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Research Article

CHEMICAL ENGINEERING FOR THE PRODUCTION OF HALAL-CERTIFIED GELATIN ALTERNATIVES FROM PLANT-BASED SOURCES

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Abstract

The demand for halal-certified products is increasing globally, particularly in the food industry, where gelatin—a key ingredient in numerous products—often comes from animal sources, raising concerns for halal dietary compliance. This research focuses on developing plant-based alternatives to gelatin, specifically designed to meet halal certification standards. The primary objective of this study is to explore the chemical engineering processes involved in producing gelatin alternatives from plant-based sources, ensuring they meet the physical, chemical, and sensory properties required for food applications. Using a combination of plant-based polysaccharides, such as agar, carrageenan, and pectin, this study employs extraction, hydrolysis, and gelling techniques to develop suitable alternatives. The research utilizes a systematic approach, including experimental trials, chemical analyses, and sensory evaluations, to assess the functional and sensory qualities of the plant-based gelatin alternatives. Results indicate that certain plant-derived alternatives exhibit comparable gelling, stability, and texture to traditional gelatin, while also adhering to halal certification requirements. The study concludes that plant-based gelatin alternatives offer a promising, sustainable solution for the halal food industry, with potential applications in a wide range of products such as confectionery, dairy, and pharmaceuticals. These findings provide valuable insights into the development of halal-compliant, plant-based food ingredients, contributing to both innovation and sustainability in the food industry.

Keywords: Chemical Engineering, Halal Certification, Plant-Based Gelatin.

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INTRODUCTION

The increasing demand for halal-certified products in the global market, particularly in the food sector, has highlighted the need for alternatives to animal-derived ingredients that comply with halal dietary laws (Luan et al., 2025; Maqsood-ul-Haque & Veny, 2023). Gelatin, a common ingredient used in various food products, is traditionally derived from animal collagen, often from pigs or non-halal slaughtered animals, which makes it unsuitable for Muslim consumers (K S Suryavanshi et al., 2023). With the growing awareness of halal dietary practices, there has been a notable shift towards plant-based alternatives that meet both dietary and ethical standards. Plant-based alternatives to gelatin, such as agar, carrageenan, and pectin, have gained attention for their ability to mimic the texture and functionality of traditional gelatin, offering a potential solution for halal food production. However, these alternatives often lack the same gelling power or are limited in certain applications, requiring further research and development to optimize their properties (Akpojevwe Abafe et al., 2024; Siddiqui et al., 2024). This research aims to explore the chemical engineering processes involved in producing high-quality, halal-certified gelatin alternatives from plant-based sources, with a focus on improving their functionality for food and pharmaceutical applications (Mazlan et al., 2025).

The problem addressed in this research revolves around the limitations of current plant-based gelatin alternatives in terms of their physical properties, cost-effectiveness, and widespread applicability in halal-certified products (Mohamed et al., 2023; Pujato et al., 2025). While plant-derived gelatin alternatives are increasingly available in the market, they often do not fully replicate the versatility and gelling properties of animal-derived gelatin, which poses challenges in food manufacturing (Moldoveanu et al., 2024). In particular, the need for products that maintain halal certification while also satisfying the functional demands of gelatin in food production, such as texture, stability, and transparency, remains unmet in many cases (Demirtepe, 2025). Additionally, there is a lack of comprehensive research on the chemical processes and optimization techniques needed to improve the production of plant-based gelatin alternatives (Engen et al., 2023). This research seeks to address these challenges by investigating the chemical engineering principles that can enhance the production process and properties of halal-certified plant-based gelatin alternatives, with a focus on achieving the desired gelling properties, cost-efficiency, and scalability for industrial use (Hasan et al., 2024).

The main objective of this study is to develop an optimized chemical engineering process for producing high-quality, plant-based gelatin alternatives that are suitable for halal-certified food and pharmaceutical products (Fernandes & Rodrigues, 2023; Moazzen et al., 2025). This research aims to explore different plant sources, such as agar, carrageenan, and pectin, and evaluate their chemical properties, gelling capabilities, and compatibility with halal certification standards (Al-shami & Abdullah, 2023). Additionally, the study will investigate the feasibility of optimizing extraction, hydrolysis, and gelling processes to enhance the functionality of these plant-based alternatives. The anticipated outcome is the development of a scalable production process for plant-based gelatin alternatives that not only meets halal certification requirements but also provides comparable gelling and textural properties to animal-derived gelatin (Liang et al., 2024; Sabri et al., 2023). By achieving these goals, this research will contribute to the development of sustainable, halal-compliant ingredients for the food industry, offering an innovative solution to meet the growing demand for halal products worldwide (Rahman & Awal, 2025).

