing rambutan peel can increase the value of organic waste while supporting the development of food additives based on local resources. Pectin is a complex polysaccharide found in plant cell walls and plays a role in maintaining plant tissue structure. The pectin content of plant materials can vary depending on the plant species, maturity level, raw

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material conditions, and extraction method used. Research by Laiya et al. (2021) discussed the physicochemical characteristics of pectin from rambutan peel waste, while Istrada et al. (2026) examined the effect of temperature and extraction time on the characteristics of the resulting pectin. Both studies provide the basis for evaluating the potential of rambutan peel as a pectin source based on its extraction results and chemical characteristics.

The primary structure of pectin is dominated by galacturonic acid units forming polysaccharide chains, accompanied by neutral sugar components and branched segments. Differences in composition and molecular arrangement can affect pectin's solubility, viscosity, and gel-forming ability. Therefore, pectin from rambutan peel cannot be directly assumed to have the same characteristics as citrus or apple pectin. Comparison with pectin from other sources is necessary to understand the variation in pectin properties, but the results must still take into account differences in raw materials and extraction procedures. Specifically characterizing rambutan peel pectin is a crucial step in determining its potential use in food formulations (Chandel et al., 2022).

The extraction process is a key factor determining the amount and characteristics of pectin obtained from rambutan peel. Conventional extraction using acidic solvents helps release pectin from plant tissue through the influence of acidity and heating conditions. Temperature, time, acid concentration, and the ratio of material to solvent can affect the amount of pectin extracted. Increasing the treatment intensity can facilitate pectin release, but conditions that are too strong can also cause hydrolysis and changes in the polysaccharide structure. Therefore, extraction conditions need to be optimized to achieve adequate yield without compromising product quality (Chandel et al., 2022).

Laiya et al. (2021) reported the characteristics of rambutan peel pectin obtained through extraction using HCl solvent with varying concentrations. Under extraction conditions using 0.3 N HCl, the study reported a yield of 8.02%, a moisture content of 10.584%, an ash content of 4.37%, a methoxyl content of 4.65%, and a galacturonic acid content of 91.61%. Meanwhile, Istrada et al. (2026) examined the effect of variations in temperature and extraction time and reported a yield of 7.34% using 0.1 N HCl, a temperature of 80 °C, and a time of 120 minutes. The difference in the results of the two studies indicates that pectin characteristics need to be analyzed by considering the extraction conditions used. The yield values from the two studies cannot be compared as a direct measure of method effectiveness because the solvent concentrations and treatment variables were different.

Alternative extraction methods also have the potential to increase pectin release from rambutan peel tissue. Wicaksono et al. (2026) studied the use of pulsed electric fields (PEF), a technology that uses electric field pulses to increase cell membrane permeability and facilitate the release of components from plant tissue. The use of this method needs to be evaluated based on yield, chemical characteristics, energy requirements, and process efficiency. Comparisons between conventional extraction and alternative methods also need to consider the uniformity of the raw materials, initial sample conditions, and yield calculation methods. Therefore, the most appropriate extraction method is determined not only by the amount of pectin produced, but also by its quality, efficiency, and potential application in the food industry.

Physicochemical characteristics are used to evaluate the quality of extracted pectin and predict its suitability as a food additive. Common parameters analyzed include yield, moisture content, ash content, equivalent weight, methoxyl content, galacturonic acid content, and degree of esterification. Yield indicates the proportion of product obtained from the extraction process, while moisture content relates to storage conditions and product stability. Ash content provides information about inorganic residues in the sample, while galacturonic acid content is used to assess the composition and relative purity of the pectin. Using these parameters together can provide a more comprehensive picture of pectin quality than assessment based on yield alone (Chandel et al., 2022).

