AcTion:
Aceh Nutrition Journal
July – September, 2026
Literature Review
DOI: http://dx.doi.org/10.30867/action.v11i3.3456
Pages: 1154 – 1167
p-issn 2527-3310; e-issn 2548-5741

From bioactive evidence to functional food development: barriers to the commercial translation of stingless bee honey: a narrative review

Dari bukti bioaktif menuju pengembangan pangan fungsional: hambatan translasi komersial madu lebah tanpa sengat: sebuah tinjauan naratif

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Article History:
Received: August 08, 2026; Revised: August 26, 2026; Accepted: September 11, 2026; Published: September 15, 2026.

Publisher:
Politeknik Kesehatan Aceh
Kementerian Kesehatan RI

Abstract

The growing interest in functional foods has increased attention to stingless bee (*kelulut*) honey; however, its development into standardized commercial products remains limited. This study aimed to synthesize evidence on the bioactive properties, quality determinants, and barriers to the commercial translation of stingless bee honey. This narrative review included 25 studies identified through PubMed and ScienceDirect searches conducted on September 2, 2026, covering publications from January 2015 to August 2026. Current evidence supports the antioxidant and antimicrobial potential of stingless bee honey, whereas evidence for its antidiabetic, antiobesity, and wound-healing effects remains largely preclinical. Variations in bee species, botanical origin, postharvest handling, and analytical methods limit the comparability across studies and complicate product standardization. In Indonesia, limited species- and region-specific calibration of existing quality criteria, along with insufficient validation of authentication methods, may further constrain commercialization. In conclusion, stingless bee honey has the potential to be used as a functional food ingredient. However, stronger human clinical evidence and further validation of quality criteria, authentication methods, and processing approaches are required to support standardized, evidence-based commercial translation.

Keywords: Bioactive compounds, commercial translation, Meliponini, quality standardization, stingless bee honey

Abstrak

Meningkatnya minat terhadap pangan fungsional mendorong perhatian pada madu lebah tanpa sengat (kelulut), namun pengembangannya menjadi produk komersial terstandar masih terbatas. Studi ini bertujuan untuk merangkum bukti mengenai sifat bioaktif, faktor penentu mutu, serta hambatan komersialisasi madu lebah tanpa sengat. Metode, tinjauan naratif ini mencakup 25 studi yang diperoleh melalui pencarian PubMed dan ScienceDirect pada 2 September 2026, dengan periode publikasi Januari 2015 hingga Agustus 2026. Hasil, bukti saat ini menunjukkan potensi antioksidan dan antimikroba madu lebah tanpa sengat, sedangkan bukti mengenai efek antidiabetes, antiobesitas, dan penyembuhan luka masih didominasi studi praklinis. Perbedaan spesies lebah, asal botani, penanganan pascapanen, dan metode analisis membatasi keterbandingan antarstudi serta menyulitkan standardisasi produk. Di Indonesia, keterbatasan kalibrasi kriteria mutu berdasarkan spesies dan wilayah, serta validasi metode autentikasi yang belum memadai, dapat menghambat komersialisasi. Kesimpulan, madu lebah tanpa sengat berpotensi dikembangkan sebagai bahan pangan fungsional. Namun, diperlukan bukti klinis pada manusia serta validasi lebih lanjut terhadap kriteria mutu, metode autentikasi, dan proses pengolahan untuk mendukung komersialisasi yang terstandar dan berbasis bukti.

Kata Kunci: Autentikasi, komersialisasi, madu lebah tanpa sengat, pangan fungsional, standardisasi mutu

Introduction

The global functional food market continues to expand alongside the growing burden of noncommunicable diseases (NCDs), such as type 2 diabetes, obesity, cardiovascular disease, and metabolic syndrome. This trend has increased consumer and scientific interest in foods that may provide physiological benefits beyond basic nutrition (Debri et al., 2026) and has renewed attention to naturally derived bioactive products, including bee products (Vit et al., 2025). This trend is reinforced by evidence linking sugar-sweetened beverage consumption to elevated obesity risk (Jannah et al., 2025), which has intensified consumer and industry interest in natural sweeteners such as honey as functional alternatives in beverage and food formulation. Among these, honey has received particular interest because its phenolic compounds, flavonoids, organic acids, and enzymes have been associated with antioxidant, antimicrobial, and anti-inflammatory activities in compositional and experimental studies (Cianciosi et al., 2018). However, these findings primarily demonstrate biological activity under experimental conditions and should not be interpreted as direct evidence that honey prevents or treats NCDs in humans.

