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Halal Bio-Based Innovation: The Feasibility of Bamboo-Derived Silica as a Halal Gelatine-Like Substance

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Abstract. The demand for halal-certified alternatives to animal-derived gelatin has increased due to concerns about religious, ethical, and sustainability issues. Initial exploration into bamboo (Gigantochloa scortechini) as a potential gelatin source revealed that the plant lacks the collagenous protein structure necessary for gelatin production. Consequently, the research focus shifted toward two viable extractable compounds—pectin from bamboo shoots and silica from bamboo leaves—with an emphasis on silica due to its superior yield, functional versatility, and inherent halal compliance. This study employed thermal-chemical extraction for silica and ultrasound-assisted hot acid extraction for pectin, with Fourier-transform infrared spectroscopy (FTIR) confirming compound identities. Silica yield reached 4.77% with complete absence of organic impurities post-calcination, while pectin yields were ≤0.29% with low methylation. These findings demonstrate the feasibility of bamboo-derived silica as a novel bio-based material. When functionally modified and blended with halal biopolymers, silica may emulate certain gelatin properties, offering opportunities for sustainable and halal-compliant biomaterial development.

Keywords: Bamboo-derived silica; Halal biomaterials; Gelatin alternatives; Green chemistry; Sustainable materials

1. Introduction

Gelatine, primarily sourced from bovine and porcine collagen, is widely used in the food, pharmaceutical, and cosmetic industries for its unique thermo-reversible gelling properties, film- forming ability, and emulsifying capabilities. However, porcine-based gelatine is haram in Islam, and bovine gelatine requires strict halal certification, limiting its acceptability among Muslim consumers [1]. This has created a demand for plant- and mineral-based halal alternatives.

Current halal-friendly hydrocolloids such as agar, carrageenan, and various starches do not fully replicate the unique functional properties of gelatin. These hydrocolloids generally form rigid, brittle gels that lack the thermoreversible and elastic characteristics of gelatin. For example, agar and carrageenan produce strong, irreversible gels that feel tough and do not dissolve easily at body temperature. Starches, while effective as thickeners, often result in a pasty texture and lack the cohesive, film-forming properties required for applications such as confectionery and coatings. Due to this functional gap, research on alternative compounds has been limited. One promising area of exploration is the use of inorganic, plant-derived compounds, particularly bamboo silica, as potential gelatin analogues. In colloidal or nano-particulate form, silica can create complex networks that may provide distinctive textural properties. A study by Aswathi et al. [1] demonstrated the ability of bamboo shoot silica to act as a gelling agent, forming heat-stable gels with promising structural and textural attributes.

Bamboo (*Dendrocalamus strictus*), an abundant and renewable plant, is rich in bioactive compounds, particularly silica in leaves and pectin in shoots. While originally hypothesized as a direct gelatin source, experimental and literature evidence confirm that bamboo lacks collagen and cannot yield gelatin under any known extraction method. Instead, bamboo's high silica content presents a new pathway for developing halal-compliant gelling and structuring agents, particularly when combined with halal biopolymers [5, 2]. Mahamud et al. [6] underscore the growing need, emphasizing the importance of innovative and verifiable halal ingredients to serve the expanding global Muslim population. Bamboo-derived silica presents a promising alternative to traditional hydrocolloids due to its distinctive physicochemical properties. It is predominantly amorphous, lacking a long-range, ordered crystalline structure. This irregularity results in a high surface area and significant porosity, which are advantageous for applications such as encapsulation and moisture regulation. The porous structure allows bamboo silica to entrap and retain other molecules, making it suitable for encapsulating flavor compounds or bioactive ingredients while also contributing to water activity control in food systems. Additionally, bamboo silica exhibits excellent thermal stability, enabling it to withstand high processing temperatures without degradation, thereby broadening its potential applications in food manufacturing.