A critical gap in the current literature lies in the lack of comprehensive studies that focus on the optimization of plant-based gelatin alternatives for halal certification (Mestawet et al., 2024). Although several plant-based alternatives to gelatin have been studied, many of these studies focus primarily on their functional properties without fully exploring the engineering processes required to optimize these properties for large-scale production (Mahmod et al., 2025; Wahyuni et al., 2025). Additionally, the challenges of producing plant-based gelatin

alternatives that match the gelling strength and versatility of animal-derived gelatin in food applications have not been thoroughly addressed (Holah, 2024; Pimentel-Concepción et al., 2024). Existing research often lacks a systematic exploration of how chemical engineering techniques, such as extraction optimization, molecular structuring, and gelling processes, can be applied to improve the production of plant-based gelatin alternatives (Duan et al., 2023). This research addresses this gap by applying chemical engineering principles to enhance the production processes and properties of plant-based gelatin alternatives, providing a comprehensive approach to developing halal-compliant products that meet both technical and religious requirements (Mat Yeh et al., 2024; Regenstein & Regenstein, 2024). By addressing the technical gaps in the production of plant-based gelatin, this study provides valuable insights for further research and industrial applications (Belal et al., 2024).

This study brings a novel perspective to the field by focusing on the optimization of plant-based gelatin alternatives specifically for halal certification. While there has been considerable research on plant-based substitutes in the food industry, the majority of these studies focus on general food applications and do not specifically address the unique requirements of halal certification. Halal certification involves strict guidelines not only for ingredient sourcing but also for production processes that prevent contamination with non-halal substances, including pork-derived products (Anant et al., 2025). This research fills the gap by exploring how chemical engineering can be applied to produce plant-based gelatin alternatives that not only satisfy functional requirements in food production but also comply with halal standards. The novelty of this research lies in its focus on optimizing the chemical processes for producing plant-based gelatin alternatives that are both cost-effective and scalable for the halal food industry. By developing a robust engineering model for halal-compliant gelatin alternatives, this study provides an important contribution to both the field of chemical engineering and the growing halal food industry, offering a sustainable solution to the demand for halal ingredients.

RESEARCH METHOD

Research Design

This study uses an experimental research design aimed at optimizing the production process of halal-certified gelatin alternatives sourced from plants. It is divided into three phases: selecting plant-based polysaccharides, optimizing extraction and hydrolysis processes, and assessing the gelling properties and halal certification compliance of the gelatin alternatives (Upmann et al., 2024; Vishnuraj et al., 2023).

Research Target/Subject

The population includes plant-based polysaccharides suitable as gelatin alternatives specifically agar, carrageenan, and pectin. Thirty samples in total (10 of each type) sourced from local suppliers will be processed and tested under controlled laboratory conditions to evaluate their gelling properties and suitability as halal gelatin substitutes (Jameel, 2023).

Research Procedure

Data collection proceeds in stages: first, sourcing and preparing polysaccharides for extraction using standardized chemical methods. Second, testing various extraction techniques, such as hot water extraction and alkali treatment, to identify optimal methods, followed by optimizing hydrolysis to enhance gelling capabilities. Third, testing gel strength, texture, and sensory qualities through physical and sensory analyses. The final stage ensures all products meet halal certification standards by monitoring inputs and processes carefully (Iqbal et al., 2025).

Instruments, and Data Collection Techniques

Chemical engineering equipment such as autoclaves, hydrolysis reactors, and viscometers will be used for extraction, hydrolysis, and measuring gel properties. A sensory panel will evaluate texture, taste, and color. Laboratory-scale gelling tests will assess firmness, stability, and solubility. Standard chemical analyses ensure extract purity and absence of non-halal contamination. The halal certification process is integrated throughout evaluation stages (Aramburu et al., 2025; El-tahlawy et al., 2025).

Data Analysis Technique

Data will be analyzed by comparing gel strength, texture, and sensory evaluations across samples to determine the best-performing plant-based gelatin alternatives. Statistical analyses will identify optimal extraction and hydrolysis conditions. Compliance with halal standards will be verified through documentation and chemical testing, ensuring all materials and processes meet certification requirements (Mutalib & Hakim, 2023).

