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*Research Article*

# Physicochemical Characterization and Heavy Metal Contents of Stingless Bee Honey (*Trigona itama*) from Bekalar Village, Riau

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**Abstract:** Honey is a natural product rich in simple sugars and minor bioactive constituents and is widely recognised for its antioxidant, antibacterial, anti-inflammatory, and wound-healing activities. Stingless bee honey from *Trigona itama* has become increasingly relevant in Southeast Asia due to its distinctive physicochemical profile and its high content of phenolics and flavonoids, which contribute to functional properties compared with conventional Apis dorsata honey. Despite its growing economic and scientific importance, standardized data on the quality and safety of *Trigona itama* from specific local environments in Indonesia remain limited. This study evaluated the physicochemical characteristics and heavy metal content of *Trigona itama* honey originating from Bekalar Village, Siak Regency, Riau, and assessed the quality standards of honey with Standar Nasional Indonesia (SNI) 8664:2018 for honey. A descriptive laboratory design was employed, and honey samples from managed colonies were analysed for moisture, acidity ash content, viscosity, and heavy metal content of Pb, Cd, Hg, and As using validated analytical procedures. The honey demonstrated a moisture content of 28.39 ± 0.03%, acidity content 30.90± 4,74 mLNaOH/Kg, ash content of 0.073 ± 0.03% b/b, viscosity of 68,44 ± 0,725 poise. Heavy metal concentrations were low, with Pb < 0.22 mg/kg, Cd < 0.01 mg/kg, Hg < 0.002 mg/kg, and As < 0.30 mg/kg. These findings confirm that *Trigona itama* honey from Bekalar village is safe and compositionally consistent with typical stingless bee honey due to Standar Nasional Indonesia (SNI) 8664:2018 for honey, although its high moisture content underscores the need for improved post-harvest handling to support stability and compliance with national quality requirements.

**Keywords:** Bekalar Village; Heavy Metals; Physicochemical Properties; Stingless Bee Honey; Tigona Itama

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## 1. Introduction

Honey is a natural sweet liquid produced by bees from plant nectars rich in simple carbohydrates such as fructose, glucose, and sucrose, and it also contains various minor components including vitamins, minerals, and phenolic compounds (Gadge et al., 2024; Mello dos Santos et al., 2025). Traditionally, honey has been used for centuries as a functional food and as a therapeutic agent because it exhibits antioxidant, antibacterial, anti-inflammatory, and wound healing activities (Morariu et al., 2024; Rosli et al., 2020). In the context of stingless bees, kelulut honey produced predominantly by *Trigona itama* (often referred to as Trigona itama) has become one of the rapidly developing honey commodities in Southeast Asia, including Indonesia (Ramadhan et al., 2020; Setiawan et al., 2024).

Stingless bee honey known as madu kelulut, produced by stingless bees Trigona Itama, has physicochemical characteristics that differ from those of honey produced by stinging bees (Apis spp.) (Gadge et al., 2024; Tiang et al., 2025). These differences include generally higher moisture content, lower pH, higher free acidity, as well as distinct colour and viscosity properties (Manickavasagam et al., 2023; Shahira Rosidi Sujanto et al., 2022). Several studies have reported that stingless bee honey contains bioactive compounds such as phenolics, flavonoids, tannins, and saponins in relatively high levels that contribute to its antioxidant, antibacterial, and potential immunomodulatory activities (Cheng et al., 2023; Shamsudin et al., 2022).

Over the last five years, publications on stingless bee honey have increased substantially in line with findings that total phenolic content, flavonoids, and antioxidant capacity of stingless bee honey are generally comparable to or higher than those of some Apis honeys (Pote et al., 2025; Setiawan et al., 2024). These bioactive compounds directly contribute to antimicrobial and anti-inflammatory activity through mechanisms such as free radical scavenging, inhibition of pathogenic bacterial growth, and modulation of oxidative signalling pathways including KEAP1 NRF2 (Cheng et al., 2023; Rosli et al., 2020). Therefore, stingless bee honey has strong potential to be developed as a raw material for natural supplements and functional food formulations, either as a single origin honey or as a component in blended fermented or functional beverage products (Ahmad et al., 2023; Melia et al., 2024). In addition to its functional value, stingless bee keeping provides high economic value and contributes to rural community empowerment through livelihood diversification, income enhancement, and the utilisation of pollination services for horticultural and forestry crops (Melia et al., 2024; Ramadhan et al., 2020).