Stingless bee honey, commonly known as kelulut honey in Southeast Asia, is produced by bees of the tribe Meliponini, including species from the genera *Heterotrigona, Tetragonula, Geniotrigona,* and *Trigona*. It has been proposed as a potential functional food because of its distinctive physicochemical characteristics and bioactive composition (Gebreyes et al., 2025; Harianja et al., 2023). Studies have reported relatively high phenolic content and antioxidant capacity compared with *Apis mellifera* honey (Zaldivar-Ortega et al., 2024b), along with antimicrobial and anti-inflammatory activities (Gebreyes et al., 2025). However, evidence concerning antidiabetic (Junaidin et al., 2025), antiobesity (Bakar, 2024), and wound-healing properties (Abd Jalil et al., 2017) remains less consistent and is largely derived from preclinical research. These findings justify further investigation but do not yet establish clinically meaningful benefits in humans. In Indonesia, the expansion of meliponiculture across Sumatra, Kalimantan, and Nusa Tenggara highlights the potential of stingless bee honey as a commodity with both functional food and economic value (Harianja et al., 2023).

Translating reported bioactive properties into standardized functional food products is challenging. One major concern is the substantial variability in the composition and biological properties of stingless bee honey according to the bee species, botanical source, geographic origin, and harvest season (Nordin et al., 2018). Consequently, stingless bee honey cannot be considered a compositionally uniform raw material, complicating the development of reproducible quality specifications and standardized commercial products. This issue has become increasingly relevant as meliponiculture and commercial interest in stingless bee honey have expanded across Southeast Asia.

Quality regulation presents additional challenges. Malaysia has established specific standards for stingless bee honey (Department of Standards Malaysia, 2017), although regulatory approaches differ across jurisdictions. In Indonesia, SNI 8664:2018 explicitly recognizes stingless bee (*Trigona*) honey as a separate category and establishes category-specific quality requirements, including a higher permissible moisture content than that applied to some other honey categories (Badan Standardisasi Nasional [BSN], 2018). Therefore, the principal issue in Indonesia is not the absence of a regulatory standard but whether the existing criteria are sufficiently calibrated and validated across variations in stingless bee species, botanical origins, geographic regions, and processing conditions.

The available evidence is fragmented across food chemistry, microbiology, pharmacology, and food technology research. Much of the literature consists of *in vitro* and animal studies with heterogeneous methodologies, whereas clinical evidence remains limited. Previous reviews have generally examined the individual aspects of stingless bee honey, including its physicochemical characteristics, phytochemical composition, antioxidant activity, and potential health effects. However, these domains have rarely been critically integrated with quality standardization, authentication, processing, and regulatory considerations that determine whether experimental findings can be translated into credible and functional food products.

Accordingly, the novelty of this review lies in its translational integration of biological evidence with quality and regulatory requirements relevant to functional food development. This review critically examines the reported bioactive and health-related properties of stingless bee honey, distinguishing evidence derived from *in vitro*, preclinical, and human studies. It further evaluates the quality determinants, standardization criteria, authentication approaches, processing considerations, and barriers to commercial application. By integrating these dimensions, this review aims to clarify which claims are currently supported by evidence, identify remaining knowledge gaps, and define priorities for the standardized and evidence-based development of stingless bee honey as a functional food.

Methods

Study Design

This study used a narrative review design, supported by a structured and reproducible literature search. A narrative approach was selected because the literature on stingless bee (*kelulut*) honey encompasses heterogeneous study designs, experimental models, and research domains, including physicochemical characterization, *in vitro* bioactivity, preclinical investigations, and product development studies. This heterogeneity was considered more appropriate for critical and integrative synthesis than for a quantitative meta-analysis.

Reporting was informed by the Scale for the Assessment of Narrative Review Articles (SANRA), particularly with respect to the justification of the review, description of the literature search, appropriate referencing, and balanced interpretation of the evidence. Relevant elements of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework were used to improve transparency in study identification, screening, eligibility assessment, and reporting. These frameworks were used to guide the reporting and did not classify the review as systematic or scoping.

Literature Search

Relevant literature was identified through structured searches of PubMed and ScienceDirect databases. Search terms combined concepts related to stingless bees and kelulut honey with terms addressing composition, bioactivity, health effects, quality, authentication, standardization, and functional-food applications. The search terms and syntax were adapted to the indexing systems and search functions of each database.

The final database search was conducted on September 2, 2026, and covered publications from January 2015 to August 2026. Google Scholar was used only for supplementary citation searches and did not contribute additional primary studies to the final review.