The research results of Laiya et al. (2021) showed that rambutan peel pectin has physicochemical characteristics that can be evaluated through methoxyl and galacturonic acid levels. However, the results of this study need to be distinguished from those of Istrada et al. (2026) and Wicaksono et al. (2026) because each used different extraction conditions and characterization approaches. Differences in raw materials, pretreatment, and analytical procedures can affect the obtained parameter values. Therefore, comparisons between publications must include information regarding

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experimental conditions to avoid erroneous conclusions. This approach is also necessary to determine the characteristics of rambutan peel pectin that are most relevant for food applications.

Methoxyl content and degree of esterification are interrelated parameters, but they have different meanings. Methoxyl content indicates the methoxyl group content in pectin based on the analytical method used, while degree of esterification indicates the proportion of galacturonic acid carboxyl groups that are in the esterified form. The distinction between these two parameters is important because the degree of esterification relates to the number of free carboxyl groups that can interact with other components in the food system. Pectin with a high and low degree of esterification can exhibit different gel formation mechanisms. Therefore, characterizing methoxyl content and degree of esterification is necessary to estimate the functional properties of pectin, but cannot replace direct viscosity and gel strength testing (Chandel et al., 2022).

The molecular structure of pectin is crucial for explaining the relationship between its chemical composition and behavior in food systems. Pectin is composed primarily of chains rich in galacturonic acid, with other regions containing rhamnose and neutral sugars, forming branched structures. In addition to the degree of esterification, molecular weight, chain length distribution, and degree of branching can influence the interactions between polysaccharide chains. This structure is related to the ability of pectin to form networks in solution and influences its rheological properties. Therefore, molecular structure analysis is necessary to complement physicochemical characterization in evaluating pectin's potential as a thickener and gelling agent (Chandel et al., 2022; Zdunek et al., 2021).

Pectin structure characterization can be performed using several analytical methods, including Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). FTIR is used to identify functional groups based on infrared absorption patterns, while SEM is used to observe surface morphology and changes in the physical structure of the material. FTIR results can help indicate the presence of groups related to the pectin structure, but do not directly determine the molecular weight or gel strength. Meanwhile, SEM observations can show changes in tissue morphology after extraction treatment, but are not sufficient to determine the detailed chemical composition of the molecule. Therefore, both methods need to be complemented with other analyses if the research objective includes the relationship between molecular structure and functional properties of pectin.

Extraction conditions have the potential to affect pectin structure through the release, hydrolysis, and alteration of specific chemical groups. Acid and heat treatments can help dissolve pectin from plant tissue, but overly intensive treatments can potentially alter the length of the polysaccharide chains. These changes can affect molecular weight, viscosity, and gel-forming ability. However, structural changes cannot be determined solely based on an increase or decrease in yield or methoxyl content. For rambutan peel pectin, measurements of molecular weight, monosaccharide composition, and chain characteristics are still needed to clarify the relationship between extraction conditions and the resulting molecular structure. Therefore, further research needs to combine chemical characterization and structural analysis to gain a more comprehensive understanding.

The ability of pectin as a thickening agent is related to the interactions between polysaccharide chains and the behavior of molecules when dispersed in water. Pectin can increase the viscosity of a solution, but the magnitude of the increase is influenced by concentration, molecular weight, chain structure, pH, temperature, and other components in the food system. Therefore, high levels of galacturonic acid do not automatically indicate better thickening ability of a pectin. Rheological testing is necessary to determine changes in pectin viscosity at various concentrations and measurement conditions. This characterization is important for determining the potential use of rambutan peel pectin in food products that require specific consistency and texture (Chandel et al., 2022).

The mechanism of pectin gel formation is influenced by the degree of esterification and formulation conditions. High-methoxyl pectin generally forms gels under acidic conditions and high dissolved solids concentrations, while low-methoxyl pectin can form gels through interactions with calcium ions. In low-methoxyl pectin, free carboxyl groups can interact with calcium ions and help form interchain networks. Conversely, gel formation of high-methoxyl pectin is more influenced by interactions between ester groups and hydrogen bonds under appropriate conditions. These differences in mechanisms indicate that the chemical characteristics of pectin need to be considered when determining its use in certain food formulations (Chandel et al., 2022).