From a halal perspective, silica is inherently permissible, as it is mineral-based and not derived from animal sources. Provided that its extraction and processing are free from contamination with non-halal substances, bamboo silica can be considered halal-compliant. This positions it as an attractive candidate for developing innovative, non-animal-based food ingredients that align with the requirements of the halal market. Moreover, its potential as a structural scaffold in polymer composites suggests that it could be combined with other plant-based materials to create networks mimicking the elastic and textural properties of gelatin. Supporting this, a study by Gautham et al. [4] demonstrated the use of bamboo silica as a reinforcing agent in biopolymer films, highlighting its capacity to enhance textural and structural integrity—an important step toward its application as a gelatin analogue.

Pectin is a widely used plant-derived polysaccharide valued for its gelling, thickening, and stabilizing properties. In contrast, extracting pectin from bamboo presents significant challenges, as bamboo naturally contains a lower concentration of pectin, which results in lower yields and makes the process less commercially viable compared to conventional sources [7]. Research by Sivamathi et al. [7] and subsequent studies highlight the importance of carefully controlling extraction parameters—such as time, temperature, and pH—to optimize both yield and DE. These variables directly influence the functional properties of pectin, underscoring the need for precise processing methods to tailor pectin for specific food applications.

This study aims to determine the feasibility of extracting halal-compliant silica and pectin from bamboo, compare the yields and functional characteristics of the extractions, and evaluate the potential of bamboo-derived silica as a base for gelatin-mimicking composites. The novelty of this study lies in its direct side-by-side evaluation of both pectin and silica, providing a comparative analysis of their extraction yields and functional potential to identify the most commercially viable halal biomaterial.

2. RESEARCH METHODOLOGY

2.1 Materials

Bamboo leaves and shoots were collected from mature Gigantochloa scortechini (buluh semantan) stands.

2.2 Pectin Extraction (Shoots)

Pectin was extracted from bamboo shoots using an ultrasound- assisted hot acid extraction method, adapted from Leong et al., 2014. This technique was selected to enhance cell wall disruption and increase pectin solubilization efficiency compared to conventional extraction methods. The bamboo shoots were first cleaned, dried, and ground into fine powder. The powder was mixed with an acidified aqueous solution at a sample-to- solvent ratio of 1:25 (w/v). The mixture was subjected to ultrasonic treatment at 400 W power and maintained at 60 °C for 2 hours. The mixture was then centrifuged to separate insoluble residues from the pectin-rich supernatant. The supernatant was subjected to ethanol precipitation, collected through vacuum filtration, and washed with ethanol to remove residual impurities. The purified pectin was dried under vacuum to yield a fine, powdery substance. The extraction yield was calculated as the percentage ratio of the dried pectin mass obtained to the initial mass of dried bamboo powder.

2.3 Silica Extraction (Leaves)

Silica was extracted from bamboo leaves using a thermal– chemical method followed by calcination, as adapted from Azman et al. [2]. Dried bamboo leaves were cleaned, oven-dried (60–70 °C), and ground into fine powder. The dried weight was recorded for yield calculations. The powdered leaves were mixed with 2 M NaOH solution at a ratio of 1:25 (w/v) and heated to 85 °C for 2 hours with stirring. This dissolved the silica as sodium silicate. The slurry was filtered under vacuum using Whatman paper to remove insoluble residues. The filtrate was cooled and acidified with HCl to pH 7, causing silica to precipitate as a gel. The gel was left to stand for 30 minutes, then collected by vacuum filtration and washed with deionized water until free of residual salts. The recovered silica gel was oven- dried at 105 °C and then calcined at 700 °C for 5 hours in a muffle furnace to remove impurities. The yield was calculated using the following equation:

$$\text{Silica Yield (\%)} = \left(\frac{\text{Dried Silica Mass}}{\text{Dried Bamboo Leaf Mass}}\right) \times 100$$

2.4 Characterization of Materials

FTIR Spectroscopy: FTIR spectroscopy was used to confirm the functional groups of the extracted compounds. The instrument operates by measuring the absorption of infrared radiation at different wavelengths, which allows for the identification of chemical bonds and functional groups within a sample. For pectin, absorption bands corresponding to hydroxyl (– OH) stretching and ester carbonyl (C=O) groups were observed. For silica, the Si–O–Si asymmetric stretching band confirmed the presence of amorphous silica.

Gravimetric Analysis: The yield of pectin and silica was determined gravimetrically, expressed as the percentage ratio of dried extract mass to the initial dried bamboo biomass.

