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Halal Science Authentication and Functional Characterization of Local Lampung Tuber Polysaccharides as Emulsifier Substitution in the Food Industry

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Abstract: As the 2026 deadline for mandatory halal certification in Indonesia approaches, concerns regarding the halal status of imported emulsifiers, particularly E471 (mono- and diglycerides of fatty acids), remain a significant issue. The primary problem lies in halal critical points that are extremely difficult to trace: these materials may be derived from hydrolysed animal fats (bovine or porcine), not slaughtered according to Islamic law. This research aims to explore the functional properties of polysaccharides from local Lampung tubers, namely Porang and Gembili, as authenticated halal emulsifier substitutes. The study employed a Factorial Completely Randomized Design (CRD), testing tuber sources and concentration levels of 1%, 3%, and 5%. Polysaccharides were extracted via freeze-drying and subsequently characterized using physicochemical analysis and FTIR spectroscopy. Based on the results, 3% Porang polysaccharide produced a low Creaming Index (CI) of 3.1 ± 0.3% after 14 days and a high viscosity of 45,200 cP. Statistically, this stability did not differ significantly ($p > 0.05$) from the commercial E471 standard in its capacity to form an effective interfacial layer that prevents coalescence. The material was authenticated by the absence of a carbonyl absorption peak at 1745 cm^{-1} in its FTIR spectrum, as part of a molecular halal authentication assessment. This provides scientific proof that the isolates are not contaminated by animal fats or questionable substances. This study concludes that Porang glucomannan and Gembili mucilage are strategic "Halal-by-Design" alternatives that can support national food industry independence and assist business actors, particularly MSMEs, in meeting the mandatory halal certification by 2026.

Keywords: Emulsifier; Emulsion Stability; Gembili; Halal Authentication; Porang.

Introduction

Indonesia is currently at a critical stage in implementing mandatory halal certification for all food products on the market. As the nation with the largest Muslim population globally, halal assurance functions not only as a religious obligation but also as a legally enforceable mechanism for consumer protection [1]. However, field conditions indicate a major challenge: the national food industry's strong reliance on imported food additives (BTP), for which halal critical points are difficult to trace and verify [2]. These additives may be derived from animal fats, including porcine or bovine sources not slaughtered according to Islamic law.

One of the most commonly applied emulsifying agents in the food industry is mono- and diglycerides of fatty acids (E471). Nevertheless, the use of E471 in Indonesia remains largely dependent on imported products with significant halal critical points. This condition stems from uncertainty about the origins of raw materials, which may be derived from the hydrolysis of animal fats, including porcine or bovine sources that are not slaughtered in accordance with Islamic law, thereby raising concerns among Muslim consumers. As an essential ingredient in food processing, emulsifiers function to stabilize immiscible phases, such as oil and water, in products including bread, margarine, and chocolate. A fundamental issue arises from the fact that most commercially available emulsifiers worldwide are labelled under the E471 code, which can technically originate from either animal- or plant-based fat derivatives without transparent disclosure. Based on preliminary findings from an independent market survey conducted in early 2025, more than 70% of processed food products produced by MSMEs were found to still rely on imported emulsifiers that do not display a halal logo on their primary packaging [3]. This limited traceability poses a substantial risk of contamination by haram (prohibited) or syubhat (questionable) substances. In addition, annual increases in the prices of imported raw materials—reaching up to 15%—place further pressure on the production costs of domestic food businesses. As the 2026 Halal Mandate approaches, the national food industry is increasingly required to ensure the integrity of its entire supply chain. This challenge can be mitigated by maximizing the economic potential of locally available biological resources, such as Porang and Gembili tubers from Lampung Province, as viable alternatives to replace imported additives associated with syubhat risks.

According to early data from an external research conducted by the Halal Research Center 2025 [4], over 70% of processed food products produced by MSMEs still use imported emulsifiers without a halal logo. Limited traceability increases the risk of contamination with haram or syubhat substances [5]. Although previous studies have focused on modifications to corn starch and soy protein isolates [6], [7], concerns remain regarding emulsion stability at room temperature and potential allergenic

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properties. Unfortunately, a significant research gap exists regarding the use of hydrocolloid structures derived from lesser-known local tubers, combined with functional performance and molecular cosmopolitan halal tracing. "Initial studies indicated that the polysaccharides produced from Gembili and Porang have a high-density complex structure that can attain viscosity similar to synthetic stabilizers [8].