Based on the characteristics studied, rambutan peel pectin has the potential to be developed as a food additive, but its effectiveness as a thickener and gelling agent cannot be confirmed solely through

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extraction and chemical characterization. Further testing is needed to assess viscosity, gel strength, storage stability, and the effects of pH and formulation components such as sugar or calcium ions. The obtained pectin can also be tested in products such as jams, jellies, sauces, or fruit preparations to determine its performance compared to commercial pectin. Direct application testing is necessary because the characteristics of pectin in extract form do not necessarily demonstrate the same behavior when used in complex food systems. Therefore, the potential utilization of rambutan peel pectin needs to be assessed based on the results of integrated characterization and functional testing.

Utilizing rambutan peel as a source of pectin can support increased added value of agricultural by-products and the development of food additives based on local resources. However, its application depends on the ability to produce pectin of consistent quality and an efficient production process. Extraction methods need to be evaluated based on yield, purity, energy consumption, solvent use, purification requirements, and waste management. Studies on pectin extraction from various tropical and subtropical fruits indicate that the choice of method needs to be tailored to the characteristics of the raw material and the intended use of the final product (Picot-Allain et al., 2022). Therefore, the utilization of rambutan peel requires consideration of technical, economic, and environmental aspects to ensure its potential for sustainable application.

A major limitation of this study is the lack of direct evidence linking the molecular structure of rambutan peel pectin to its thickening and gelling properties. Studies reporting yield, methoxyl content, galacturonic acid content, and degree of esterification provide a basis for assessing chemical characteristics, but these parameters are insufficient to confirm its functional performance. Furthermore, differences in raw materials, solvent concentration, temperature, extraction time, and testing procedures can make direct comparisons between publications difficult. Future research should combine physicochemical characterization, molecular structure analysis, and rheological testing to clarify the relationship between extraction conditions, pectin structure, and its functional properties. These results are expected to provide a basis for determining appropriate extraction conditions and assessing the suitability of rambutan peel pectin as a food additive.

Overall, rambutan peel has the potential to be an alternative source of pectin, but its use as a thickening and gelling agent requires further experimental confirmation. Extraction conditions influence yield and can affect the chemical characteristics of pectin, while molecular structure plays a role in determining its behavior in food systems. Testing for viscosity, gel strength, and stability in food formulations is an important step in linking characterization results to real-world applications. Evaluation of process efficiency and economic and environmental feasibility is also necessary before industrial-scale application is recommended. Therefore, the development of rambutan peel pectin should be carried out through an integrated approach that considers material quality, molecular structure, functional properties, and process sustainability.

Implications and Limitations

Research on the extraction of pectin from rambutan (Nephelium lappaceum L.) peel contributes to the development of food technology, agricultural waste processing, and sustainable resource utilization. Rambutan peel, which is generally waste after the fruit is consumed, has the potential to be processed into pectin, thus having higher utility and economic value. This utilization can also help reduce the accumulation of organic waste if accompanied by an appropriate collection and processing system. Wicaksono et al. (2026) studied the use of rambutan peel as a raw material for pectin through a pulsed electric field-assisted extraction method, which shows the potential for technological development to optimize the utilization of this fruit by-product. Thus, this research can be a foundation in developing rambutan peel processing into products that are beneficial to industry and society.

In food technology, pectin obtained from rambutan peel has the potential to be used as a gelling agent, thickener, and stabilizer in various food products. The use of pectin in products such as jams, jellies, sauces, and fruit preparations can help shape texture and maintain product characteristics. Picot-Allain et al. (2022) explained that pectin derived from tropical and subtropical fruits has the potential to be used as a functional ingredient in the food industry. However, the application of pectin from rambutan peel requires considering several characteristics, such as yield, color, purity, water content, degree of

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esterification, and gel-forming ability. Testing these characteristics is necessary to determine the quality of pectin and determine its suitability for the processing needs of various food products.

