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Stingless bee honey: Nutraceutical properties and urgent call for proposed global standards

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ABSTRACT

Background: The traditional uses of stingless bee honey, also known as pot-honey, have accumulated scientific evidence of their nutraceutical utilization as dietary supplement, functional food, and medicinal food to continue innovative developments for expanded applications. The anticataract, anti-inflammatory, antimicrobial, antioxidant, antiproliferative, and neuroprotective bioactivities are nutraceutical properties of stingless bee honey. Proposals of stingless bee honey quality standards have been subject of attention since 2004. The first state norm for Bahia, Brazil (2014) and the six national norms for Malaysia (2017), Tanzania, (2017), Indonesia (2018), Argentina (2019), Australia (2024), and Thailand (2024) evidence perfect timing to escalate the international Codex Alimentarius scenario.
Scope and approach: This review aims to value the nutraceutical properties of stingless bee honey as a powerful reason of developing proposed global standards by the Codex Alimentarius Commission in the frame of the United Nations-Sustainable Development Goals (UN-SDG): SDG1, SDG2, SDG3. Considering safe health benefits for consumers, the proposal of quality control for biodiverse bee origin of pot-honey, different from *Apis mellifera*, and the urgent call for global standards.
Key findings and conclusions: Nutraceutical properties of pot-honey, their active chemical components, and applications were emphasized. The ancestral use for health could impact with innovation while pursuing UN-SDGs. A preliminary dataset of 414 stingless bee honey was prepared to shape global standards. The design of the first Melipona honey norm from the Bahia state, Brazil (2014), and the six national norms from Malaysia (2017), Tanzania (2017), Indonsesia (2018), Argentina (2019), Australia (2024), and Thailand (2024) were contrasted for comparative fit with the CODEX STAN. This accurate evidence-based information is expanding to achieve the historical inclusion by the Codex Alimentarius, to benefit consumers and producers of stingless bee honey, as well as scholars.

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1. Introduction

Nutraceuticals refer to the pharmaceutical benefits derived from food nutrients, a name coined by Stephen De Felice in 1989, founder and chairman of the Foundation for Innovation in Medicine, which is an American organization located in Cranford, New Jersey, USA (Meštrović, 2022). Essentially, every type of food has micronutrients (enzymes, minerals, secondary metabolites, vitamins), macronutrients (carbohydrates, fat, proteins), and water. Any additional health benefit provided by a specific food, beyond its basic nutritional value, is categorized as a nutraceutical. This includes dietary supplements, functional food, medicinal food, and even pharmaceuticals. Honey is all of them. A natural product rich in metabolites of multifactorial origin, bioactive as an antioxidant, antimicrobial, anti-inflammatory, anti-tumoral, and moisturizer for wound-healing applications. In short, stingless bee honey is a nutritional food with therapeutic properties (Gadge et al., 2024).

Compared to honey produced by the common Western European honey bee, *Apis mellifera* Linnaeus 1758 (tribe Apini), stingless bees of the related tribe Meliponini process their honey with further fermentation. Indeed, the higher water content is needed for microbial transformations increasing free acidity to preserve this material of the nest. Instead of rigid honeycombs, a unique flexible cerumen pot structure characterizes the storage area in the nest, functional for the changes in volume that result from fermentation. This bioreactor was used to name the pot-honey, advantageous for scientific thinking, although stingless bee honey (SBH) is the valid traditional name for regulatory purposes (Vit et al., 2013).

Stingless bee honey eye drops delay ocular lens opacification (Vit and Camargo, 1988) and pioneered the presence of pot-honey in pharmacies. Reviews have followed the exploration of medicinal uses of pot-honey from Guatemala, Mexico, and Venezuela, and the first honey standards proposed for the genera *Melipona*, *Scaptotrigona* and *Trigona* by Vit et al. (2004). Recent attention has been directed towards the therapeutic potential of stingless bee honey, as highlighted by Pimentel et al. (2021). This includes the proposal and development of innovative nanofibrous membranes infused with stingless bee honey, curcumin and gelatin (Samraj et al., 2021), the examination of therapeutic properties of raw stingless bee honey and optimized hydrogels for wound dressing (Esa et al., 2022), exploration of nutraceutical and medicinal applications for human health (Martínez-Puc et al., 2022), and its consideration as a superfood with potential in cancer therapies (Huq et al., 2021; Rozman et al., 2022). In Kenya, stingless bee honeys were generally free of side effects, having top-most medicinal uses for respiratory and stomach disorders, oral candidiasis, healing wounds, measles, and poisoning, including further applications for cancer, allergies, and pain (Kiprono et al., 2022a, 2022b).

Driven by the escalating demand for raw stingless bee honey and its derived preparations, rural communities are increasingly embracing stingless bee farming as an alternative source of income (Mustafa et al., 2018; Grüter, 2020, p. 385, Project ChanulPOM: Abejas para la Vida, 2021; Main, 2022; Cevallos Erazo et al., 2023; Loayza and Solórzano, 2023; Duangphakdee et al., 2024), with further scopes of empowering the *Women for Bees* project (Lakshmanan, 2021). Therefore, innovation is needed to modify the processes of production, marketing, organization, societal understanding and perception, technology, and pot-honey presentation. The promotion of stingless bee honey envisages a sustainable growth of meliponiculture, which in turn requires a sensible suite of conservation strategies for stingless bees (Domínguez et al., 2023).

The European Food Safety Authority, n.d. dictates that food supplements are regulated as food in Europe. A chronological comparison between the U.S. Food and Drug Administration FDA and the European Union EFSA demonstrates that perception from consumers and the manufacturing industry is constantly evolving (Giunta et al., 2010). The European nutraceutical market is expected to grow from USD 79.95 billion in 2023 to USD 101.60 billion by 2028 (Mordor Intelligence, 2023). Their report offered market size and values for the following segments of the nutraceutical market in Europe based on three factors: 1. Product type (functional food, functional beverage, and dietary supplements); 2. Distribution channel (convenience stores, supermarkets/hypermarkets, specialty stores, online retail stores, and other distribution channels); and 3. Country (United Kingdom, Germany, France, Spain, Italy, Russia, and the rest of Europe), during the forecasted years.