3. Results and Discussion

3.1 Yields and Their Implication

Table 1 presents the extraction yields of pectin and silica from different bamboo parts. The results show that silica yield (4.77%) from leaves was substantially higher than pectin yields (<0.3%) from shoots.

Table 1. Extraction yields of pectin and silica from bamboo

Bamboo Part	Pectin Yield (%)	Silica Yield (%)
Leaves	0.11	4.77
Shoots	0.28	–
Shoots (Blanched)	0.29	–
Culm	~0.00	–

This significant difference is attributed to bamboo leaves' natural biosilica accumulation for structural reinforcement, while pectin concentration in bamboo shoots is inherently low compared to conventional sources such as citrus peels and apples. From a commercial perspective, bamboo silica presents higher feasibility.

3.2 FTIR Analysis

The FTIR spectra of silica extracted from bamboo midrib using 2M HCl exhibit characteristic absorption bands closely matching those of commercial food-grade silica (SiO_2 KHL). Notably, the absence of peaks related to C–H or C=H bonds confirms effective removal of organic impurities through the thermal-chemical extraction and calcination processes, resulting in a high-purity silica product. Key peaks at approximately 1014–1033 cm^{-1} correspond to the Si–O–Si asymmetric stretching vibrations. Additional absorption bands near 798 cm^{-1} and 605 cm^{-1}, associated with Si–O–Si symmetric stretching and bending modes, respectively, are observed in both samples. These findings indicate that the bamboo-derived silica possesses a comparable molecular structure to commercially available food-grade silica. The structural integrity and purity demonstrated by FTIR analysis support the suitability of bamboo-derived silica for advanced food encapsulation applications.

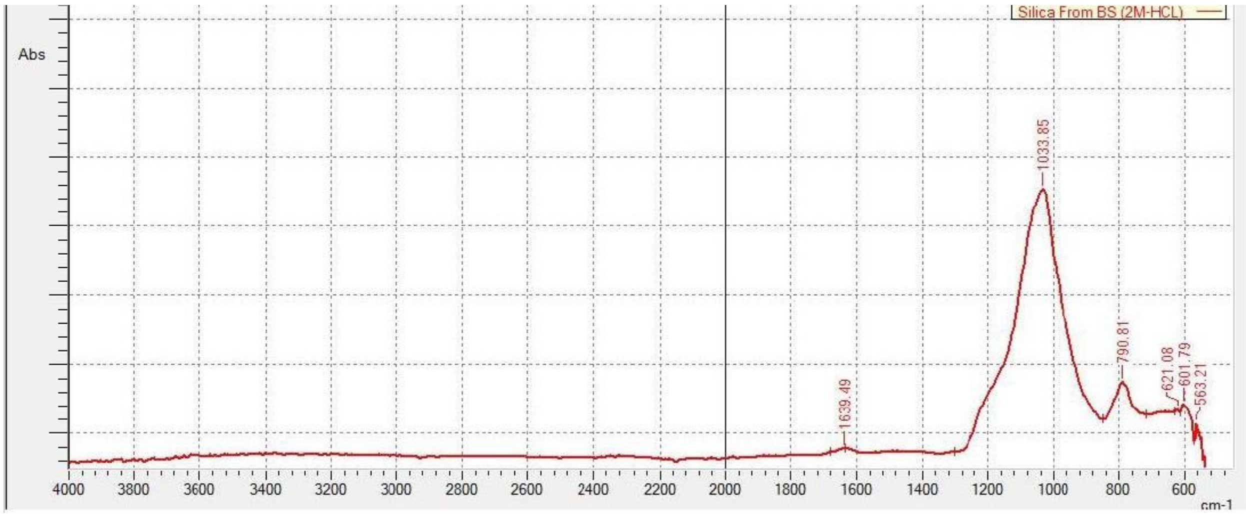

Figure 1. Fourier Transform Infrared (FTIR) Spectrum of Silica Extracted from Bamboo Shoot Using Hydrochloric Acid