This research also has the potential to encourage the development of more effective and environmentally friendly extraction methods. The success of pectin extraction is influenced by several factors, including solvent type, acid concentration, temperature, extraction time, and the ratio between the material and the solvent. Variations in these conditions can cause differences in the amount of pectin produced and the physicochemical properties of the final product. Picot-Allain et al. (2022) discussed various pectin extraction approaches, including conventional methods and technology-assisted alternative methods, which can be developed according to the characteristics of the raw material and the processing objectives. Therefore, research on pectin from rambutan peel can be used to evaluate extraction conditions capable of optimal pectin production, taking into account efficiency of time, energy, and chemical use.

From an economic perspective, processing rambutan peel into pectin offers the potential to increase the added value of previously underutilized agricultural byproducts. Materials that were previously discarded can be processed into products with the potential to be used as industrial raw materials, thus opening up opportunities for diversifying the use of rambutan commodities. Wicaksono et al. (2026) reported that pectin extraction from rambutan peel using a pulsed electric field could be optimized and yielded 4.37% under optimum conditions. These findings provide an initial overview of the potential of rambutan peel as an alternative pectin source. However, commercial application still requires further analysis of raw material costs, energy requirements, solvent usage, purification processes, and production capacity to determine its economic feasibility.

From an environmental perspective, this research supports the implementation of the circular economy concept by converting waste into useful materials. Utilizing rambutan peel as a source of pectin can help reduce the amount of organic waste while increasing the efficiency of raw material use from agricultural products. Picot-Allain et al. (2022) outlined the potential of tropical and subtropical fruit by-products as alternative pectin sources that can support product development with more optimal resource utilization. However, the environmental benefits of the extraction process need to be comprehensively assessed, taking into account energy consumption, chemical use, and the management of the resulting residues and wastewater. Therefore, further research is needed to ensure that the pectin processing process provides benefits commensurate with the environmental impacts during production.

In the development of science, research on pectin extraction from rambutan peel can be a reference for further studying the characteristics of pectin produced from local raw materials. Quality assessment can be carried out through testing the yield, water content, ash content, methoxyl content, galacturonic acid content, degree of esterification, and gel-forming ability. Wicaksono et al. (2026) reported that rambutan peel pectin obtained through the pulsed electric field-assisted extraction method had a galacturonic acid content of 75.72% and a degree of esterification of 65.66% under the optimum conditions studied. These results can be used as a comparative reference, although the characteristics of the resulting pectin may differ due to variations in rambutan varieties, initial material treatment, and extraction conditions. Therefore, the results of this study can be a basis for optimizing the extraction process as well as developing studies on the use of rambutan peel pectin in various food applications.

In general, research on pectin extraction from rambutan peel has the potential to support organic waste reduction, the development of alternative food additives, increasing extraction efficiency, and creating economic value from local materials. In addition to providing information on the potential of rambutan peel as a pectin source, this study can explain the relationship between extraction conditions and the characteristics of the resulting product. The success of pectin utilization is determined not only by its yield, but also by its quality, safety, stability, functional ability, and production costs. Therefore, physicochemical testing and application to food products are necessary to assess the feasibility of rambutan peel pectin as an alternative to commercial pectin. The research results are expected to support the development of more efficient, value-added, and sustainability-oriented fruit by-product processing technologies.

Although research on pectin extraction from rambutan peel shows potential as an alternative food additive, several limitations remain. Picot-Allain et al. (2022) in their literature review explained that conventional pectin extraction requires relatively large amounts of energy and involves the use of mineral acids. This situation highlights the importance of developing alternative extraction methods that can increase process efficiency while maintaining the characteristics of the resulting pectin.