Table 1. Keywords and search string examples used across databases (PubMed & ScienceDirect)

Theme	Keywords	Search String
Species & physicochemical characterization	*Kelulut* honey, stingless bee honey, Heterotrigona, Trigona, Meliponini, physicochemical	("stingless bee honey" OR "*Kelulut* honey" OR Heterotrigona OR Trigona OR Meliponini) AND (physicochemical OR characterization OR composition OR properties)
Bioactive compounds & biological activity	bioactive, phenolic, flavonoid, antioxidant, antimicrobial, anti-inflammatory	("stingless bee honey" OR *Kelulut*) AND (bioactive OR phenolic OR flavonoid* OR antioxidant* OR antimicrobial OR "anti-inflammatory")
Quality & standardization	quality, standardization, adulteration, moisture content, HMF	("stingless bee honey" OR *Kelulut*) AND (quality OR standardization OR adulteration OR authenticity OR "moisture content" OR HMF OR hydroxymethylfurfural)
Functional food application	functional food, yogurt, fermented milk, synbiotic, edible coating	("stingless bee honey" OR *Kelulut*) AND ("functional food" OR yogurt OR "fermented milk" OR synbiotic OR "edible coating")
Health Benefits & Therapeutic Potential	antidiabetic, antihypertensive, wound healing, anticancer, obesity, metabolic syndrome	("stingless bee honey" OR *Kelulut*) AND (health OR therapeutic OR antidiabetic OR antihypertensive OR "wound healing" OR anticancer OR obesity OR "metabolic syndrome")

PubMed strings are shown as representative examples, and equivalent Boolean strings were adapted to the indexing syntax of ScienceDirect.

Eligibility Criteria

Studies were eligible if they met the following criteria: (1) they were original peer-reviewed research articles or, for regulatory evidence, official documents issued by recognized standard-setting or regulatory institutions; (2)

they investigated honey produced by stingless bees of the tribe *Meliponini*, including *Heterotrigona, Trigona, Tetragonula*, or other clearly identified stingless bee taxa; (3) they addressed at least one predefined review domain, including bioactive composition, biological activity, health-related effects, quality determinants, authenticity, standardization, or functional food and product applications; and (4) they provided sufficient methodological information for interpretation, including the study model or sample, intervention, exposure, or test material, comparator when applicable, analytical or experimental methods, and outcomes.

Studies were excluded if they did not specifically investigate stingless bee honey, focused exclusively on *Apis* honey without relevant comparison with stingless bee honey, did not address a predefined review domain, or provided insufficient methodological information for meaningful interpretation. Non-peer-reviewed sources were excluded, except for official standards and regulatory documents required to contextualize quality and regulatory requirements. The final synthesis comprised 25 primary research studies, and standards and regulatory documents were considered separately as contextual evidence.

Study Selection

Study selection was conducted in two stages. First, the titles and abstracts were screened against predefined eligibility criteria. Potentially relevant records were then subjected to full-text assessment. One reviewer conducted the initial screening, and a second reviewer independently assessed the eligibility at the full-text stage. Disagreements were resolved through discussion and consensus; any unresolved disagreements were adjudicated by the senior author.

Database searches identified 2,595 records. After excluding non-original publications, 1,060 records remained. The removal of 661 duplicate records resulted in 399 unique records for title and abstract screening. Of these, 226 were excluded, and 173 articles were assessed for eligibility. A further 148 articles were excluded, primarily because they did not specifically examine stingless bee honey, did not report outcomes relevant to the predefined domains, or were outside the scope of the review. Accordingly, 25 primary research studies were included in the final narrative synthesis. The selection process and reasons for exclusion at the full-text stage are summarized in a PRISMA-informed flow diagram (Figure 1).

Data Extraction

Data were extracted using a predefined framework that included publication characteristics, stingless bee species or taxonomic group, geographic and botanical origin, honey characteristics and processing conditions, study design, analytical or experimental methods, bioactive compounds and physicochemical parameters, biological or health-related outcomes, and major findings.

For studies addressing product development or quality, information on formulation, processing, storage, quality characteristics, and regulatory considerations was extracted when relevant.

Data extraction was performed by one reviewer and checked by a second reviewer for completeness and consistency of the data. Discrepancies were resolved through discussion and consensus agreement.

Evidence Synthesis

The extracted evidence was organized into five predefined thematic domains: (1) bioactive composition and physicochemical characteristics, (2) biological and health-related activities, (3) factors influencing composition and quality, (4) product development feasibility, and (5) quality standardization, authentication, and regulatory considerations.

Because of substantial heterogeneity in study designs, experimental models, analytical methods, outcomes, and methodological quality, the findings were synthesized narratively rather than quantitatively. Evidence from *in vitro*, animal, and human studies was distinguished throughout the synthesis to minimize the inappropriate extrapolation of experimental findings to clinical or population-level effects.