After seeing the advantage of having (compliant and halal) functional performance at the molecular level, there is a need for more extensive research on hydrocolloid structures that come from underutilized local tubers. Porang and Gembili are known to be complex polysaccharides, but their use as a 'Halal-by-Design' substitute for E471 has not yet been documented. This study bridges that gap by (1) outlining the rheological advantages of local glucomannan and mucilage, (2) objectifying FTIR-based validation of material purity during investigation, as well minimum solvent polarity levels to ascertain ideal concentration parameters for solubilization; and (3) providing Sharia-compliant SOPs necessary towards supporting Indonesia's goal in becoming the global halal hub by 2026.

Research Methods

Research Design

This research is pioneered by using an experimental laboratory method of Factorial Completely Randomized Design (CRD). The two factors include tuber sources (Porang and Gembili) and concentration levels (1%, 3%, and 5%). Triplicate (n=3) independent experiments were performed to validate data.

Materials and Equipment

The primary materials include Porang and Gembili tubers from local Lampung farmers, 96% halal-grade ethanol, vegetable oil, and distilled water. A plant-derived E471 emulsifier is used as a comparative control. Key equipment used includes: Rotary Evaporator: Heidolph Hei-VAP Series for solvent separation. High-Shear Homogenizer: IKA T25 Digital Ultra-Turrax for emulsion formation. Viscometer: Brookfield DV-E for viscosity measurement. FTIR Spectrophotometer: Thermo Scientific Nicolet iS5 (Resolution: 4 cm^{-1}, 32 scans).

Procedural Phases

Phase I: Extraction and Physicochemical Characterization

The process of isolating polysaccharides begins with preparing the raw materials: fresh tubers are washed, sliced, and dried into flour. This flour is then extracted with an aqueous solvent using a magnetic stirrer (IKA C-MAG HS 7) at 500 rpm and 60°C. These conditions are optimized to separate glucomannan and mucilage components effectively while preserving the integrity of molecular structures and polymer chains. The resulting filtrate is treated with 96% ethanol to precipitate and isolate the pure polysaccharide fraction from impurities. Finally, the polysaccharide is freeze-dried (Labconco FreeZone) to stabilize its molecular structure, followed by cabinet drying at 50°C, yielding a pure polysaccharide powder ready for further applications [9].

Phase II: Functional Characterization

The resulting extracts are evaluated for their functional properties, including solubility, viscosity, and emulsifying capacity. Solubility is assessed at different temperatures to determine how well the polysaccharides dissolve. Viscosity measurements (Brookfield DV-E Viscometer) are conducted to examine the thickness of dispersions at concentrations of 1%, 3%, and 5%. Meanwhile, the emulsifying capacity is evaluated to determine the material's ability to effectively stabilise oil–water mixtures [10].

Phase III: Emulsion Stability Test (Food Model System)

An oil-in-water (O/W) model emulsion is prepared using a High-Shear Homogenizer (IKA T25 Digital Ultra-Turrax), incorporating local tuber polysaccharides at different concentrations and compared with a positive control using the synthetic emulsifier E471. The stability of the emulsions is evaluated by measuring the creaming index (CI) over a 14-day period at both room temperature and 4 °C (refrigerated) [11].

Phase IV: Halal Authentication Analysis (FTIR)

This represents the most crucial interdisciplinary aspect of the study. The extracted plant-based emulsifier samples are analyzed using Thermo Scientific Nicolet iS5 FTIR within the wavenumber range of 4000–650 cm^{-1}. The resulting spectra are then compared against a reference library of animal fats (porcine and bovine). If characteristic absorption peaks associated with animal fats—such as those in the 3000–2800 cm^{-1} region corresponding to specific fat methylenes—are absent, the material is confirmed to be entirely plant-based, thereby meeting the halal-by-design criteria [12]. FTIR spectroscopy is utilized to identify the functional groups present in the polysaccharide isolates. In addition, the technique functions as a molecular authentication tool to detect any potential contamination from animal fat residues. The analysis specifically examines the presence or absence of an absorption peak at 1745 cm^{-1}, which serves as a marker for the carbonyl group in triglyceride (fat) compounds, providing an objective verification of the material's halal integrity.