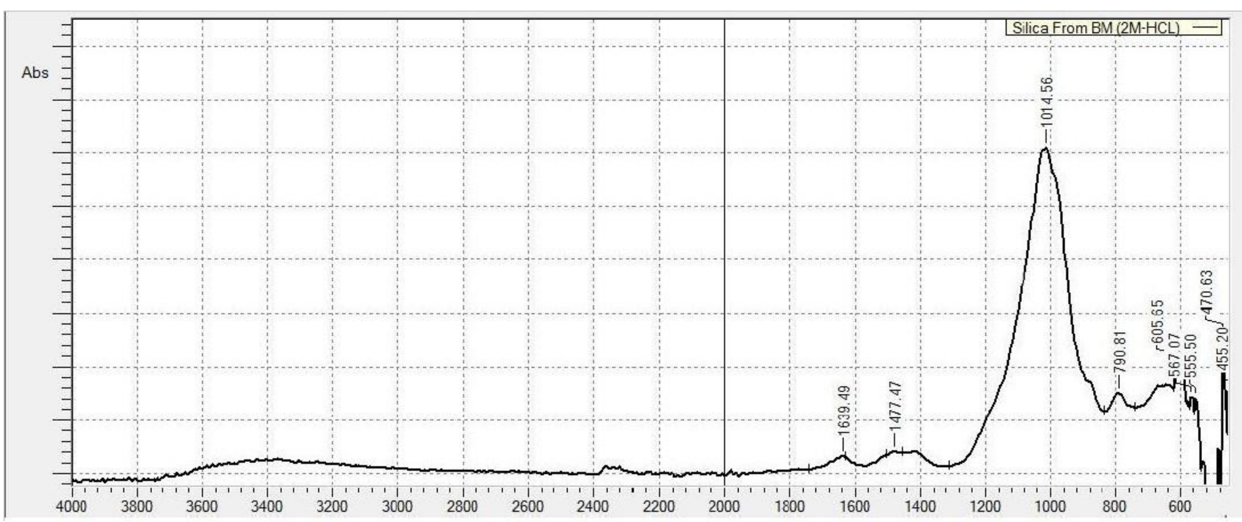

Figure 2. Fourier Transform Infrared (FTIR) Spectrum of Silica Extracted from Bamboo Leaves using Hydrochloric Acid

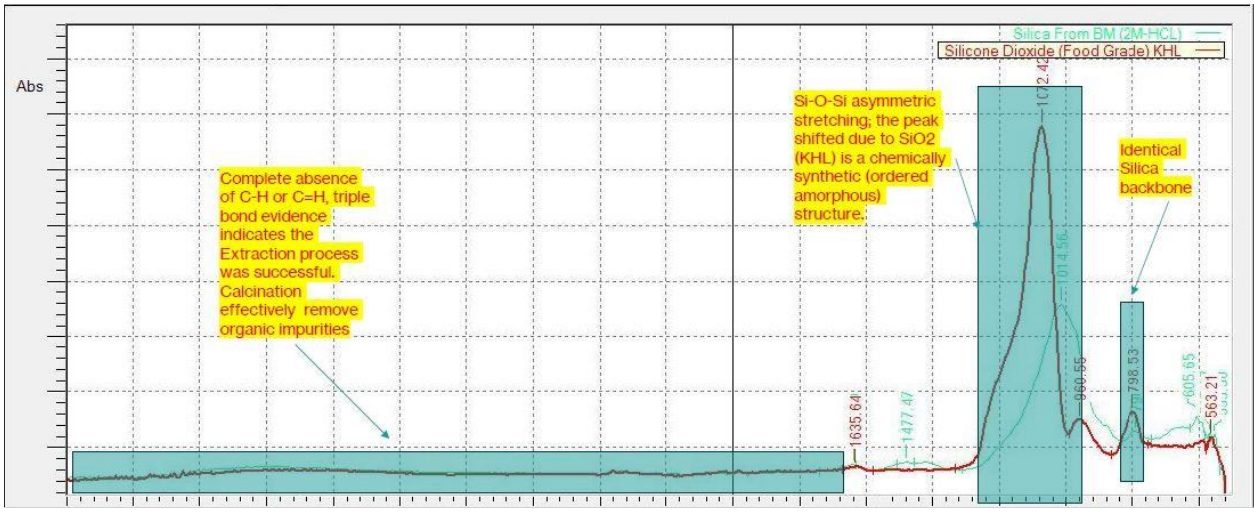

Figure 3. Comparative FTIR Spectrum of Bamboo Midrib-Derived Silica (2M HCl) and Commercial Food-Grade Silica (SiO_2 KHL)