The momentum of pharmacological development of stingless bee honey is now growing, with six national norms from Malaysia (Department of Standards Malaysia, 2017), Tanzania (Tanzania Bureau of Standards, 2017, pp. 1–18), Indonesia (Indonesian National Standard, 2018, pp. 1–27), Argentina (Secretaría de Regulación y Gestión Sanitaria y Secretaría de Alimentos y Bioeconomía, 2019), Australia (Australia New Zealand Food Standards, 2024), and Thailand (Thai Agricultural Standard, 2024). A sustained transition from the ancestral knowledge to the nutraceutical market, with the creation of international stingless bee honey Codex Stan norms and sections of Meliponini pharmacopea. The unique *Apis mellifera* honey of the CODEX STAN CXS 12–1981 (2022) norm has been necessarily expanded since Vit et al. (2004) to encompass Indomalayan and Australian species by Zawawi et al. (2022), and ongoing metadata analysis.

Nest elements can be clearly discerned from an Angelita *Tetragonisca angustula* (Latreille, 1811) stingless bee nest from Merida, Venezuela and Channarong *Tetragonula laeviceps* (Smith, 1857) from Chiang Mai, Thailand, in Fig. 1. The microbial cell factory where materials collected

Fig. 1. Open nests of stingless bees from Venezuela and Thailand kept in wooden boxes. 1. Angelita *Tetragonisca angustula*, Food Science Department at Universidad de Los Andes from Merida, Venezuela. Honey pots, pollen pots, propolis, brood combs, and its involucrum are visualized. Photo: ©P Vit. 2. Channarong *Tetragonula laeviceps* from Chiang Mai, Thailand, showing honey pots, pollen pots, and brood combs. Photo: ©B Chuttong.

from nature by foraging bees, are transformed into materials of the stingless bee nest (SBN) (Vit, 2024), including honey pots and pollen pots in the storage area, some pillars, and the brood combs with involucrum layers for *T. angustula*. However, *T. laeviceps* features brood combs arranged in stack layers that lack the involucrum cover.

The aim of our review is to support crucial actions for stingless bee honey (SBH) with scientific literature up to the present date, pinpointing needed resources of pharmaceutical laboratories for innovation to consider honey produced by over 600 stingless bee (SB) species (Vit et al., 2024), and the great potential for the development of new nutraceutical products. There are seemingly endless new opportunities for discoveries and delivery of pharmaceutical honey (P. Vit interviewed for National Geographic by D. Main, 2022). One step at a time; thus, first nutraceutical properties of stingless bee honey, with few stingless bee species selected by meliponiculturists, and by authors' social interest and scientific domain. They support the urgent call for proposed SBH global standards based on scientific literature and expertise.