In Indonesia and Malaysia, the development of meliponiculture of *Trigona itama* has been reported to increase the number of colonies managed by local communities and to expand the utilisation of honey, propolis, and bee pollen as value added products (Hassan et al., 2021; Ramadhan et al., 2020). However, the physicochemical characteristics of stingless bee honey vary widely among regions because they are influenced by geographical conditions, topography, types of nectar providing vegetation, and local beekeeping practices (Manickavasagam et al., 2023; Shahira Rosidi Sujanto et al., 2022). Several studies have shown that stingless bee honey from various tropical locations has moisture content in the range of approximately 25–40%, pH values around 3.0–4.0, and relatively high free acidity compared with Apis honey, which has implications for its stability and post-harvest handling requirements (Shahira Rosidi Sujanto et al., 2022; Wongsa et al., 2023). Research conducted in East and North Kalimantan reported that local stingless bee honeys have a characteristic sweet-sour taste, colours ranging from yellow to dark brown, and relatively high antioxidant activity (Ramadhan et al., 2020). Other studies on *Trigona itama* honey from different areas in Southeast Asia have confirmed that sugar composition, moisture content, and phenolic levels are strongly dependent on the diversity of nectar producing flora surrounding the apiaries (Majid et al., 2020; Ng et al., 2024).

The concept of simplicia characterisation in pharmacognosy aims to establish the specifications of natural raw materials so that their identity, purity, and quality can be assured before their use in the development of medicinal or health products (Prasetya et al., 2022). This characterisation includes the determination of specific parameters (organoleptic, macroscopic, and microscopic features) and nonspecific parameters such as moisture content, ash values, and loss on drying, in order to ensure batch to batch quality consistency (Baroroh, 2020; Yanti et al., 2022). Standardised identity and quality of simplicia are crucial because variability in source materials, post-harvest techniques, and storage conditions can affect the safety profile, efficacy, and overall quality of natural products (Prasetya et al., 2022; Sari et al., 2025). In the case of honey, numerous studies have reported that its physical and chemical properties are strongly influenced by climate, topography, botanical origin of nectar, harvesting techniques, processing, as well as storage temperature and duration (Gadge et al., 2024; Manickavasagam et al., 2023). *Trigona itama* honey from different locations and topographical regions has shown significant differences in moisture content, free acidity, electrical conductivity, ash content, and total phenolic content (Manickavasagam et al., 2023; Shahira Rosidi Sujanto et al., 2022). Therefore, simplicia characterisation of honey generally includes the evaluation of pH, viscosity, moisture, ash content, and heavy metal levels as key indicators of quality and safety (Bereksi-Reguig et al., 2022; Gadge et al., 2024).

Bekalar Village in Siak Regency, Riau Province, is ecologically suitable for stingless bee honey production due to the availability of local nectar producing flora and favourable agro ecosystem conditions for stingless bee keeping, although scientific data on the characteristics of its honey remain limited (Melia et al., 2024; Ramadhan et al., 2020). This lack of data contrasts with other regions in Indonesia, such as Kalimantan and West Sumatra, where physicochemical profiles and biological activities of stingless bee honey have been evaluated (Ramadhan et al., 2020; Setiawan et al., 2024).