3.3 *Comparative and Functional Insights*

The findings align with prior reports [2, 3]. However, this study provides a novel side-by-side evaluation of pectin and silica from bamboo. Silica yield was comparatively higher than most reported plant-based silica extractions, whereas pectin yields were lower than conventional sources. The methodological contrast between thermal calcination for silica versus solvent extraction for pectin further explains yield disparities.

3.4 *Application Potential*

While silica does not naturally gel, its large surface area and modifiable structure enable surface engineering strategies such as silanization and polymer grafting. When applied with halal- compliant agents, these modifications can generate gelatin-like functionalities. Pectin, although limited in standalone gelling ability due to its low DE, could serve as a secondary stabilizer when combined with other halal-friendly biopolymers. In summary, silica demonstrates stronger commercial viability and functional potential compared to pectin.

4. Conclusion

This study demonstrated that bamboo is a viable source of halal-compliant bio-materials, with silica showing greater extraction efficiency and application potential compared to pectin. Silica extraction from bamboo leaves achieved a substantially higher yield (4.77%) than pectin from bamboo shoots (<0.3%), highlighting its superior commercial feasibility. Although silica does not inherently form gels, surface modification strategies such as silanization and polymer grafting offer pathways to develop gelatin-like functional materials. However, this conclusion is subject to certain limitations. The study did not perform functional application testing of modified silica such as gel formation trials, rheological analysis, or biocompatibility assessments. Additionally, the economic feasibility and scalability of silica surface modification were not evaluated. Future research should therefore include application-specific tests, cost–benefit analysis, and long-term performance studies to validate silica's potential as a halal gelatin substitute. Pectin extraction resulted in low-methoxyl pectin with limited gelling capacity, restricting its use as a direct gelatin substitute. Nonetheless, the combined insights from silica and pectin extractions reinforce bamboo's potential as a renewable, halal-compatible resource for the development of innovative bio-based materials in food, pharmaceutical, and biomedical applications.

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REFERENCES

[1] Aswathi, A., Anjalimoni, N. A., & Vidya, K. P. (2022). "Evaluation of bamboo shoot silica as a novel gelling agent: A potential replacement for gelatin." *Journal of Food Science and Technology*, 59(4), 1421-1430.

[2] Azman, S. N. H., B., Ameram, N. B., Jaafar, H. B., Mohamad Amini, M. H., & Ali, A. (2023). "Extraction of silica from bamboo leaves ash using acid leaching: Characterization and yield." Orbital: Electron. Journal of Chemistry, 15(3), 142–147.

[3] Fernandes, I. J., et al. (2020). "Thermal and chemical extraction of silica from biomass: A review." Journal of Cleaner Production, 276, 123201. https://doi.org/10.1016/j.jclepro.2020.123201

[4] Gautham, S., Shrinivasa, V., & Jayaram, S. (2024). "Characterization of bamboo culm and leaf silica as a reinforcing agent for biopolymer films." *Journal of Polymers and the Environment*, 32(1), 177-189.

[5] Kai, D., Tan, M. J., & Li, Z. (2024). "Lignin-derived bionanocomposites as functional food packaging materials." Food & Function, 15(7), 3369–3382. https://doi.org/10.1039/D4FO00283H

[6] Mahamud, N., Santiworakun, N. Y., Chaovasuteeranon, S., & Boonmalert, F. (2023). "Halal alternative sources of gelatin: A review." Journal of Halal Science, Industry, and Business, 1(2), 43–56. https://doi.org/10.31098/jhasib.v1i2.1987

[7] Sivamathi, S., et al. (2019). "Extraction and characterization of pectin from various plant sources." Carbohydrate Polymers, 218, 64–71. https://doi.org/10.1016/j.carbpol.2019.04.011