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Furthermore, pectin characteristics can be influenced by the source of the raw material and the extraction method, so research results from one type of fruit cannot be fully generalized to other materials. Therefore, research on rambutan peel pectin still needs to be expanded to obtain more comprehensive information regarding the effect of extraction conditions on its quality and functional properties.

Another limitation relates to the evidence of rambutan peel pectin's ability to act as a thickening and gelling agent. Picot-Allain et al. (2022) discussed the characterization and potential applications of pectin from various tropical and subtropical fruit by-products, including the importance of evaluating pectin characteristics to determine its potential use in food systems. However, chemical characteristics such as galacturonic acid content and degree of esterification do not, by themselves, demonstrate the thickening or gelling ability of a pectin in a given food product. Testing for viscosity, gel strength, stability, and the influence of formulation conditions is still necessary to directly determine its functional performance. Therefore, the potential of rambutan peel pectin needs to be assessed based on a combination of chemical characterization and functional testing, rather than solely on its yield or molecular structure.

From a technological and industrial application perspective, the use of alternative extraction methods also needs to be evaluated based on process efficiency and product characteristics. Wicaksono et al. (2026) reported that pulsed electric field-assisted rambutan peel pectin extraction produced a yield of 4.37%, a galacturonic acid content of 75.72%, and a degree of esterification of 65.66% under optimum research conditions. These results provide initial evidence of the potential use of rambutan peel as a pectin source, but are not sufficient to confirm its commercial viability as a substitute for commercially available pectin. Further evaluation is needed regarding production costs, energy requirements, purification processes, quality consistency, material safety, and pectin performance when applied to food products. Therefore, larger-scale research and direct testing in food formulations are needed before industrial application can be recommended.

In the context of a Narrative Literature Review, limitations may also arise from the scope and availability of the literature used. The study by Picot-Allain et al. (2022) discussed pectin from various tropical and subtropical fruits, so the findings can generally be used to explain the principles of pectin extraction, characterization, and application, but do not fully represent the specific characteristics of rambutan peel pectin. While studies directly testing the functional properties of rambutan peel pectin are limited, discussions on viscosity and gel formation should be supported by studies of pectin from other sources, explaining the limits of their application. Differences in extraction methods, experimental conditions, and testing parameters between studies should also be considered when comparing results. Therefore, the study's conclusions should be aligned with the available evidence and clearly distinguish between characteristics directly tested in rambutan peel pectin and potential properties that still require further verification.

Conclusion

Rambutan (Nephelium lappaceum L.) peel has the potential to be used as an alternative source of pectin to increase the utility value of agricultural waste. Based on the results of the literature review, the conclusions and solutions to the problems raised are as follows:

1. Pectin characteristics are influenced by extraction conditions. Temperature, time, and solvent type determine the yield and physicochemical quality of the resulting pectin. Extraction using 0.1 N HCl at 80 °C for 120 minutes resulted in a yield of 7.34%. Therefore, optimizing extraction conditions is necessary to obtain pectin with the appropriate yield and characteristics.
2. Physicochemical characteristics and molecular structure determine the functional potential of pectin. Parameters such as galacturonic acid content, methoxyl content, and degree of esterification can be used to evaluate pectin quality and estimate its potential as a thickening and gelling agent. However, this potential has not been sufficiently demonstrated through chemical characterization alone. Therefore, further research is needed to directly test viscosity, gel strength, and gel-forming ability.
3. Developing efficient extraction methods is a solution to increase the utilization of rambutan peel. Alternative extraction methods need to be studied, taking into account yield, pectin quality,

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processing time, energy consumption, and chemical use. Larger-scale testing is also needed to evaluate quality consistency and the economic feasibility of production.

4. The use of rambutan peel pectin requires application testing and production feasibility studies. Pectin has the potential to be used in food products, such as jams, jellies, and sauces. However, testing for safety, stability, functional properties, and suitability of pectin characteristics to product formulations is necessary before industrial application. These efforts are expected to increase the economic value of rambutan peel while supporting organic waste reduction and sustainable resource utilization.

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