2. Medicinal uses of stingless bee honey from selected tropical countries

About 605 species of stingless bees produce pot-honey in the

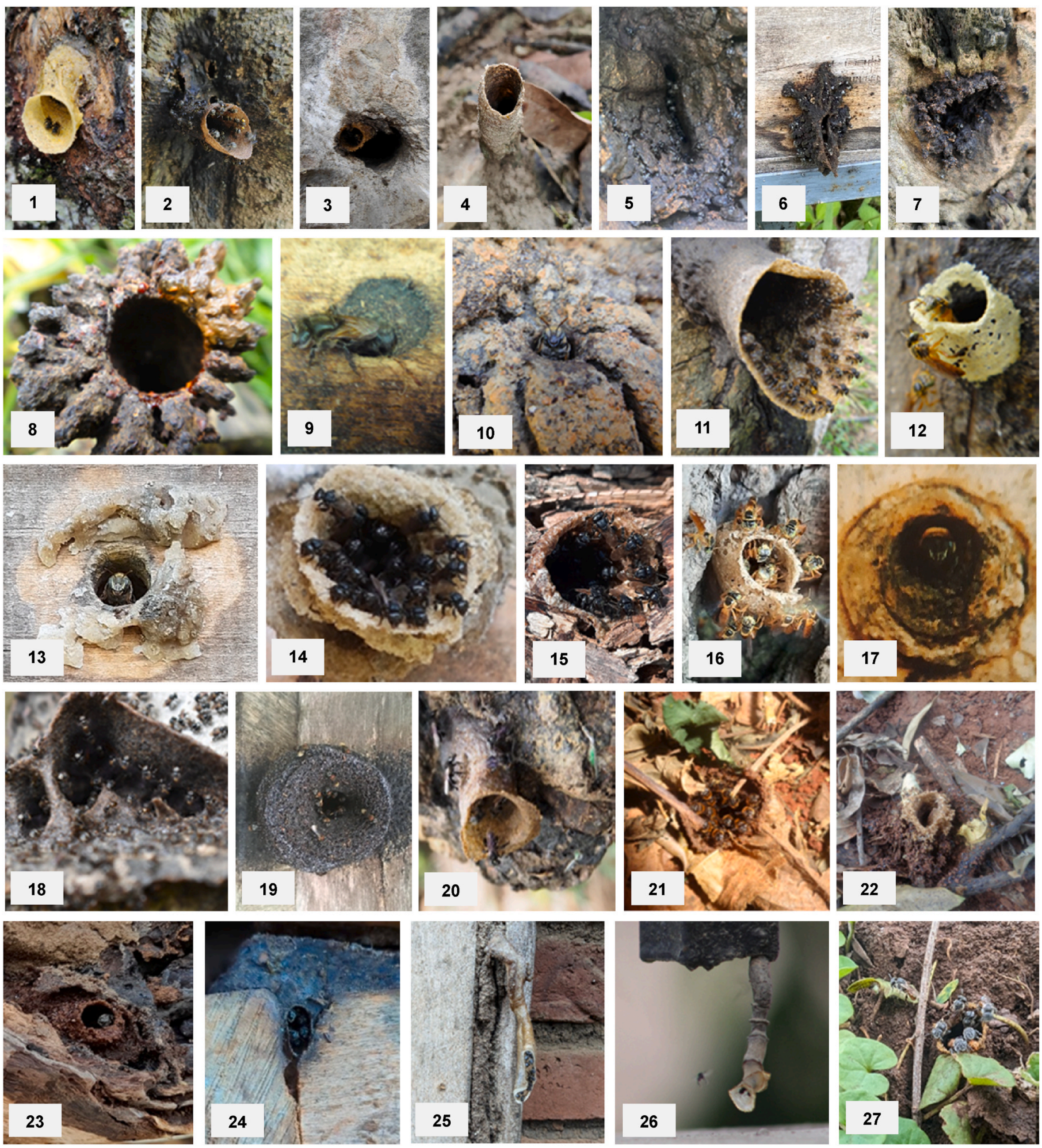


Fig. 2. Entrances to the nests of stingless bee species. Tropical China: 1. *Lepidotrigona flavibasis*, 2. *Lepidotrigona terminata*, 3. *Ebaiotrigona carpenteri*, 4. *Tetragonilla collina*, 5. *Tetragonula gressitti*, 6. *Tetragonula laeviceps*, 7. *Tetragonula pagdeni*. Photos: ©Z Wang. Ecuador: 8. *Melipona grandis*, 9. *Melipona indecisa*, 10. *Melipona mimetica*, 11. *Scaptotrigona vitorum*, and 12. *Tetragonisca angustula*. Photos: ©P Vit. Mexico: 13. *Melipona beecheii*, and 14. *Scaptotrigona mexicana*. Photos: ©E Ramírez-Arriaga. Argentina: 15. *Scaptotrigona jujuyensis*, and 16. *Tetragonisca fiebrigi*. Photos: ©F Vossler. Venezuela: 17. *Melipona favosa* Photo: ©P Vit. Philippines: 18. *Tetragonula biroi*. Photo: ©C Cervancia. Thailand: 19. *Geniotrigona thoracica*, and 20. *Heterotrigona itama*. Photos: ©B Chuttong. Kenya: 21. *Meliplebeia beccarii*, and 22. *Plebeina armata*. Photos: ©S Kimoloi. Tanzania: 23. *Axestotrigona ferruginea*, 24. *Axestotrigina togoensis*, 25. *Hypotrigona gribodoi*, 26. *Hypotrigona ruspolii*, and 27 *Plebeina armata*. Photos: ©CA Mduda.

worldwide tropics, 474 Neotropical species, 98 Indomalayan, Papuasian, and Australian species, and 33 Afrotropical species (Engel et al., 2023). These species have distinctive biology and entrances to the nest, as illustrated for 27 stingless bee species: Seven from China, five from Ecuador, two from Mexico, two from Argentina, one from Venezuela, one from the Philippines, two from Thailand, two from Kenya, and five from Tanzania in Fig. 2.

This conspicuous biodiversity of stingless bees unfolds a range of pot-honeys, pot-pollen, cerumen, propolis, and other natural compounds, processed in the stingless bee nests (SBN) from available resources foraged from the environment, such as floral nectar, extrafloral nectar, honeydew, fruit juices, epicarp, plant sap, floral pollen, plant resins, latex, gums, seeds, leaves, bark, wood pulp, floral and leaf oils, fungi, ash, sweat, tears, mud, feces, urine, little stones, sand, and water (Grüter, 2020, p. 385; P. Vit, Personal observations). Pot-honey and pot-pollen are fermented in cerumen pots of the storage area in the nest. Most non floral resources are used for nest construction and defense.

In this section, the medicinal uses of honey produced by a few species of stingless bees were considered for each selected country. The ITIS, n.d. on-line database was used to validate stingless bee species names, authors, and years. Recently described new species are not yet integrated into the ITIS database.

2.1. Argentina

Pot-honey alone, or mixed with pot-pollen is used as a nutraceutical nourishment, diluted with water or mate (infusion of Yerba mate *Ilex paraguariensis*), and to elaborate alcoholic beverages mostly used to treat respiratory diseases (Arenas, 2003, p. 562; Roig-Alsina et al., 2013).

Scaptotrigona jujuyensis (Schrottky, 1911), called Negrita, Peluquera, Yana. Applied to treat respiratory diseases.

Tetragonisca fiebrigi (Schwarz, 1938), called Yateí. Used for skin, respiratory and urinary infections, ocular diseases, and healing wounds.

2.2. Australia

Tetragonula carbonaria Smith, 1854, called Carby or Sugarbag. A medicinal agent used as a gastrointestinal cleanser (Massaro et al., 2015).

2.3. Brazil

Melipona scutellaris Latreille, 1811, called Uruçú. Healing of rat wounds infected with Gram positive *Staphylococcus* were treated with this honey, and have clinical potential (Medeiros et al., 2016).

Tetragonisca angustula (Latreille, 1811), called Jataí. Honey eye drops are used to treat ocular cataracts (Vit, 2001).

2.4. China

These following seven species of Chinese stingless bees are kept in the Xishuangbanna Tropical Botanical Garden meliponary. Their pot-honey is mixed with medicinal herbs of Chinese Traditional Medicine (CTM) to treat and cure cough. *Lepidotrigona flavibasis* (Cockerell, 1929), *Lepidotrigona terminata* (Smith, 1878), *Ebaiotrigona carpenteri* (Engel, 2000), *Tetragonilla collina* (Smith, 1857), *Tetragonula gressitti* (Sakagami, 1978), *Tetragonula laeviceps* (Smith, 1857), *Tetragonula pagdeni* (Schwarz, 1939).

2.5. Colombia

Tetragonisca angustula (Latreille, 1811), called Angelita. Used as eyedrops alone or combined with fruit juice of *Physalis peruviana*.

2.6. Costa Rica

Tetragonisca angustula (Latreille, 1811), called Mariola. Used as eyedrops and wound dressing.

2.7. Ecuador

Melipona grandis Guérin, 1834, called Bunga negra. Potential ovarian cancer healer (Huq et al., 2021).

Melipona indecisa Cockerell, 1914, called Cananambo. Applied for relief of sore throat (Vit et al., 2015).

Melipona mimetica Cockerell, 1914, called Bermejo. Used to treat blood, kidneys, eyes, inflammation, and sore throats (Vit et al., 2015).