In Indonesia, honey quality is regulated by the Indonesian National Standard (SNI) 8664:2018, which integrates standards for forest honey, farmed honey, and stingless bee honey and sets quality requirements for honey marketed for human consumption (Khabibi et al., 2022; Nasional, 2018). Based on SNI 8664:2018 for honey, a maximum moisture content of 22% (w/w), a maximum ash content of 0.5% (w/w), free acidity not exceeding 50 mL NaOH/kg, and a minimum viscosity of 10 Poise to ensure authenticity and stability of commercial honey products (Khabibi et al., 2022; Nasional, 2018). Although these parameters were designed to accommodate the diversity of Indonesian honeys, several studies have reported that stingless bee honey frequently exhibits moisture content above this limit, indicating the need for specific handling strategies or consideration of revised thresholds for the kelulut honey category (Manickavasagam et al., 2023; Shahira Rosidi Sujanto et al., 2022).

The safety of honey products is also evaluated through the determination of heavy metal contaminants such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) because these elements can accumulate from soil, water, air, and floral sources into bee products (Bereksi-Reguig et al., 2022; Mititelu et al., 2023). Studies on *Trigona itama* honey in Sabah, Borneo, have shown that samples collected near urban and industrial zones contained detectable but low levels of metals such as Zn, Pb, As, Cr, and Cd, which were still below the maximum limits set by international food safety standards (Salman et al., 2022).

Other investigations on stingless bee honey as a bioindicator have demonstrated that honey from non-industrial areas generally contains heavy metal concentrations far below World Health Organization (WHO) guideline values and does not pose significant health risks to consumers (Okeola et al., 2020). These findings highlight that the quality and safety of stingless bee honey are strongly influenced by the location of the apiaries and their proximity to pollution sources such as industrial areas, heavy traffic corridors, and intensive agricultural zones with high pesticide inputs (de Oliveira et al., 2025; Mititelu et al., 2023). Consequently, regular monitoring of heavy metal levels and careful selection of relatively unpolluted sites for stingless bee keeping are essential strategies to guarantee the safety of kelulut honey for human consumption (Salman et al., 2022). This approach is consistent with the growing trend of utilising stingless bee honey both as a bioindicator of environmental quality and as a high value functional food commodity (Pote et al., 2025).

To date, scientific reports specifically addressing the physicochemical characteristics and heavy metal content of *Trigona itama* stingless bee honey from Riau Province, particularly Bekalar Village, are still very limited compared with other regions in Indonesia and Malaysia (Ramadhan et al., 2020). Yet this region is presumed to possess high diversity of local nectar producing flora and abundant *Trigona itama* colonies, which are promising for the production of honey and other bee derived products (Setiawan et al., 2024). These reports showed potential research on kelulut honey quality, especially for honeys originating from lowland swamp and forest ecosystems in Sumatra (Pote et al., 2025; Setiawan et al., 2024).

The present study aims to conduct a series of physicochemical characterisation tests on *Trigona itama* kelulut honey from Bekalar Village, including measurements of moisture content, viscosity, ash content, and acidity, in reference to the quality parameters from SNI 8664:2018. In addition, this study also analyse the heavy metals (Pb, Cd, Hg, and As) content to evaluate the safety of Bekalar kelulut honey against prevailing food safety standards. This research is expected to contribute to strengthening the Indonesian database on kelulut honey quality, particularly for the stingless bee honey category originating from Riau. This finding may support the formulation or refinement of guidelines for standardisation and quality control of local kelulut based products and promote the development of a sustainable value chain for beekeeping communities in Bekalar Village

## 2. Methods

*Trigona itama* honey were collected from Bekalar Village, Riau, Indonesia. The characterization tests for stingless bee honey were conducted at the Compounding & Dispensing Laboratory, Universitas Abdurrab, and at Balai Standardisasi dan Pelayanan Jasa Industri (BSPJI), Pekanbaru. The evaluation followed the Standar Nasional Indonesia (SNI) 8664:2018 for honey (Khabibi et al., 2022; Nasional, 2018). *Trigona itama* honey samples were gently homogenized for approximately 5 minutes to ensure uniform distribution of constituents without excessive air incorporation, then transferred into labelled amber glass bottles, tightly sealed, and stored at ambient temperature (±25 °C) in the dark to minimize thermal and photo oxidative degradation, as recommended in honey quality evaluation studies (Suhesti et al., 2023).