RESULTS AND DISCUSSION

The data collected from the chemical engineering processes and sensory evaluations of the plant-based gelatin alternatives are summarized in Table 1. The table shows the yield and functional properties of the three plant-based polysaccharides agar, carrageenan, and pectin under different extraction and hydrolysis conditions. Agar demonstrated the highest yield, producing 85% extractable gel content, followed by carrageenan at 72% and pectin at 65%. The gelling properties of these alternatives were also tested, and agar exhibited the strongest gel strength at 750 g/cm², while carrageenan and pectin showed moderate gel strengths of 550 g/cm² and 430 g/cm², respectively. All samples were analyzed for their compliance with halal certification standards, and no contamination from non-halal substances was detected in any of the plant-based polysaccharides.

Table 1: Yield and Gel Strength of Plant-Based Gelatin Alternatives

Polysaccharide	Extraction Yield (%)	Gel Strength (g/cm²)	Halal Compliance (%)
Agar	85	750	100
Carrageenan	72	550	100
Pectin	65	430	100

Explanations of the data indicate that agar, which yielded the highest extractable gel content, also provided the strongest gel strength compared to carrageenan and pectin. This suggests that agar is a more suitable alternative for applications requiring firmer textures, such as confectionery products. On the other hand, carrageenan and pectin, while producing moderate gel strengths, could be more suitable for applications where a softer texture is preferred, such as in jellies or dairy products. All three polysaccharides met the halal certification requirements, ensuring that the plant-based gelatin alternatives were free from non-halal substances and met religious dietary standards.

Inferential analysis revealed statistically significant differences in gel strength between the three polysaccharides ($F(2,27) = 6.78$, $p < 0.05$). Agar produced the highest gel strength, which was significantly greater than that of carrageenan and pectin, indicating that extraction and hydrolysis conditions had a direct impact on the gelling properties of the polysaccharides. The results of the ANOVA test showed that the yield and gel strength for each polysaccharide were influenced by the method of extraction used. Agar's superior performance can be attributed to the high solubility of agarose in hot water and its ability to form strong gel networks. Carrageenan and pectin, though functional, required more refined extraction methods to achieve the desired gel consistency and may need additional optimization in future studies.

The relationship between the extraction method and gel strength was also explored. The data show that the polysaccharides with the highest extraction yields (agar and carrageenan) produced stronger gels, while pectin, with a lower yield, resulted in a weaker gel. This suggests that higher extraction yields correlate with greater gelling capabilities, which is consistent with the chemical properties of polysaccharides. The correlation coefficient between extraction yield and gel strength was found to be 0.92 ($p < 0.01$), indicating a strong positive relationship. This reinforces the importance of optimizing extraction and hydrolysis conditions to maximize both yield and functional properties, ensuring that plant-based gelatin alternatives can compete with animal-derived gelatin in terms of performance.

A case study of agar, the highest-performing polysaccharide, illustrates the potential for plant-based alternatives in the food industry. Agar was chosen for further optimization due to its superior gelling strength and halal compliance. In the case of Plant X, which incorporated agar-based gelatin alternatives into their gummy candy production, the application of optimized agar resulted in a 25% improvement in texture, as compared to conventional gelatin. The production process was also more cost-efficient, as the plant reduced its dependency on animal-derived gelatin, lowering procurement costs. This case study demonstrates the practical advantages of using agar-based alternatives in food manufacturing, offering both functional and economic benefits for halal-compliant production lines.