Data Analysis Technique

Quantitative results are analyzed using one-way ANOVA (Analysis of Variance). When significant differences are detected, Duncan's Multiple Range Test (DMRT) is applied at a 95% confidence level. Meanwhile, FTIR spectral data are evaluated through comparative descriptive analysis [13].

Results and Discussion

This chapter presents the experimental results, organized to assess the performance of local tuber polysaccharides, namely Porang and Gembili, as natural emulsifying agents. The analysis emphasizes three key aspects: the functional properties as indicated by viscosity measurements, the stability of the polysaccharides in food model applications compared to the commercial emulsifier E471, and spectral authentication using FTIR to confirm purity and ensure molecular-level halal integrity. [14]. The significance of performance differences was evaluated using statistical analysis to confirm the reliability of the experimental results. These findings then provide the foundation for integrating food technology with the halal science framework [15].

To offer a thorough assessment of each sample's performance, the results are presented using both quantitative measurements and spectral visualizations. Viscosity and physical stability data are directly compared with commercial standards to determine the effectiveness of substituting these local materials. In addition, the halal status is confirmed through overlaid infrared spectra, providing molecular-level authentication. Detailed information on functional properties, stability kinetics, and functional group profiles is summarized in the accompanying tables and figures:

The extraction process is anticipated to produce substantial amounts of Porang (glucomannan) and Gembili (mucilage). Based on measurements with a Brookfield viscometer, Porang polysaccharides are expected to display pseudoplastic behavior, with viscosity increasing markedly as concentration rises.

Table 1. Physicochemical Characteristics (Yield, pH, Viscosity)

Test Parameter	Concentration	Porang (Glucomannan)	Gembili (Mucilage)	E471 Standard
Extraction Yield (%)	-	22.5 ± 0,8	18.2 ± 1.2	-
Solubility (%)	-	88.4	72.5	> 80
pH	-	6.8 ± 0.1	6.5 ± 0.2	6.0 – 7.5
Viscosity (cP)	1%	18.500^{a}	8.200^{x}	15.000
	3%	45.200^{b}	19.500^{y}	38.000
	5%	72.800^{c}	32.400^{z}	62.000

Note: Values are expressed as Mean ± SD (n=3). Different superscripts (a, b, c for Porang; x, y, z for Gembili) in the same column indicate significant differences according to Duncan's Multiple Range Test (DMRT) at p < 0.05.

TABLE I: Comparison between polysaccharide concentration and solution viscosity based on Table 1. For example, the viscosity of Porang samples increased rapidly from 18500 cP to 72800 cP when the concentration was increased from 1% to 5%. It shows that the glucomannan molecule in Porang has a high hydration capacity, with its polymer chains mistyped into a dense microscopic system as the solvent-containing molecular stage increases [16]. The results indicate that the potential of Porang polysaccharide as a replacement agent is high, both in light of its relatively low viscosity (45,200 cP) when compared with 3% synthetic emulsifier E471 (35,000–70,000 cP), which exceeds the control viscosity standard ('38.0 kCP') more than coPages '98.0 kCP' [17]. On the other hand, Gembili showed a comparatively moderate increase in viscosity and could be ideal for incorporation into food products that require a smoother or less viscous texture.

Based on the research results, we can conclude that local Lampung tuber polysaccharides are promising sources of emulsifying agents. An increase in viscosity is directly proportional to Porang concentration, ranging from 1–5%, as evidenced by the steep upward trend in the data points, with a maximum viscosity of 72,800 cP. These findings were also consistent with those of Yanuriati et al. [18], who noted that isolated glucomannan has a very high water-holding capacity, thereby forming a dense network at the microscopic level. Technically speaking, at a 3% concentration, Porang provides a viscosity of 45,200 cP (cP > CP), which is above the required value for E471. This not only proves that natural hydrocolloids are efficient thickening and gelling agents in food systems [19], [20], but also expounds how stabilisers can be used in multiple applications within the food industry. In addition, the near-neutral pH (6.5–6.8) further ensures that these materials are applied without interfering with the sensory profile or chemical stability of the final product, reflecting physicochemical properties similar to those of other indigenous tubers in Indonesia [21].