Paratrigona aff. *eutaeniata* Camargo and Moure, 1994, called Pirunga. Used for eye treatments (Vit et al., 2015).

Scaptotrigona vitorum Engel 2022, called Catiana. This honey is used as a sweetener of infusions known as aromatic waters in Ecuador, healing bruises and wounds to prevent scars, a small goblet of Catiana honey on an empty stomach purifies the blood, and mixed with beetroot water promotes sleeping (Abelardo Roman Castillo†, Personal communication). Multiple medicinal uses as a balm, to clear out blood, kidneys, eyes, inflammation, sore throat, tumors, and wounds (Vit et al., 2015).

Tetragonisca angustula (Latreille, 1811), called Abeja ángel. Used as eyedrops for ocular diseases.

2.8. Guatemala

Geotrigona acapulconis (Strand, 1917), called Talnete. Used for eye treatments, bone traumatism, as an anticancer agent, and for the treatment of stomach tumors.

2.9. Kenya

Honey of two ground stingless bees *Meliplebeia beccarii* (Gribodo, 1879) and *Plebeina armata* (Magretti, 1895) are used by the communities in Baringo County to treat respiratory and stomach disorders, oral thrush, wounds, measles, poisoning, cancer, allergies, and pain (Kiprono et al., 2022a, 2022b).

2.10. Malaysia

Geniotrigona thoracica (Smith, 1857), called Kelulut. The honey has antifungal activity against *Alternaria brassicae* from Borneo, Sarawak, Malaysia (Tuksitha et al., 2018).

Heterotrigona itama (Cockerell, 1918), called Kelulut. Honey supplemented (1 g/kg/day) to Wistar rats fed with high-carbohydrate and high-fat diet for eight weeks significantly prevented indicators of metabolic syndrome (fat mass, serum triglyceride, systolic blood pressure, diastolic blood pressures, adipocyte area, and adipocyte perimeter) at week 16. Thus, deserving further research on molecular mechanisms in alleviating the disease (Ramli et al., 2019).

2.11. Mexico

Scaptotrigona mexicana (Guérin-Méneville, 1844), called Pisilnekmej. A post-harvest fermentation prior to bottling is believed to enhance the healing power of this honey to treat respiratory diseases (Vit et al., 2004).

Melipona beecheii Bennett, 1831, called Xunan-cab. Digestive disorders and eye diseases are treated with this honey (Vit et al., 2004).

Commercial eye-drops of *S. mexicana* and *M. beecheii* are used to treat ocular cataracts (Vit, 2001).

2.12. Philippines

Tetragonula biroi (Friese, 1898), called Kiwot. A potential nutraceutical with antibiotic and antioxidant activities (Suarez et al., 2021). Minimized hippocampal and cerebrocortical damage after ischemic stroke in rats and ameliorated neurologic deficits (Desamero et al., 2016).

2.13. Tanzania

Axestotrigona ferruginea (Lepeletier, 1836), called Upula or Impula, the honey is used for cough, asthma, wounds, ulcers, reproductive issues, intestinal worms, skin antifungal, detoxification.

Axestotrigona togoensis (Stadelmann, 1895), called Nyori, the honey is used for the treatment of cough, asthma, wounds, ulcers, reproductive issues, speed up healing of broken bones, relieve bone and waist pain.

Hypotrigona gribodoi (Magretti, 1884), called Ntwazi, and *Hypotrigona ruspolii* (Magretti, 1898), called Mpunze, produce a honey used to treat kidney stones, reproductive problems, respiratory infections, urinary tract disorder, stomach ulcers, and digestive disorders.

Plebeina armata (Magretti, 1895), called Ubhuhuraa honey heals cough and stomach disorder, preventive medicine, menstrual painkiller, and blood purifier (Héger et al., 2023).

2.14. Thailand

Tetragonula laeviceps (Smith, 1857), called Channarong, is the most widespread species used for its soothing effect for sore throats.

2.15. Venezuela

Melipona favosa (Fabricius, 1798), called Erica. It is used to treat sore throats, alone or mixed with a lemonade. Applications of honey eyedrops are reputed to cure ocular cataracts and other eye diseases (Vit, 2001).

Tetragonisca angustula (Latreille, 1811), called Angelita. Honey eyedrops are believed to be therapeutic for ocular cataracts (Vit, 2001).