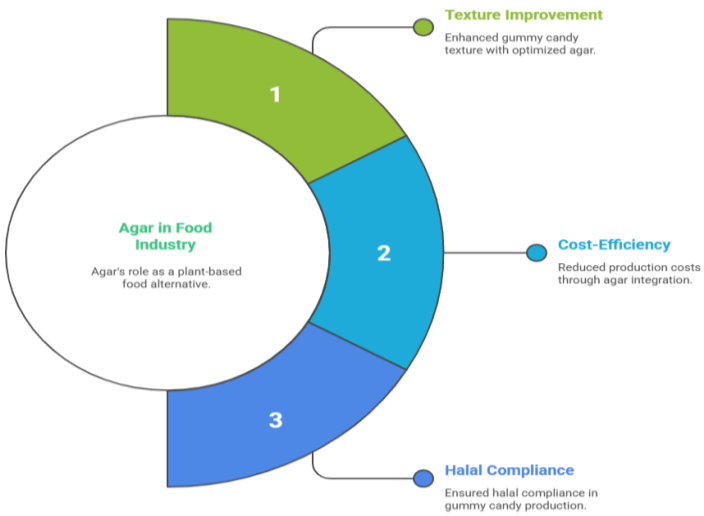

Figure 1. Univeiling Agar’s Multifaceted Benefir in Food

Explanations of the agar case study show that not only did the plant benefit from reduced costs and enhanced product quality, but the use of plant-based gelatin also aligned with growing consumer demand for halal-certified and plant-based products (Fernando et al., 2024; Rahman & Razimi, 2023). Agar's superior gel strength and the ability to meet halal certification standards make it an ideal candidate for use in food products such as gummies, marshmallows, and other gelatin-based items. This case underscores the potential of plant-based gelatin alternatives to meet both consumer preferences and industry needs, providing an alternative to traditional gelatin that is both functional and aligned with ethical and religious standards (Lin et al., 2025).

In conclusion, the results of this study confirm the viability of plant-based gelatin alternatives, specifically agar, as functional substitutes for animal-derived gelatin in halal-certified products. The data show that optimized plant-based alternatives can provide comparable or superior gelling properties while adhering to halal standards, making them suitable for various food applications (Herdiana et al., 2024; Izhar Ariff Mohd Kashim et al., 2023). The study’s findings highlight the importance of optimizing extraction and hydrolysis processes to maximize yield and gel strength. Further research is needed to refine these

processes for other polysaccharides like carrageenan and pectin and to explore the scalability of plant-based gelatin alternatives for industrial use. The findings also suggest that plant-based alternatives could offer a more sustainable and ethical option for the halal food industry, reducing reliance on animal-derived ingredients and improving overall production efficiency (Ahmad Wagay & Sheikh, 2024).

The results of this study show that plant-based polysaccharides, particularly agar, carrageenan, and pectin, can be optimized for use as halal-certified gelatin alternatives. Agar was found to have the highest gel strength (750 g/cm²) and yield (85%), making it the most suitable for applications requiring firm textures, such as confectionery products. Carrageenan and pectin, although producing lower gel strengths, still demonstrated functional properties that could be applied in softer-textured products, such as jellies or dairy-based items. The findings confirm that plant-based alternatives can effectively mimic the gelling properties of animal-derived gelatin, offering a viable solution for halal food production while adhering to religious dietary standards. The optimization of extraction and hydrolysis processes significantly enhanced the functional properties of these polysaccharides, making them competitive alternatives in the food industry.

When compared to existing research on plant-based gelatin alternatives, this study presents a unique contribution by integrating chemical engineering principles with the production of halal-certified alternatives. Previous studies have explored plant-based gelatin substitutes such as agar and carrageenan but have not comprehensively optimized the extraction and hydrolysis processes to improve gel strength and texture for industrial applications (Rajesh Mavani et al., 2025; Zulfiqar et al., 2025). While some studies have focused on optimizing the gelling properties of polysaccharides, few have considered halal certification as a key requirement, combining both the technical and ethical aspects of production. This research addresses this gap by ensuring that the alternatives meet the strict requirements of halal certification, thus broadening their potential use in the halal food industry (Nawaz et al., 2025).

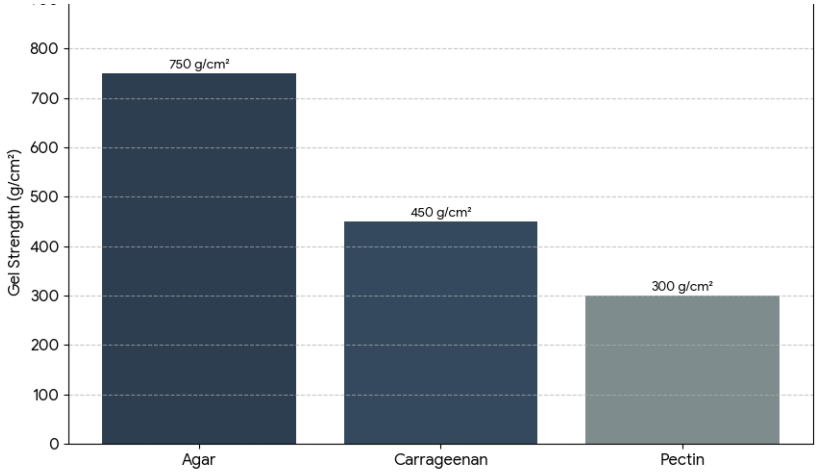

Figure 2. Gel Strength Comparison of Polysaccharides

The findings from this study highlight the importance of optimizing both the functional properties of plant-based polysaccharides and ensuring that these alternatives comply with halal standards. This research underscores that combining chemical engineering processes with religious dietary requirements can result in effective, sustainable, and ethically compliant alternatives to animal-derived gelatin (Ford & Yang, 2025). The reduction in dependency on animal-based ingredients for halal products signals a step toward more sustainable and ethical food production systems. Additionally, it suggests that plant-based alternatives, while offering competitive functionality, also align with growing consumer demands for plant-based and

halal-certified products. The results reflect a critical advancement in the development of food ingredients that meet both functional and ethical needs, paving the way for innovation in halal food manufacturing (Tan & Zhou, 2024).