Methodological Quality and Risk-of-Bias Assessment

Because the included studies had substantially different methodological designs, a single risk-of-bias instrument was not considered appropriate for all studies. The risk of bias in the four included *in vivo* animal studies (Mohd Rafie et al., 2018; Ramli et al., 2019; Shaheran et al., 2025a; Shajahan et al., 2026) was assessed using SYRCLE's Risk of Bias tool for animal intervention studies. The assessment considered sequence generation, baseline characteristics, allocation concealment, random housing, blinding, random outcome assessment, blinded outcome assessment, incomplete outcome data, selective outcome reporting, and other potential sources of bias.

For physicochemical, analytical, *in vitro*, and food application studies, no single validated quality-assessment instrument was considered applicable across heterogeneous designs. The methodological quality was evaluated according to the transparency and adequacy of reporting, including sample size or experimental replication, botanical and geographic provenance, description and validation of analytical methods, use of appropriate controls or comparator honey where applicable, and consistency between the reported methods, findings, and conclusions.

Table 2. SYRCLE risk-of-bias assessment of the four included in vivo animal studies

Domain	Mohd Rafie (2018)	Ramli (2019)	Shaheran (2025)	Shajahan (2026)
Sequence generation	Unclear	Unclear	Unclear	Unclear
Baseline characteristics	Low	Low	Low	Low
Allocation concealment	Unclear	Unclear	Unclear	Unclear
Random housing	Unclear	Unclear	Unclear	Unclear
Blinding (caregiver/investigator)	Unclear	Unclear	Unclear	Unclear
Random outcome assessment	Unclear	Unclear	Unclear	Unclear
Blinding outcome assessor	Unclear	Unclear	Unclear	Unclear
Incomplete outcome data	Unclear	Low	Low	Low
Selective outcome reporting	Low	Low	Low	Low
Other bias	Low	Low	Low	Low

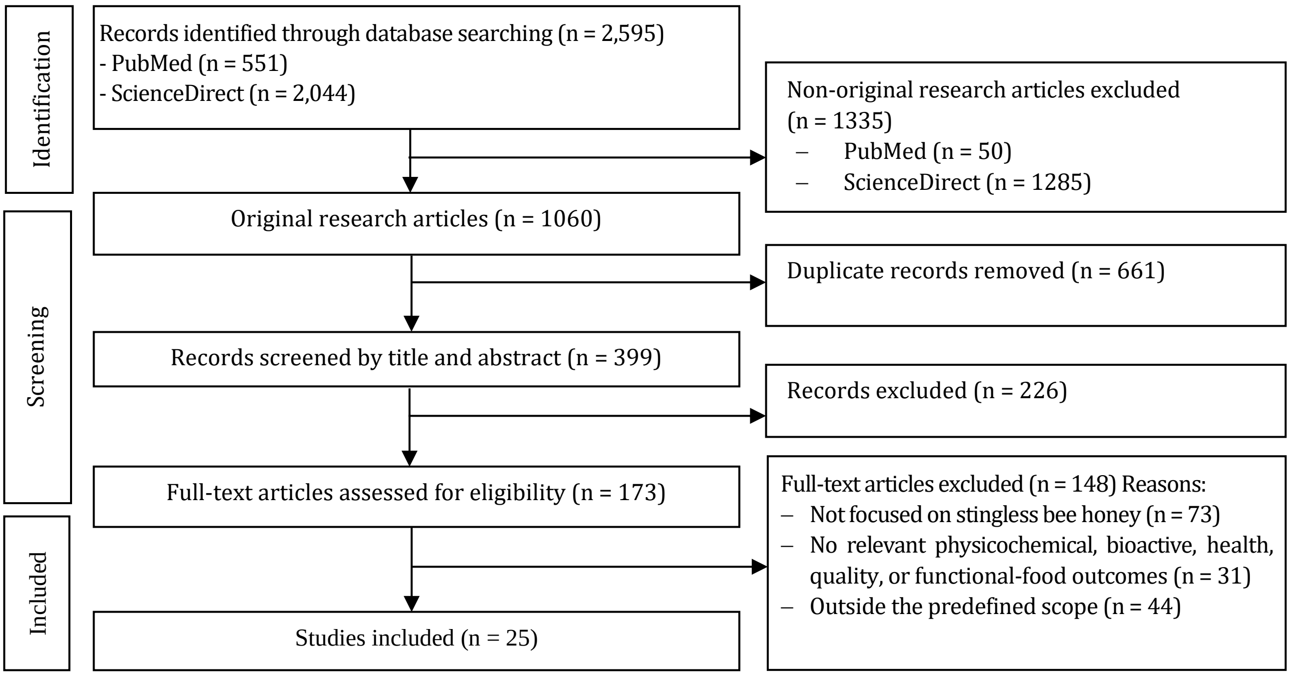

Figure 1. PRISMA-informed flow diagram of literature identification, screening, eligibility assessment, and study selection process.