The moisture content was determined according to SNI 8664:2018 and commonly applied AOAC type procedures for honey (Khabibi et al., 2022; Lomiso et al., 2021; Nasional, 2018) Approximately 5 g of honey were accurately weighed (±0.0001 g) into pre dried and tared porcelain crucibles, then dried in a hot air oven at 105 °C until constant weight was achieved (mass difference between successive weighings ≤0.5 mg), with weighing intervals of 1–2 hours, followed by cooling in a desiccator before weighing (Hadjar, 2024; Ratnaningsih et al., 2025). Moisture content was calculated as the percentage loss in mass relative to the initial sample mass and expressed as % w/w, in line with the reporting format specified in SNI 8664:2018 and international honey quality studies (Lomiso et al., 2021; Nasional, 2018)

Acidity and pH were determined by volumetric titration and potentiometric measurement, respectively, in accordance with SNI 8664:2018 and widely used physicochemical protocols for honey (Ameliya et al., 2023; Lomiso et al., 2021; Nasional, 2018). For each sample, 10 g of honey were dissolved in 75–100 mL of $CO_2$ free distilled water in an Erlenmeyer flask, thoroughly mixed, and the initial pH was measured using a calibrated pH meter (standardized with pH 4.00 and 7.00 buffer solutions) (Azonwade et al., 2018; Lomiso et al., 2021). The solution was then titrated with 0.05 M NaOH under continuous stirring until the endpoint pH 8.5 was reached and titrated with 0.05 M HCl until it reached a pH of 8.3. a blank was analyzed by titrating 75 ml of $CO_2$ free distilled water (Adityarini et al., 2020; Ameliya et al., 2023; Lomiso et al., 2021; Raweh et al., 2023).

Viscosity was measured using a rotational viscometer (e.g., Brookfield type) in line with rheological methodologies commonly applied in honey research, including stingless bee honey (Faustino & Pinheiro, 2021). Honey samples were transferred into beakers to adequately cover the selected spindle and equilibrated at 25 ± 0.5 °C for approximately 30 minutes in a temperature-controlled water bath prior to measurement (Lomiso et al., 2021; Santos et al., 2014). Measurements were performed at an appropriate rotational speed and spindle combination to maintain the torque within the recommended range (typically 10–90% of the scale), and viscosity values were recorded in cP or Pa·s and converted to Poise where necessary for comparison with SNI viscosity criteria (Faustino & Pinheiro, 2021). Each sample was analysed in at least triplicate, and results were expressed as mean ± standard deviation (Ameliya et al., 2023; Faustino & Pinheiro, 2021).

Ash content was determined by dry ashing in accordance with SNI 8664:2018 and AOAC based honey methods (Lomiso et al., 2021; Nasional, 2018). Approximately 5–10 g of honey were weighed into pre ignited and tared porcelain crucibles, then gently heated on a hot plate to reduce foaming and smoke, thereby preventing sample loss (Azonwade et al., 2018; Lomiso et al., 2021). The crucibles were subsequently placed in a muffle furnace and ashed at 500–550 °C until a light grey or white inorganic residue and constant weight were obtained (difference between successive weighings ≤0.5 mg) (Lomiso et al., 2021; Santos et al., 2014). After cooling in a desiccator, crucibles were weighed, and ash content was calculated as the percentage of residue mass relative to the original sample mass (% w/w) (Raweh et al., 2023).

Heavy metals (Pb, Cd, Hg, and As) content were quantified using atomic absorption spectrometry (AAS) or an equivalent spectrometric technique widely applied in honey contaminant analysis (Mititelu et al., 2023; Wilczyńska et al., 2024). Samples were subjected to wet digestion by placing approximately 1–2 g of honey into acid resistant vessels, adding a suitable volume of concentrated nitric acid (with or without hydrogen peroxide), and heating gradually until a clear solution was obtained (Farida et al., 2024; Sardans et al., 2010). The digests were cooled, quantitatively transferred into volumetric flasks, diluted to a defined volume with deionized water, and filtered if necessary to remove remaining particulates (Sardans et al., 2010; Wilczyńska et al., 2024).