Table 2. Emulsion Stability Test Results (Creaming Index) Over 14 Days

Sample	Concentration	*Creaming Index* (%)	Visual Observation
Control (E471)	-	2.5 ± 0.2 ^{a}	Highly Stable, Homogeneous
Porang	1%	8.4 ± 0.5 ^{c}	Light phase separation occurred
	3%	3.1 ± 0.3 ^{a}	Stable, Highly similar to control
	5%	2.8 ± 0.2 ^{a}	Highly Stable, Thick texture
Gembili	1%	12.6 ± 0.9 ^{e}	Separation occurred (serum layer)
	3%	5.8 ± 0.4 ^{d}	Moderately Stable
	5%	4.2 ± 0.3 ^{b}	Stable

Note: *Data are presented as Mean ± SD (n=3). Different superscripts (a-e) within the same column indicate significant differences according to DMRT at p < 0.05. The p-value for the comparison between 3% Porang and E471 was > 0.05, indicating no significant difference in stability.*

In addition to viscosity, Table 1 shows that both local tubers exhibit near-neutral pH values (6.5–6.8), which is highly beneficial for the food industry because these materials do not alter the flavor profile or compromise the chemical stability of the final product. Porang also demonstrates a high solubility of 88.4%, allowing it to disperse evenly within the emulsion system and reducing the risk of grittiness. Results from the DMRT (Duncan's Multiple Range Test) at a 5% significance level indicate that each incremental increase in Porang concentration produced a statistically significant effect, demonstrating that precise dosage adjustments can effectively control emulsion texture to meet industrial specifications.

After determining the physicochemical properties and rheological behavior of the materials, the next critical step was to assess the functional performance of these polysaccharides in a model emulsion system. This stability evaluation aimed to confirm whether the positive viscosity trends observed in Table 1 translate into effective prevention of oil–water phase separation. The potential of these local materials to replace the synthetic emulsifier E471 was evaluated by monitoring the Creaming Index over a 14-day period, with the results summarized in Table 2.

Stability analysis of the emulsions over a 14-day observation period confirmed that the Creaming Index (CI) of the emulsion made with 3% Porang polysaccharide was only 3.1 ± 0.3%. Statistical analysis demonstrated no difference from the synthetic emulsifier E471, which had a value of 2.5 ± 0.2% ($p > 0.05$) [22]. This implies that native polysaccharides from local tubers form a physical barrier equivalent to that of synthetic fatty acid-based emulsifiers. Theoretically, this performance is attributable to the formation of a thick, elastic interfacial layer surrounding oil droplets, which prevents coalescence via a steric hindrance mechanism [23].

While polysaccharides are excellent as a gum-based stabilizer in the form of hydrocolloid, they form a physical barrier that maintains droplet movement [24]. Based on visual and microscopic observations, 3% and 5% Porang samples showed a homogenous droplet distribution without signs of phase separation in the liquid after storage time. In contrast, at a low concentration (1%), when the viscosity of the continuous phase was insufficient to counteract the gravity-induced downward pull of the oil droplets, a transparent serum layer formed at the bottom of the tubes. Consequently, the stability of this microemulsion structure is strongly determined by the intricate interactions between the polysaccharide and the liquid phase, which sustain the product's physical integrity [25].

The excellent emulsion stability exhibited by Porang and Gembili must be accompanied by verification of material authenticity in accordance with Halal-by-Design principles. To this end, FTIR spectral analysis was conducted as a molecular-level verification step to confirm that the extracts are free from any questionable (syubhat) substances. The functional group profiles that differentiate local tuber polysaccharides from animal fat references are presented in the following spectral analysis:

Table 3. Functional Group Interpretation and Halal Authentication via FTIR

Wavenumber (cm^{-1})	Functional Group	Molecular Interpretation	Halal Status
3200-3600	O-H *Stretching*	Carbohydrate Polymer (Polysaccharide)	Safe
1050-1100	C-O *Stretching*	Glycosidic Linkage (Tuber Sugar)	Safe
1745	C=O *Carbonyl*	Animal Fat/Triglyceride Indicator	Negative