The methodological appraisal was used to identify study limitations and sources of uncertainty, rather than to generate an overall numerical quality score. Quality considerations were incorporated into the narrative synthesis and interpretation. Findings derived primarily from compositional or *in vitro* assays were interpreted as evidence of chemical characteristics or biological activity, rather than clinical efficacy. Animal and other preclinical findings were considered supportive evidence but were insufficient to establish health benefits in humans. Human evidence was interpreted according to the design, sample size, and methodological limitations of available studies.

Result and Discussion

The literature search identified 25 eligible studies published between 2015 and 2026 (most from 2019 onward), predominantly from Malaysia and Indonesia, with additional evidence from Brazil, Thailand, Nigeria, India, and Australia. The study characteristics and principal findings are summarized in Table 3. Classified by primary evidence model, 17 studies were laboratory-based (14 analytical/comparative and 3 in vitro bioactivity studies), 4 were animal/preclinical studies, and 4 examined postharvest or food-product applications, indicating an evidence base that is predominantly laboratory-based, with a smaller preclinical component and limited food-matrix evidence.

Laboratory-based studies commonly characterized moisture, pH, acidity, sugars, HMF, phenolic/flavonoid content, and antioxidant activity (DPPH, FRAP, ABTS), alongside antimicrobial activity against Gram-positive and Gram-negative bacteria and, in vitro, anticancer, anti-inflammatory, and α-glucosidase inhibitory effects. The four animal studies reported anti-obesity, metabolic, neuroprotective, and stress-related effects, although differences in species, honey preparation, dose, and duration limited cross-study comparisons. The four postharvest/product-development studies showed that thermal treatment and storage altered moisture, HMF, phenolics, antioxidant activity, and viscosity, and that incorporation into fermented goat milk or use as a postharvest coating produced measurable technological effects. Collectively, these findings demonstrate biological activity and technological feasibility under experimental and preclinical conditions; however, they should not be interpreted as evidence of clinical efficacy or direct health benefits in humans.

Importantly, none of the 25 included studies were human clinical studies. Therefore, the current evidence base supports the characterization of physicochemical properties and experimentally observed biological activity, with additional preclinical support from animal models, but remains insufficient to establish clinically meaningful health effects, effective human doses, or therapeutic efficacy, which is central to this review's assessment of commercial translation.

Table 3. Study design and key findings of the 25 studies included in this narrative review

Study	Country	Species	Design / evidence type	Key finding
Shamsudin et al. (2019)	Malaysia	*H. itama*	Comparative / analytical	The botanical origin of honey affected its moisture, pH, acidity, sugar, and amino acid content, and PLS-DA was used to discriminate honey origins.
Ahmad et al. (2019)	Malaysia	*H. itama*	In vitro (cell-based)	Honey (0.625–10%) inhibited U-87 MG glioma proliferation and induced apoptosis in a dose- and time-dependent manner.
Shaheran et al. (2025)	Malaysia	NR	In vivo (CRS mouse)	SBH reduced corticosterone levels, increased dopamine/BDNF levels, and improved hippocampal integrity.
Chuah et al. (2023)	Malaysia	Multi-species (monofloral)	Comparative metabolomics	AMS with PCA/PLS-DA identified phenolic biomarkers that differentiated monofloral SBH by origin.
Costa dos Santos et al. (2022)	Brazil	Multi-species	Comparative / analytical	Identified 13 aliphatic organic acids (5 first reports); profiles varied by species.
Phonmat et al. (2025)	Thailand	*T. pagdeni*	Comparative / analytical	Physicochemical and antioxidant properties varied by area, and floral diversity was linked to stronger antibacterial activity.
Das et al. (2025)	India (Assam)	*T. iridipennis*	Comparative / analytical	It has the highest TPC/TFC and a broader antibacterial spectrum than Apis honey.
Mohamat et al. (2023)	Malaysia	NR	Experimental (adulteration)	HFCS (10–50%) elevated TSS/pH/viscosity and reduced trehalulose; HPLC-ELSD detected adulteration.
Braghini et al. (2020)	Brazil	NR	Experimental (storage)	Storage at 40 °C accelerated HMF formation and reduced diastase, phenolics, and antioxidant capacity compared to 22°C.
Maringgal et al. (2021)	Malaysia	Kelulut (unspecified)	Experimental (postharvest)	The 15% nanoparticle coating slowed papaya ripening and preserved ascorbic