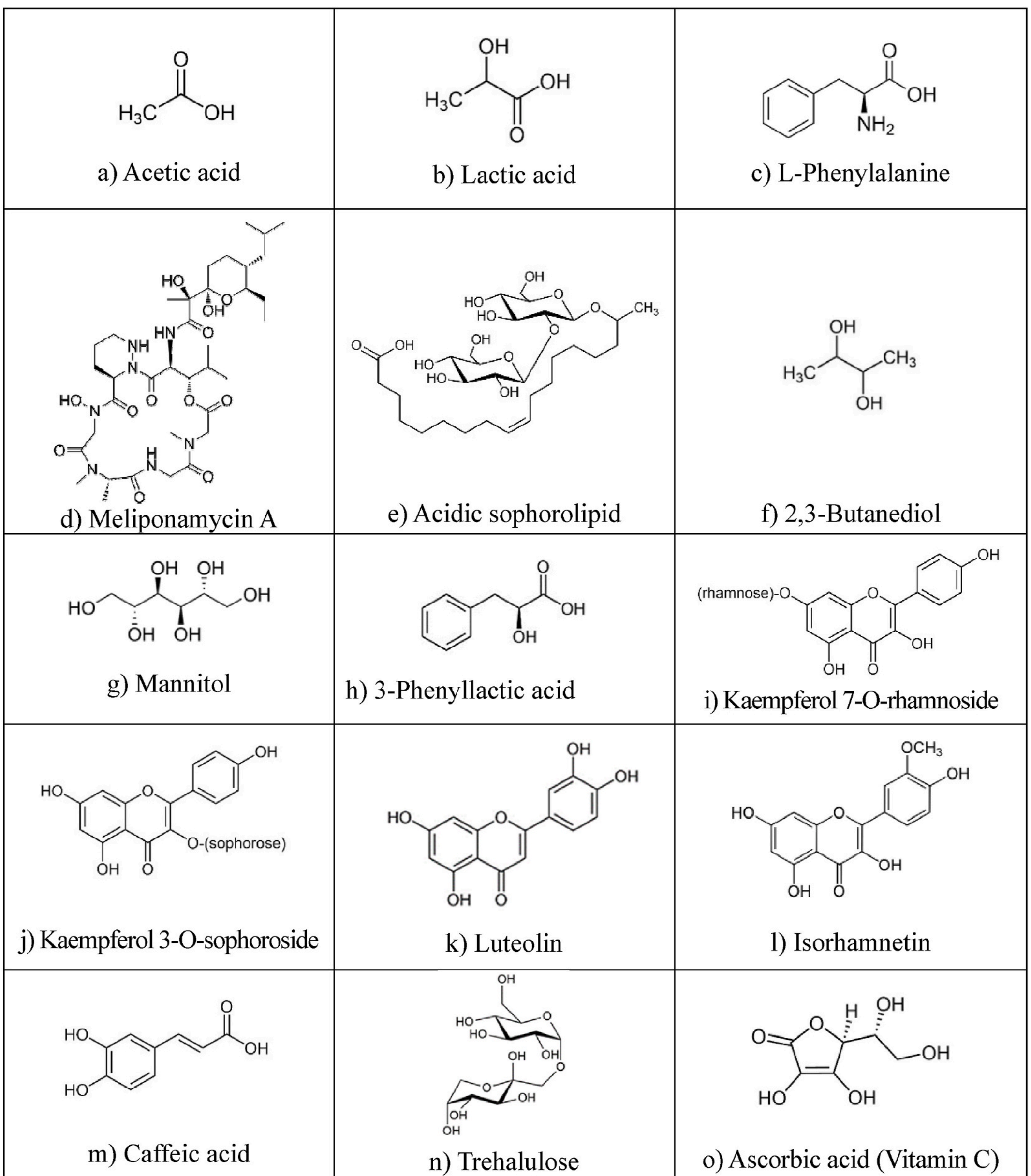


Fig. 3. Chemical structures of selected nutraceutical metabolites present or suspected in stingless bee honey.

3. Nutraceutical metabolites of stingless bee honey

Nutraceutical metabolites present in materials within the stingless bee nest, including honey, originate from multiple sources. These sources encompass the bees themselves, the plants they visit while collecting nectar and honeydew, as well as the microbial communities associated with stingless bees that aid in the honey fermentation process within cerumen pots. Additionally, residual pollen, often used as a fingerprint or indicator of the botanical origin of honey, and interactions with other nest materials can introduce further metabolites into stingless bee honey. The chemical structures of selected metabolites detected and quantitated in stingless bee honey are presented in Fig. 3, in the order of their text.

3.1. Aliphatic organic acids (AOA)

Acetic acid (Fig. 3a) and lactic acid (Fig. 3b) are produced by acetic acid bacteria AAB and lactic acid bacteria LAB fermentations. They are metabolites of microbial origin. These AOA were distinctive in Ecuadorian pot-honeys, with the highest contents of acetic acid 19.60 $\pm$ 1.45 g/kg and lactic acid 24.30 $\pm$ 1.65 g/kg *Geotrigona* honey. Twenty-four AOA of stingless bee honey were reviewed and the highest content was 5.8% in the honey of *Axestotrigona ferruginea* from Tanzania (Vit and Simova, 2023).

3.2. Amino acids

L-Phenylalanine (Fig. 3c) is a precursor of tyrosine, the primary constituent of tyrosine receptor kinase B (TrkB). TrkB serves as a receptor for the brain-derived neurotrophic factor (BDNF) which is essential for the survival, growth and maturation of nerve cells. A behavioral study in mice supplementing *Heterotrigona itama* honey from Malaysia showed that L-phenylalanine is essential in the brain, acting directly on the BDNF to enhance synaptic function which improves brain function including memory (Mustafa et al., 2019).

3.3. Antibacterial cyclodepsipeptide

Meliponamycin A (Fig. 3d) two novel cyclic hexadepsipeptides, meliponamycin A and meliponamycin B, were isolated from the largest genus of Actinomycetota, *Streptomyces* sp. ICBG1318, a symbiont associated with *Melipona scutellaris* nurse bees in Brazil; both showed strong antimicrobial activity against the honey bee pathogen *Paenibacillus larvae*, as well as against two human pathogens *Staphylococcus aureus* and *Leishmania infantum* (Menegatti et al., 2020).

3.4. Biosurfactants

Sophorolipids SL (Fig. 3e) are biosurfactants with a soforose sugar and a fatty acid chain. Their presence is suspected of honey with positive response to the Honey Biosurfactant Test, such as *Scaptotrigona depilis*, *Scaptotrigona vitorum*, and *Tetragonula carbonaria*, as well as the suggested association of these stingless bees with a *Starmerella* yeast producing them (Vit, 2022a).

3.5. Dihydroxy and polyhydroxy alcohols (diols and polyols)

The dihydroxy alcohol 2,3-butanediol (Fig. 3f) is a botanical marker of Spanish rosemary and thymus honey (Pérez et al., 2002), and Austrian dandelion, robinia, rape, fir tree, chestnut, linden, orange, and lavender (Siegmund et al., 2018). It is also a major soil-borne bacterial VOC, synthesized by *Enterobacter aerogenes* via pyruvate and its precursor acetoin (D'Alessandro et al., 2014). The polyol mannitol (Fig. 3g) is known for its low glycemic and anti-cariogenic benefits. This nutritional sweetener with reduced digestibility, has lower sweetening power than sucrose, but compared to synthetic sweeteners, it has a sucrose-like perception without off-flavors (Tan et al., 2019), reinforcing its versatile role in food and health (Caffé et al., 2024). The antioxidant activity of Malaysian *Heterotrigona itama* honey fed with Acacia *Acacia mangium*, Gelam *Melaleuca cajuputi*, and Starfruit *Averrhoa carambola*, was positively correlated with the mannitol contents quantitated by gas chromatography-mass spectrometry (GC-MS) (Shamsudin et al., 2022).