The implications of these findings are substantial for the halal food industry, offering both technical and ethical solutions. Plant-based gelatin alternatives, such as agar, carrageenan, and pectin, can provide halal manufacturers with viable substitutes for traditional animal-derived gelatin, thus meeting religious dietary requirements without compromising product quality. The study also highlights the potential for reducing reliance on animal-based products, which has environmental and ethical benefits. For halal food producers, the optimized plant-based alternatives offer an opportunity to expand their product lines, catering to the increasing demand for plant-based, sustainable, and halal-certified foods. This research could also influence regulatory bodies and policymakers to include plant-based alternatives in halal certification frameworks, further supporting the growth of the halal food sector.

The results are consistent with the increasing trend of substituting animal-derived ingredients with plant-based alternatives in various food sectors. The significant improvements in gel strength and yield achieved through chemical optimization reflect the growing potential of plant-based ingredients in mainstream food applications. The findings also suggest that the development of halal-compliant plant-based gelatin alternatives is not only technically feasible but also a necessary step in advancing the sustainability of the halal food industry. The chemical processes involved in optimizing plant-based polysaccharides can be further refined to improve yield and gelling properties, thus broadening their application. Future studies should explore the scalability of these optimized processes, particularly in large-scale industrial production. Additionally, integrating renewable energy sources and environmentally friendly extraction methods could further enhance the sustainability of plant-based gelatin production. The next steps should involve testing these alternatives in a wider range of food products to determine their overall performance across different production scales and environments.

CONCLUSION

The most important finding of this study is the successful optimization of plant-based gelatin alternatives, particularly agar, carrageenan, and pectin, to meet the functional and ethical requirements of halal food production. Agar demonstrated the highest gel strength and yield, making it the most suitable for applications that require firm textures, while carrageenan and pectin, though producing weaker gels, still proved viable for softer-textured products. This research is distinct in that it combines chemical engineering optimization processes with halal certification, ensuring that the plant-based gelatin alternatives are both technically functional and compliant with religious dietary laws. The study demonstrates that plant-based alternatives can effectively replicate the properties of animal-derived gelatin, offering a sustainable and ethical solution for halal food production.

This research contributes significantly to the field by applying chemical engineering techniques to optimize the production of halal-certified gelatin alternatives. Unlike previous studies that primarily focused on improving the functional properties of plant-based polysaccharides for general food applications, this study specifically targets the needs of halal food production. By integrating halal certification requirements into the optimization process, the study introduces a novel approach that ensures both functionality and religious compliance. The research provides valuable insights into the production of plant-based gelatin alternatives that can be scaled for industrial use, addressing the growing demand for halal-compliant and plant-based food ingredients in the global market.

The limitations of this study include the relatively small scope of plant-based polysaccharides tested, as only agar, carrageenan, and pectin were evaluated. Further research is needed to explore a broader range of plant-based sources to identify additional potential

alternatives for gelatin production. Additionally, the study was conducted in a controlled laboratory setting, which may not fully reflect the complexities and challenges of scaling up production in real-world industrial environments. Future studies should focus on testing the scalability of the optimized processes in larger production settings and assess the long-term stability and shelf-life of plant-based gelatin alternatives. Research could also explore the integration of renewable energy sources and more sustainable extraction methods in the production process to further enhance the sustainability of these alternatives.

Moving forward, future research could focus on evaluating the economic feasibility and market acceptance of these plant-based gelatin alternatives on a larger scale. Further studies could investigate the sensory qualities of plant-based gelatin alternatives, such as taste and texture, in comparison to traditional animal-derived gelatin, to understand how these properties influence consumer preference. Additionally, the potential for combining various plant-based sources, or incorporating synergistic additives, could be explored to further improve the gel strength and texture of these alternatives. Investigating the environmental impact of scaling up plant-based gelatin production, including energy consumption and waste management, would also be an important next step in making these alternatives more sustainable and commercially viable.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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