Study	Country	Species	Design / evidence type	Key finding
				acid/phenolics over 21-day cold storage.
Melia et al. (2024)	Indonesia (West Sumatra)	*H. itama*	Experimental (food formulation)	SBH increased LAB counts, antioxidant activity, and phenolic content in fermented goat milk.
Nweze et al. (2017)	Nigeria (Nsukka)	*Hypotrigona*	Comparative / analytical	It had higher phenolic and ascorbic acid contents and FRAP activity than Apis mellifera honey.
Raypah et al. (2022)	Malaysia	NR	Experimental (authentication)	Vis–NIR spectroscopy with PCA/PLSR (R^2CV=0.96) accurately detected and quantified SBH adulteration.
Biluca et al. (2020)	Brazil	NR	In vitro (cell-based)	We identified 26 phenolics, and SBH reduced NO/TNF-α/IL-6/IL-1β and increased IL-10 levels in LPS-stimulated macrophages.
Setiawan et al. (2024)	Indonesia (West Sumatra)	*H. itama*	In vitro (enzyme assay)	The strongest α-glucosidase inhibition was associated with higher phenolic/flavonoid content.
Suhandy et al. (2023)	Indonesia (Lampung)	NR	Experimental (authentication)	Portable fluorescence spectroscopy with PLSR (R^2>0.98) rapidly quantified SBH adulteration.
Biluca et al., (2017)	Brazil	Meliponinae (generic)	Comparative / analytical	A total of 26 phenols were identified (salicylic acid dominant), and K/Mg/Cu were highly bioaccessible, whereas Fe/Mn/Zn were less bioaccessible.
Sousa et al., (2016a)	Brazil	Multi-species (semiarid)	Comparative / analytical	Floral source shaped polyphenolic profile; higher TPC honeys are generally more antibacterial.
Tiang et al. (2025)	Malaysia	*H. itama, L. canifrons, T. binghami*	Comparative / analytical	L. canifrons had the highest trehalulose/phenolics; H. itama had the highest antioxidant activity; and T. binghami had the highest antimicrobial activity.
Sousa et al. (2016b)	Brazil	Multi-species	Comparative / analytical	Fructose/glucose-dominant sugars, moisture, HMF, acidity, and sensory traits varied by species/origin.
Setiawan et al. (2025)	Indonesia (West Sumatra)	*T. testaceitarsis*	Experimental (storage)	Heating reduced moisture, viscosity, and antioxidant activity, but increased TSS, acidity, HMF, and phenolic content.
(Shajahan et al. (2026)	Malaysia	NR	In vivo (Alzheimer's mouse)	Improved spatial memory, reduced AChE/corticosterone, increased BDNF, and preserved hippocampal neurons.
Mwangi et al. (2024)	Kenya	NR	Experimental / analytical	High phenolic/flavonoid/antioxidant activity; inhibited multidrug-resistant S. aureus, P. aeruginosa, E. coli, and K. pneumoniae.
Mohd Rafie et al. (2018)	Malaysia	*H. itama*	In vivo (HFD obese rat)	1 g/kg/day reduced weight, BMI, adiposity, triglycerides, LDL, and leptin levels and increased HDL levels.
Ramli et al. (2019)	Malaysia	*H. itama*	In vivo (HCHF rat)	1 g/kg/day for 8 weeks reduced weight, abdominal fat, BP, glucose, and cholesterol levels and improved glucose tolerance.

Abbreviations: HFD, high-fat diet; HCHF, high-carbohydrate high-fat; HFCS, high-fructose corn syrup; HMF, hydroxymethylfurfural; LPS, lipopolysaccharide; N/A, not applicable; NR, not reported or not extracted; PLS-DA, partial least squares discriminant analysis; PLSR, partial least squares regression; SBH, stingless bee honey; TPC, total phenolic content; TFC, total flavonoid content

Table 4. Detailed experimental parameters of the four included in vivo animal studies

Study	Country	Species	Sample	Comparator	Dose	Duration
Mohd Rafie et al. (2018)	Malaysia	*H. itama*	48 male Sprague Dawley rats, 6 groups	Normal diet; HFD without treatment; orlistat	500/750/1000 mg/kg/day	6-week induction + 6-week treatment
Ramli et al. (2019)	Malaysia	*H. itama*	18 male Wistar rats, n=6/group	Standard diet control; HCHF without treatment	1 g/kg/day	16 weeks (HCHF diet for the final 8 weeks)
Shaheran et	Malaysia	*H.*	42 Swiss Albino mice,	Normal; untreated	200 & 2000 mg/kg	28-day CRS

Study	Country	Species	Sample	Comparator	Dose	Duration
al. (2025)		*itama*	7 groups	stress; paroxetine	(day 1 or day 15)	induction
Shajahan et al. (2026)	Malaysia	*H. itama*	48 Sprague Dawley rats (therapeutic groups), n=8/group	Normal; untreated AD; donepezil	500/750/1000 mg/kg	7-day induction + 14-day treatment