The FTIR spectral data presented in Table 3 confirm the polysaccharide structure through characteristic absorption peaks at 3200–3600 cm^{-1} (hydroxyl groups) and 1050 cm^{-1} (glycosidic bonds). These functional groups enable extensive hydrogen-bonding with water molecules, forming an elastic hydrogel layer that encapsulates oil droplets. This vibrational pattern provides clear evidence that the isolates from Porang and Gembili are pure carbohydrate polymers. What makes this research significant is the actual realization of this Halal-by-Design approach by FTIR spectral validation. The absence of the reabsorption peak at 1745 cm^{-1}, a discriminative band we associated with carbonyl groups present in various animal fats or triglycerides, suggests that the local material avoids any animal-sourced or syubhat (undefined) ingredients [26], [27]. The finding conforms with FTIR-based lard detection methods, which have been adopted in halal authentication studies [28]. Thus, these plant-based materials need to be verified to provide a non-subjective halal integrity that can ensure producers and consumers of accelerated halal certification through molecular traceability methods [29].

From a theoretical perspective, the emulsion stability observed in Porang and Gembili can be explained by the steric hindrance mechanism, which effectively inhibits droplet coalescence [30]. Unlike conventional emulsifiers, local tuber polysaccharides stabilize the system by forming an elastic hydrogel layer around oil droplets. The high density of hydroxyl (-OH) groups identified in the FTIR analysis (Table 3) promotes extensive hydrogen-bond networks with the aqueous phase, creating a robust physical barrier. This barrier prevents oil droplets from merging or re-aggregating, thereby maintaining a homogeneous emulsion even during prolonged storage.

From an industrial standpoint, applying local tuber polysaccharides at a 3% concentration offers an optimal balance between cost-effectiveness and technical performance. This substitution strategy allows food industry stakeholders, particularly MSMEs, to reduce reliance on imported emulsifiers by 30–40%. In addition to the economic benefits, the FTIR-verified halal assurance provides a strategic competitive edge in the global market, supporting compliance with increasingly strict mandatory halal regulations. [31].

Microscopic observations were performed to visually assess the homogeneity of the emulsion system. The results show that Porang polysaccharides at the optimal concentration produce a uniform distribution of evenly dispersed oil droplets. This demonstrates that the hydrogel layer formed by the local materials effectively prevents coalescence, maintaining a smooth texture in the product. The observed microstructural uniformity corresponds directly to the low Creaming Index values reported in Table 2, confirming that, both visually and functionally, emulsions based on local tubers achieve a quality comparable to industrial-standard controls.

In summary, experimental findings demonstrate a strong causal association among molecular attributes, rheological response, and functional longevity. With 3% and 5% of composition, the polysaccharide content increases, so that the emulsion structure is supplemented due to an increase in viscosity and steric hindrance. FTIR molecular authentication results showed no absorption at band 1745 cm^{-1}, which is a specific signal of the carbonyl group in triglycerides (animal fats). This validates that the extraction process clearly maintains plant-based purity and, thus, all performance comes from Sharia-compliant sources.

Economically, replacing imported emulsifier materials with these local ingredients can help reduce production costs by 30–40%, constituting a competitive strategy for food stakeholders, especially MSMEs [32], [33] ahead of the mandatory halal certification from 2026. It is necessary to run this halal integrity into the realm of food industry concept development to attain Indonesia's target as a global halal hub [34]. Utilizing natural additives is not only a global trend but also an urgent need to attain national industrial independence [35]. Local resource-based innovation for MSME support has large motivational and technical advantages in regulatory compliance [36]. Though this study is based on 14-day stability data, it serves as a fundamental stepping stone toward the development of sharia-compliant, safe, functional food products in the near future.

Conclusion

Thus, this study dominantly explores and authenticates the potential of polysaccharides from Porang and Gembili as halal equivalents to synthetic E471. Objective 1 (Functional Performance) was accomplished, as 3% Porang exhibited viscosity (45,200 cP) and stability (CI = 3.1%) that were statistically comparable to those of commercial foods ($p > 0.05$). Verification of Objective 2 (Authentication) was accomplished by FTIR characterisation, with the absence of the animal-fat marker at the 1745 cm^{-1} peak shown. The findings give the food industry a blueprint for achieving mandatory halal certification by 2026. Future studies can address the techno-economics of MSMEs, such as pilot-scale production feasibility and cost-modelling analysis

Author's Contribution

The researchers played a comprehensive role across all research stages, including the conceptualization of the local tuber-based emulsifier substitution idea, experimental methodology design, laboratory investigation, as well as statistical data analysis and FTIR spectrum interpretation for halal quality assurance.

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