3.6. Hydroxiacid

The 3-phenyllactic acid (Fig. 3h) is a metabolite of microbial origin also measured as a botanical marker by targeted ^{1}H NMR (Vit et al., 2023b). The yield 3-phenyllactic acid was higher than lactic acid in fermented Chinese vegetable using *Lactobacillus crustorum* (Xu et al., 2021). The amino acid phenylalanine was used as a precursor of 3-phenyllactic acid biosynthesis, which accumulated to extend shelf-life of pickles. The function of 3-phenyllactic acid in honey could be of preservation as well.

3.7. Flavonoids

Flavonoids are secondary plant metabolites. The flavonoid content is measured with a routine spectrophotometric modified method with aluminum chloride using quercetin Q standard as mg QE/100 g honey (Woisky and Salatino, 1998). Advanced High-Performance Liquid Chromatography/Photodiode-Array Detection/Electrospray Ionization Ion Trap Mass Spectrometry (HPLC/DAD/ESI-MS) are needed for flavonoid separations, identifications and quantitation. Total flavonoids varied from 2.6 to 31.0 mg quercetin equivalents/100g honey of ten Peruvian stingless bee species (Rodríguez-Malaver et al., 2009). Some flavonoids are distinctive according to the entomological origin of stingless bee honey, either by their food choices or for the geographical availabilities of plant resources. For example, kaempferol 7-O-rhamnoside (Fig. 3i) (Truchado et al., 2011), and (Fig. 3j) kaempferol 3-O-sophoroside was present in *Tetragonula carbonaria* honey from Australia (Truchado et al., 2015). Luteolin (Fig. 3k) and the monomethoxy flavonol isorhamnetin (Fig. 3l) were frequent in Venezuelan pot-honey (Vit and Tomás-Barberán, 1998). Total flavonoid contents varied between 28.4 and 73.7 mg QE/100 g honey produced by *Axestotrigona*, *Hypotrigona*, and *Plebeina* species from Tanzania (Mduda, 2023).

3.8. Polyphenols

The polyphenols comprise flavonoids and phenolic acids such as caffeic acid (Fig. 3m). They are generally measured using a spectrophotometric method with the Follin-Ciocalteu reagent and gallic acid GA standard as mg GAE/100 g honey (Singleton et al., 1999) in the research on honey bioactivity, and are also useful for postharvest honey transformations (Vit et al., 2022), more related to the antioxidant activity of tropical honey. Total polyphenols varied from 99.7 to 464.9 mg gallic acid equivalents/100g honey of ten Peruvian stingless bee species (Rodríguez-Malaver et al., 2009). Total polyphenols averaged between 55.6 and 132 mg GAE/100 g honey produced by *Axestotrigona*, *Hypotrigona*, and *Plebeina* species from Tanzania (Mduda, 2023).

3.9. Sugars

The content of fructose and glucose is reduced while the AOA increase during sugar fermentation, causing a unique sugar spectra of stingless bee honey (Vit et al., 2023b). The monosaccharide content in *Axestotrigona ferruginea* honey from Tanzania was lower than 40%, the fructose/glucose ratio was exceptionally above 2, and it was rich in di- and trisaccharides (Popova et al., 2021). Trehalulose (Fig. 3n), an isomer of sucrose, is a honey sugar recently discovered by Fletcher et al. (2020) in pot-honey harvested from stingless bees from Australia (*Tetragonula*), Brazil (*Tetragonisca*), and Malaysia (*Geniotrigona* and *Heterotrigona*), and it was suggested as a standard in the international regulation for honey of some stingless bee honey types (Popova et al., 2021; Vit et al., 2023a; Zawawi et al., 2022). This sugar has a low glycemic index (GI), low insulinemic index and is acariogenic (Fletcher et al., 2020). These properties are due to the different hydrolysis rate of trehalulose compared to sucrose.

3.10. Vitamins

Ascorbic acid (Vitamin C) (Fig. 3o) is the most studied vitamin in stingless bee honey. Honey of *Heterotrigona itama* from Thailand has a 69.13 ± 63.27 mg Vitamin C equivalent/100 g (Meechai et al., 2020). Contents of 6.49–13.58 mg/100 g *Tetragonula laeviceps* honey varied in relation to geographicl origin across Indonesia (Agussalim et al., 2022). The content of ascorbic acid varied between 14 and 40.3 mg/100 g honey produced by *Axestotrigona*, *Hypotrigona*, and *Plebeina* species from Tanzania (Mduda et al., 2023a).

4. Studies on bioactivity for potential therapeutic uses of stingless bee honey

4.1. Anticataract

Direct applications of stingless bee honey eyedrops alone are putative anticataract agents (Vit, 2001). More recently, combinations with fruit juices such as *Physalis peruviana*, and root extracts of *Carota dauca* are available online. The consumption of stingless bee honey is even believed to protect from pterygium and ocular cataracts (Vit P, unpublished data). Luteolin and derivatives were the most active of 20 commercial flavonoids studied in *ex vivo* ovine lens models of opacification caused by 45% hypotonic, hyperglycemic and hypercalcemic stress (Vit, 1997). Luteolin (Fig. 3k) and derivatives such as isorhamnetin (Fig. 3l). Possibly there is not one anticataract active component but a set of them of diverse entomological origins. We could also predict diverse mechanisms of action according to the etiology of the ocular cataract. Stingless bee honey remains a bioresource used to treat ocular cataracts in traditional medicine (Vit and Jacob, 2008).

4.2. Anti-inflammatory

Honey of *Tetragonula laeviceps* from Indonesia immunomodulated lymphocyte proliferation and decreased two proinflammatory markers, interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α) in lymphocyte culture supernatant of normal and malnourished rats (Agussalim et al., 2022).