Abbreviations: AD, Alzheimer's disease; CRS, chronic restraint stress; HCHF, high-carbohydrate high-fat; HFD, high-fat diet

What the Evidence Shows, and Where It Becomes Uncertain

Across the 25 studies synthesized in this review, the most consistent evidence supported three claims. First, the physicochemical profile of kelulut honey differs systematically from that of Apis mellifera honey, notably with higher moisture content (approximately 25–33%), reflecting production biology rather than a processing defect (Costa dos Santos et al., 2022; Nweze et al., 2017b; Phonmat et al., 2025; Tiang et al., 2025a). Second, it commonly shows higher phenolic content and antioxidant capacity than A. mellifera honey under comparable conditions, with a recent meta-analysis reporting mean differences of 33.69 mg GAE/100 g (TPC) and 63.39 μmol Fe(II)/100 g (FRAP) (Zaldivar-Ortega et al., 2024a), with similar patterns observed in Nigeria, Thailand, Malaysia, and India (Das et al., 2025b; Nweze et al., 2017; Phonmat et al., 2025; Tiang et al., 2025). Third, in vitro antimicrobial activity against Gram-positive, Gram-negative, and multidrug-resistant organisms has been reported in several studies, plausibly reflecting osmolarity, acidity, hydrogen peroxide, and flavonoid fractions, although the contribution of each mechanism remains inferential (Dallagnol et al., 2022; Das et al., 2025; Mwangi et al., 2024; Suarez et al., 2021). These findings provide laboratory-level evidence of bioactivity, but not high-certainty evidence of human health effects.

Beyond this core, the evidence is less consistent. Antioxidant potency and total phenolic content do not always track together; in one Malaysian comparison, H. itama showed the strongest antioxidant activity, while L. canifrons had the highest phenolic content (Tiang et al., 2025b), indicating that phenolic content is compositional rather than a direct proxy for antioxidant function. Evidence for antidiabetic, anti-obesity, neuroprotective, and wound-healing effects remains preclinical: in vitro α-glucosidase inhibition (Setiawan et al., 2024) and four rodent studies (Mohd Rafie et al., 2018; Ramli et al., 2019; Shaheran et al., 2025a; Shajahan et al., 2026)are supportive but cannot establish human efficacy, as none reported randomization, allocation concealment, or blinding, and one (Shaheran et al., 2025b) had unexplained attrition. Adulteration-detection methods, such as HPLC-ELSD, Vis-NIR aquaphotomics, and portable LED fluorescence spectroscopy, report high accuracy for different adulterants, honey types, and datasets, demonstrating analytical feasibility rather than cross-validated field performance (Mohamat et al., 2023; Raypah et al., 2022; Suhandy et al., 2023).

Much of this inconsistency is structural rather than evidence that kelulut honey bioactivity is unreliable. Many comparative studies vary in terms of bee species, floral sources, and origin simultaneously, confounding the attribution to any single factor (Gebreyes et al., 2025). Studies also differ in assay choice (DPPH, FRAP, ABTS) and typically report class-level measures rather than individually quantified compounds, limiting mechanistic interpretation, given that compounds within the same class can differ substantially in activity (Dallagnol et al., 2022; Suarez et al., 2021). Post-harvest storage further alters moisture, HMF, phenolics, and antioxidant activity independently of species (Braghini et al., 2020b; Setiawan et al., 2025); therefore, some apparent regional differences may partly reflect handling rather than biology. Therefore, future comparative studies should control or stratify species, origin, harvest timing, and storage using harmonized methods.

Barriers to Commercial Translation

Three barriers specifically block the translation of these foods into commercial functional foods, and they compound rather than operate independently.

Quality standard calibration. SNI 8664:2018 recognizes stingless bee honey as a distinct category, with a higher moisture ceiling (27.5%) than conventional honey (BSN, 2018). However, authentic Indonesian samples do not always fall within these thresholds: H. itama honey from Kampar, Samarinda, and Bangka Tengah each exceeded or fell short of at least one SNI parameter, particularly moisture (up to >30% in some samples) (Evahelda et al., 2021; Saputra &

Nurlina, 2022; Suhesti et al., 2024), alongside broader reports of quality variability among Indonesian producers (Afifah et al., 2026). This does not prove that the standard is wrong, but points to the need for a systematic evaluation of SNI thresholds across species, regions, and production systems, with Malaysia's MS 2683:2017 as a comparator rather than a template to adopt uncritically.