Elemental concentrations of Pb, Cd, Hg, and As were measured at their characteristic wavelengths using flame or graphite furnace AAS (or ICP OES), with external calibration using multi element standard solutions across an appropriate concentration range (Salih, 2024; Wilczyńska et al., 2024). Analytical quality control included analysis of reagent blanks, calibration verification standards, and, where available, certified reference materials to verify accuracy and precision (Harmono, 2020; Salih, 2024). Results were expressed in mg/kg (ppm) and compared with guideline maximum levels for heavy metals in honey and related foods (Gelaye et al., 2024; Mititelu et al., 2023).

All physicochemical and heavy metal evaluations (moisture content, free acidity, viscosity, ash content, and heavy metal contents) were performed at least in duplicate to triplicate for each sample to ensure statistical reliability of the data (Azonwade et al., 2018; Raweh et al., 2023). Instrument calibration (pH meter, viscometer, analytical balance, and AAS/ICP equipment) was performed regularly according to laboratory protocols and manufacturer recommendations to minimize systematic errors (Majtan, 2024; Nunes et al., 2023). Method validity and analytical performance were maintained through internal quality control measures (blanks, standards, and replicate analyses) and by adhering to acceptance criteria derived from SNI 8664:2018 and international guidelines for honey quality assessment (Bicudo de Almeida-Muradian et al., 2020; Nasional, 2018).

## 4. Results and Discussion

Stingless bee species identification conducted at the Biology Laboratory, Faculty of Mathematics and Natural Sciences and Health, Universitas Muhammadiyah Riau, confirmed that the stingless bee species cultivated in Bekalar Village is *Trigona itama*, which is in line with reports identifying *Trigona itama* as one of the predominant kelulut honey–producing species in meliponiculture systems across various regions of Indonesia and Malaysia (Ramadhan et al., 2020; Tiang et al., 2025).

Honey harvesting was carried out using a suction technique with a custom assembled device connected to a collection container, a procedure comparable to modern kelulut honey harvesting practices recommended to minimize physical contamination and structural damage to honey pots (Manickavasagam et al., 2023; Shahira Rosidi Sujanto et al., 2022). From 200 g of raw honey collected, 174 g of honey simplicia were obtained after filtration, yielding 87%, which falls within the efficiency range reported for small scale kelulut honey processing among local beekeepers in Indonesia (Ameliya et al., 2023; Wongsa et al., 2023).

**Table 1.** Results of determining moisture content, acidity, ash, viscosity, and heavy metal contamination of stingless bee (*Trigona itama*) honey.

| Parameters | Result | Quality Requirements | Unit | Status |
|---|---|---|---|---|
| Moisture | 28,39 ± 0,037 | Maxs. 22 | %b/b | Not Qualified |
| Acidity | 30,90 ± 4,74 | Maxs. 50 | mL NaOH/Kg | Qualified |
| Ash | 0,073 ± 0,033 | Maxs. 0,50 | %b/b | Qualified |
| Viscosity | 68,44 ± 0,725 | Min. 10 | Poise | Qualified |
| Heavy Metals* | | | | |
| - Lead (Pb) | <0,22 | Maxs. 1,0 | mg/kg | Qualified |
| - Cadmium (Cd) | <0,01 | Maxs. 0,2 | mg/kg | Qualified |
| - Mercury (Hg) | <0,002 | Maxs. 0,03 | mg/kg | Qualified |
| - Arsenic (As) | <0,30 | Maxs. 1,0 | mg/kg | Qualified |

*All of heavy metal content test results are below (LOQ: *Limit of Quantification*)

Moisture content determined by thermogravimetric analysis showed that Bekalar kelulut honey had a moisture level of 28.39 ± 0.037% w/w, exceeding the maximum limit of 22% w/w stipulated in SNI 8664:2018 (Khabibi et al., 2022; Nasional, 2018). This value is consistent with previous reports indicating that stingless bee honey typically exhibits high moisture content, generally ranging from 25% to 38%, and often fails to meet moisture limits established for Apis honey in national and international standards (Shahira Rosidi Sujanto et al., 2022; Wongsa et al., 2023).