4.3. Antimicrobial activity

A comprehensive range of antimicrobial properties attributed to stingless bee honey is extensively documented in scientific literature. Various pot-honey types produced by diverse stingless bee species exhibit promising potential in combating bacterial and fungal infections in vitro, making them potential candidates for therapeutic use. Notably, the antibacterial effectiveness of *Tetragonisca angustula* honey from Colombia has been found to surpass that of *Apis mellifera* honey. This distinction is highlighted by the minimum inhibitory concentration (MIC) assays conducted against a spectrum of 3 Gram-negative and 3 Gram-positive bacteria (Gamboa Abril and Figueroa Ramírez, 2009). In vitro studies have demonstrated that honey from Tanzanian *Axestotrigona*, *Hypotrigona*, and *Plebeina* species exhibited significant antimicrobial potency against gram-positive and gram-negative bacteria, as well as fungi, with MICs between 0.2% and 20% (Mduda et al., 2023b).

4.4. Antioxidant activity

Dietary antioxidants are functional food with therapeutic action in human diseases originated by oxidative stress causing cellular damage via free radicals (Lobo et al., 2010). Diverse chemical components of pot-honey are antioxidants. Their overall antioxidant activity is measured by multiple methods based on distinct mechanisms of action, such as AOA hydrogen peroxide H_2O_2 scavenging assay measured using uric acid UA standard, mM EUA/100 g honey (Koracevic et al., 2001), HR hydroxyl radical scavenging activity measured as the inhibition % HR formation/100 g honey (Halliwell et al., 1987), ABTS radical cation decolorization essay using Trolox standards measured as μmoles of TE/100 g honey (Re et al., 1999), and DPPH scavenging capacity of hydrogen providers or free-radical scavengers (FRS), measured as antioxidants IC_{50} inhibition of DPPH % (Blois, 1958; Kedare and Singh, 2011). The antioxidant activity varied from 93.8 to 569.6 μmoles Trolox equivalents/100 g honey of ten Peruvian species of stingless bees (Rodríguez-Malaver, 2009). The antioxidant activity of a *Tetragonisca angustula* nest materials from Venezuela was higher in the cerumen of honey pots than in the entrance tube, involucrum of the brood, and propolis (Pérez-Pérez et al., 2013). Honey produced by Tanzanian *Axestotrigona*, *Hypotrigona*, and *Plebeina* species exhibited significant antioxidant activity assessed by DPPH radical scavenging activity between 32.8 and 77.5%, and ferric reducing antioxidant power (FRAP) ranging from 69.3 to 160.6 μmol Fe(II)/100 g (Mduda, 2023).

4.5. Antiproliferative activity

Pot-honey produced by 16 species of stingless bees from Australia, Brazil, Mexico, and Venezuela were tested against cultured parent A2780 and cisplatin resistant $A2780^{cisR}$ human ovarian cancer cell lines using the MTT [3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide] reduction essay to assess cytotoxicity. The lowest resistance factor $RF = IC_{50}\ A2780^{cisR}/IC_{50}\ A2780$ was 0.26 observed for a *Melipona favosa* honey from Venezuela (Vit et al., 2013). The stingless bee *Melipona grandis* in Ecuador produces a potential anticancer honey with a resistant factor of 0.32, compared to 1.01 for *Scaptotrigona vitorum* and 1.18 for *Geotrigona leucogastra*, using the human ovarian cancer cell model (Vit, 2023a).

4.6. Neuroprotective activity

Dietary supplementation with *Heterotrigona itama* honey from Malaysia improved Swiss albino mice's spatial working memory in seven days and reference memory in 35 days, possibly via the memory-enhancing effects of the dietary amino acid phenylalanine acting directly on brain-derived neurotrophic factor (BDNF), consequently, upgrading brain signaling and physiology (Mustafa et al., 2019). Behavior analysis was conducted with the Morris water maze (MWM), gene expression of mice striatum by RT-PCR, and metabolomics analysis of honey by protonic NMR. Gene expression analyses after 7 days at 2000 mg *H. itama* honey/kg –equivalent to a human dose of 162 mg/kg– demonstrated significant upregulation of BDNF and Itpr1 genes involved in synaptic function, and the honey phenylalanine as essential precursor for tyrosine function at the BDNF receptor (Mustafa et al., 2019). *H. itama* honey flavones can mimic the BDNF downstream pathways acting in neurogenesis and synaptic plasticity. New delivery methods based on nanoparticles may promote brain uptake of honey biomolecules assessed with this model (Zulkifli et al., 2023).

5. Botanical origin of bioactive nutraceuticals in stingless bee honey

Morphologies of residual pollen grains found in honey are fingerprints of the botanical origin of stingless bee honey (Barth et al., 2021; Ramírez-Arriaga and Martínez-Hernández, 2007). Their presence and frequency are also distinctive according to the geographical distribution of plant taxa, entomological origin (Barth et al., 2013), hypo representation (Barth et al., 2015, p. 15), and unifloral honeys with more than 45% pollen counts, for example a *Coffea arabica* honey of *Tetragonisca* *angustula* (Moreno et al., 2023). Caffeine is an alkaloid more concentrated in the unifloral honey than in the floral nectar; it has diverse biological activities such as stimulant, energy boosters, anti-inflammatory, antioxidant, and healing. Additionally, botanical markers have been proposed to support the melissopalynological identification because a suite of bioactive nutraceuticals are phytochemicals derived from plant metabolites. The targeted ^{1}H NMR selected 10 botanical markers in the reference tube for food used in honey analysis (Vit et al., 2023b).

For example, looking at flavonoids in *Apis mellifera*, sunflower honeys are rich in quercetin, alder honey only 8-methoxy kaempferol (Soler et al., 1995), *Eucalyptus* honey had constant relative amounts of myricetin, tricetin, and luteolin (Martos et al., 2020). Myricetin can be considered a marker of *Eucalyptus* honey, but kaempferol is a flavonoid frequent in most honeys. Luteolin is also considered a nutraceutical flavonoid of citrusy origin.