Authentication validation was performed. HPLC-ELSD offers high precision but requires laboratory infrastructure (Mohamat et al., 2023); Vis-NIR aquaphotomics is non-destructive but instrument-dependent (Raypah et al., 2022); portable LED fluorescence spectroscopy is field-portable but has lower resolution (Suhandy et al., 2023). None of these methods have been validated across multiple adulterants, species, and test sets; therefore, each remains promising rather than a nationally validated authentication system.

Dose and compound level characterization. Most bioactivity data are reported as total phenolic or flavonoid content rather than dose-characterized compounds, leaving no reproducible biologically meaningful dose defined for any indication. A rough feasibility estimate can nonetheless be drawn from the four animal studies reviewed (200–2000 mg/kg in mice, 500–1000 mg/kg in rats): converting the most effective doses to human-equivalent doses (Reagan-Shaw et al., 2008) gives approximately 8.5–11.4 g/day for a 70 kg adult — within or just below a single tablespoon (15–21 g) — suggesting effective animal doses fall within an achievable dietary range, though this assumes cross-species bioavailability equivalence that has not yet been established.

Toward Evidence-Based Product Development

Among the reviewed applications, fermentation-based formulations have generated the most consistent preliminary evidence, although they are still at an early, non-commercial stage. Kelulut honey improved lactic acid bacteria counts, antioxidant activity, and phenolic content in fermented goat milk (Melia et al., 2024), supported probiotic survival in a pigmented-rice synbiotic (SWE et al., 2023), and as a probiotic strain source, reduced weight gain, fat accumulation, and glucose intolerance in a high-fat-diet mouse cheese model (Mohd Hasali et al., 2024).

Beyond fermentation-based systems, a recent study on non-fermented milk-honey beverages found that Kelulut honey induced pH-driven casein destabilization in UHT and pasteurized milk, with raw honey causing greater sedimentation and particle aggregation than dehumidified honey; the combination of 6% dehumidified honey with pasteurized full-cream milk achieved the most favorable colloidal stability, maintaining acceptable dispersion for up to 72 hr at ambient temperature and 14 d under refrigeration (Yahdillah & Hussain, 2026). This finding illustrates that formulation feasibility depends not only on bioactive retention but also on honey-protein physicochemical compatibility, and that honey pretreatment (e.g., dehumidification) can be a practical lever for improving product stability without altering the food matrix itself.

However, translating this into food still requires resolving formulation-level gaps: milk proteins can bind dietary polyphenols and reduce measurable antioxidant activity even when total phenolic content is preserved (Tosif et al., 2021); thermal processing and storage measurably degrade phenolics (Braghini et al., 2020); mineral bioaccessibility varies widely, with phenolic bioaccessibility not yet assessed (Biluca et al., 2017); and no product-development study identified here reported formal sensory evaluation, despite kelulut honey's characteristic acidity potentially constraining acceptable incorporation levels. Other applications remain more exploratory for Indonesia, including nanoparticle-based edible coatings that require specialized infrastructure (Maringgal et al., 2021) and untested bakery uses.

Taken together, four priorities follow from these gaps: compound-level and, where appropriate, metabolomic characterization (e.g., LC-MS/MS) paired with defined-dose human studies on endpoints such as glycemic control and lipid metabolism; systematic evaluation of SNI 8664:2018 — revised only where evidence shows a parameter is biologically inappropriate — with attention to moisture criteria, species/regional labeling, and adulteration detection, informed but not dictated by Malaysia's MS 2683:2017; validation of authentication methods for portability, cost, and performance across Indonesia's diverse species and regions, not analytical accuracy alone, given its distributed smallholder production; and near-term priority for fermentation-based product development given its comparatively mature evidence base, with future studies directly comparing it against alternative formats on formulation stability, bioactive retention, sensory acceptance, cost, and regulatory feasibility.

Conclusion

Available evidence supports the potential development of stingless bee honey as a functional food, but the strength of the evidence differs by study level. In vitro studies have consistently demonstrated antioxidant, antimicrobial, and anti-inflammatory activities, while preclinical animal studies have provided supportive biological evidence. In contrast, human evidence remains limited and insufficient to establish clinical efficacy or effective doses. Commercial translation is further constrained by incomplete quality standardization, limited region- and species-specific authentication, and insufficient evidence regarding the stability and acceptability of bioactive compounds in food matrices.

Therefore, product development should prioritize standardized physicochemical and bioactive profiles, validated authentication methods, and clearly defined quality criteria. Future research should emphasize dose-response studies, well-designed human trials, and food formulation studies to confirm bioactive stability, safety, and sensory acceptability before broader commercial application.

Acknowledgments

The authors would like to thank Universitas Internasional Batam for providing institutional support and access to scientific resources during the preparation of this review.

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