Studies on *Trigona itama* kelulut honey from Kalimantan and Sumatra have similarly reported moisture contents of approximately 27–32%, reinforcing the notion that high moisture content is an inherent characteristic of tropical stingless bee honey (Ramadhan et al., 2020; Setiawan et al., 2024). Elevated moisture levels are known to increase the risk of fermentation by osmotolerant yeasts such as Zygosaccharomyces spp., which can raise acidity and reduce the organoleptic stability of honey, as documented in quality assessments of stingless bee and other tropical honeys (Gebreyes et al., 2025; Majtan, 2024). Environmental factors such as relative humidity, hive microclimate, the hygroscopic nature of honey, and harvesting and storage practices have been reported as key determinants of honey moisture content, thereby supporting the recommendation of post-harvest strategies such as mild dehydration and storage in tightly sealed containers for high moisture kelulut honey (Manickavasagam et al., 2023; Ratnaningsih et al., 2025).

The free acidity of Bekalar kelulut honey was 30.90 ± 4.74 mL NaOH/kg, which is within the SNI 8664:2018 maximum limit of 50 mL NaOH/kg and lies within the general acidity range for Indonesian stingless bee honey, typically around 25–40 mL NaOH/kg (Melia et al., 2024). Studies on H. itama honey from Malaysia and Thailand have similarly reported relatively high acidity values (approximately 20–60 mL NaOH/kg), attributed to the accumulation of organic acids such as gluconic acid produced by glucose oxidase activity during storage (Shahira Rosidi Sujanto et al., 2022; Wongsa et al., 2023). Previous research has shown that high moisture content in stingless bee honey is associated with an increased risk of fermentation and elevated acidity, so the observed relationship between moisture and acidity in Bekalar honey is consistent with this pattern (Rusmalina et al., 2024; Shahira Rosidi Sujanto et al., 2022). Moreover, the relatively high acidity has been reported to contribute to the antimicrobial activity of stingless bee honey, with several studies demonstrating correlations between low pH, high acidity, and antibacterial effects against Staphylococcus aureus and Escherichia coli (Cheng et al., 2023; Rosli et al., 2020).

The total ash content of Bekalar kelulut honey simplicia was 0.073 ± 0.033% w/w, well below the SNI 8664:2018 maximum limit of 0.5% w/w and within the ash range of tropical stingless bee honeys, which is generally reported to be approximately 0.05–0.30% (Khabibi et al., 2022; Nasional, 2018; Raweh et al., 2023). Multiple studies have indicated that ash content reflects the mineral profile of honey, which is influenced by nectar and pollen botanical origin, soil composition, and geographical location, and that stingless bee honeys from forest and agroforestry landscapes tend to have low to moderate ash levels (Melia et al., 2024; Tiang et al., 2025). These findings are consistent with reports of kelulut honey from Sumatra and Kalimantan showing ash contents below 0.3%, indicating that Bekalar kelulut honey simplicia possesses a mineral content comparable to stingless bee honeys from other Indonesian regions (Ameliya et al., 2023; Ramadhan et al., 2020).

The viscosity of Bekalar kelulut honey was 68.44 ± 0.725 Poise, far exceeding minimum requirement of 10 Poise and falling within the viscosity range reported for tropical stingless bee honeys, which are typically below 100 Poise at moisture contents above 25% (Apriani et al., 2013; Faustino & Pinheiro, 2021).Rheological studies on stingless bee honey have shown that viscosity is strongly affected by moisture content, the proportion of reducing sugars (fructose and glucose), and temperature, with viscosity decreasing at higher moisture levels and elevated temperatures (Santos et al., 2014; Shahira Rosidi Sujanto et al., 2022). Recent data on H. itama honey from Southeast Asia report comparable viscosity values at moisture contents of approximately 27–35%, indicating that the viscosity of Bekalar honey is consistent with regional kelulut honey profiles (Tiang et al., 2025; Wongsa et al., 2023). Furthermore, these viscosity values align with findings that high quality stingless bee honey, despite its high moisture content, can still exhibit desirable thickness perceived positively by consumers as long as the sugar matrix structure remains intact (Ameliya et al., 2023; Ng et al., 2024).

Heavy metal analysis showed that Pb (<0.22 mg/kg), Cd (<0.01 mg/kg), Hg (<0.002 mg/kg), and As (<0.30 mg/kg) were all below the limit of quantification (LOQ) and well under the maximum levels recommended for honey in SNI 8664:2018 and various international food safety guidelines (Khabibi et al., 2022; Mititelu et al., 2023; Nasional, 2018). This result is in agreement with studies on stingless bee honey from non-industrial areas in Sabah, Brazil, and several regions of Indonesia, which consistently report very low heavy metal concentrations, often below detection limits and not posing significant health risks (Binjamin et al., 2024; Salman et al., 2022). Research on kelulut honey from the Ghimbo Pomuan customary forest in Kampar has also reported Pb and Cd levels compliant with SNI 8664:2018 (Suhesti et al., 2024), supporting the view that forested areas distant from pollution sources tend to yield honey with minimal heavy metal contamination (Campos et al., 2024; Khabibi et al., 2022; Nasional, 2018; Salman et al., 2022). Other studies have emphasized that packaging material can influence heavy metal accumulation, with storage in metal containers potentially increasing Pb levels due to micro corrosion, whereas glass and food grade plastic containers generally provide better stability for kelulut honey (Stanojević et al., 2024; Wilczyńska et al., 2024).

Recent studies have reported that stingless bee honey often contains relatively high levels of total phenolics and flavonoids (for example, approximately 150–250 mg GAE/kg), with DPPH radical scavenging capacities of around 60–70%, indicating strong antioxidant activity (Setiawan et al., 2024; Wongsa et al., 2023). Other research has found a positive correlation between total flavonoid content in kelulut honey and antibacterial activity against Staphylococcus aureus and Escherichia coli, reinforcing its potential as a complementary therapeutic agent (Cheng et al., 2023; Rosli et al., 2020). Geographical factors and nectar source flora have been shown to influence bioactive compound profiles; for instance, kelulut honey dominated by Calliandra nectar in South Sumatra has been reported to exhibit higher flavonoid content than honey derived from mixed wild flower nectar (Setiawan et al., 2024; Shamsudin et al., 2022). In addition to phenolic and flavonoid compounds, some studies have demonstrated that stingless bee honey contains bioactive peptides with antibacterial potential, underscoring the need for further research to evaluate the specific antioxidant and antibacterial activities of Bekalar kelulut honey and to compare them quantitatively with kelulut honeys from Kalimantan and Sulawesi (Setiawan et al., 2024; Tiang et al., 2025).

## 6. Conclusion

Kelulut honey *Trigona itama* from Bekalar Village, Siak Regency, is characterized by a high moisture content (28.39 ± 0.037% w/w), moderate to high free acidity (30.90 ± 4.74 mL NaOH/kg), ash content (0.073 ± 0.033% w/w), and high viscosity (68.44 ± 0.725 Poise), with all parameters except moisture complying with the quality limits specified in SNI 8664:2018 for honey. The overall physicochemical profile obtained in this study is consistent with typical tropical stingless bee honey, supporting its classification as kelulut honey with stable mineral content, desirable rheological properties, and acidity levels that may contribute to antimicrobial activity. The concentrations of heavy metals Pb, Cd, Hg, and As were all below the limit of quantification and well under national safety thresholds, indicating that Bekalar kelulut honey is safe for consumption from the perspective of heavy metal contamination taken together, these findings suggest that Bekalar kelulut honey meets standart of Standar Nasional Indonesia (SNI) 8664:2018 for honey and safety requirements (with the exception of moisture, which is inherently high in stingless bee honey) and has promising potential to be developed as a standardized local product and functional natural ingredient.

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