6. From pot-honey in the nest to nutraceuticals for consumers

Good manufacturing practices (GMP) in meliponiculture and the harvesting of stingless bee products from the nest guarantee the good quality of pot-honey used as raw nat for the innovative development of potential nutraceuticals in the pharmaceutical industry. Innovation is a positioning strategy in companies to value traditional uses and to showcase products from the region such as protected EU geographical indications (European Commission, n.d.). The offer of nutraceuticals based on stingless bee honey will demand a campaign of promotion for their marketing. The scientific backup of bioactive metabolites and medicinal properties need to reach out from the laboratories and scientific sources of information to benefit the consumer's health. Significant protections are needed for genuine stingless bee honey against fake honeys and their adulterations, using adequate quality control (Yong et al., 2022; Vit, 2022).

6.1. Producing safe stingless bee honey

Pot-honey safety needs to be addressed like pot-pollen safety (Belina-Aldemita et al., 2020), to supplement scientific literature on bioactivity, chemical or nutritional composition and botanical origin.

6.2. Equitable livelihoods for the stingless bee industry

Pot-honey has not been assessed by experts in food systems, to evaluate the complex networks of supply and demand value chains, involved in human health, environmental sustainability, and economic development. Despite the obvious harm caused by climate change, vandalism, and parasitic bees, little is known about their influence on stingless bee populations and how they affect smallholder farmers. These multiple threats endanger both stingless bee survival and the livelihoods of communities dependent on them. Ensuring equal and fair opportunities for stingless bee keepers needs identifying the drivers of inequality. Primary data allows direct measurements, surveys, interviews, or on-site evaluations, and secondary data is retrieved from previous reports, databases, or industry sources. Required strategies and interventions should be carefully planned, informed, and optimized for potential risks and benefits (Michel et al., 2024).

6.3. Gaining understanding on sustainability according to the UN-SDGs

Stingless bee pollination is an essential ecological service connected to food and health security, estimated to support the tropical ecosystem health with 50% of all bees visiting tropical flowering plants (Grüter, 2020, p. 385). Gaining understanding of sustainable roles of stingless bees visualizes which of the United Nation's Sustainable Development Goals (SDGs) (UN, 2015, p. 35) can be achieved. In this review, we spotlight on SDG3 Good Health and Wellbeing. Further analysis by Patel et al. (2021) suggested that the essential roles of bees potentially contribute towards 15 of the 17 SDGs, supported by relevant literature of bees' impact on sustainable development. Indicators measuring progress towards SDGs are available for effective monitoring of initiatives (Movilla-Pateiro et al., 2021) needed to ensure sustainability of the potential stingless bee industry producing medicinal food based on cultural values of native people in the tropics, scientific evidence by worldwide collaborative institutions, and pollinating important crops.

7. Urgent call for stingless bee honey global standards

Stingless bee honey standards are essential for quality control and protection of consumers who can access this genuine nutraceutical for health use, and defense of producers for fair trade, warning retailers of artificial and adulterated honey.

7.1. Following the CODEX STAN chemical quality factors of Apis mellifera honey

The chemical quality factors and the standards of honey are presented in chronological order in Table 1, where *Apis mellifera* honey (CODEX STAN, 2022) is compared with a set of proposed standards for neotropical (seven countries, three SB genera, and two SB species) and paleotropical (five countries, two SB genera and five SB species) stingless bee honeys (SBH) from scientific literature and participations in scientific events. Following the order of the quality factors in the left column, compared to the maximum moisture of 20g/100g *A. mellifera* honey, a maximum moisture of 30g/100g SBH is recommended, except for the Tanzanian *A. ferruginea* 35 g/100g. Minimum reducing sugars are variable and lower than the minimum 65g/100g *A. mellifera* honey, 40–50 g/100g in neotropical and Tanzanian honey but lower values 12–15 g/100 g for Australian *T. hockingsi*, Chinese and Thai honeys, and very low 0.6–7.0 Malaysian honey. Note that *T. carbonaria* honey minimum was 50 (Persano-Oddo et al., 2008) instead of 20 (Zawawi et al., 2022). The maximun sucrose content of 0.5g/100g *A. mellifera* honey, has a suggested range of 1.0–6.0 g/100g SBH. Lower values were from Asia, China and Thailand, and was not detected in Malaysian and Australian SBH (Zawawi et al., 2022). The maximum free acidity of 40 mEq/kg *A. mellifera* honey, increased to suggested 70–100 mEq/kg neotropical SBH, and 110–300 mEq/kg paleotropical SBH. The maximun ash content was generally 0.5 g/100g SBH, like *A. mellifera* honey, except for lower values of 0.2 in Malaysia, and higher maximum values of 1.0 g/100g Tanzanian *A. ferruginea* honey, and 0.7 for Thai *Tetragonula* honey. The maximum CODEX STAN HMF of 40 mg/kg A. *mellifera* honey was retained by the *Melipona*, *Scaptotrigona*, and *Trigona* honey from Guatemala, Mexico, and Venezuela, the *Tetragonisca angustula* honey from Brazil, Colombia, Costa Rica, Ecuador, Guatemala, and Venezuela, and the *Tetragonula* honey from Thailand. The maximum HMF was reduced to 30 mg/kg *Scaptotrigona vitorum* honey from Ecuador, 20 mg/kg *Tetragonula carbonaria* honey from Australia, 10 mg/kg *Lepidotrigona* and *Tetragonula* honey from China, and not measured by Zawawi et al. (2022) in the Australian and Malaysian SBH. The diastase activity had a low minimum of 1.0–3.0 Göthe units for the Venezuelan *Melipona* and *Scaptotrigona*, the Ecuadorian *Scaptotrigona vitorum*, the Australian *Tetragonula carbonaria*, and the Thai *Tetragonula* reported mimimum 0.2 DN for diastase activity (Chuttong et al., 2024); not measured in the Australian and Malaysian SBH (Zawawi et al., 2022) or not detected in the Chinese SBH (Zheng et al., 2024). The trehalulose is the low glycemic index sugar, a new parameter measured in Asia and Australia, with variable minimum values from 4 to 15 g/100g SBH, and exceptionally high in the Malaysian *G. thoracica* pot-honey with 40 g/100g, in turn with a very low minimum of reducing sugars 0.6 g/100 g *G. thoracica* pot-honey.

Table 1
Proposal of suggested stingless bee honey (SBH) standards to be adopted by the Codex Alimetarius (**N** = **414**, from five genera and seven species in 12 countries).

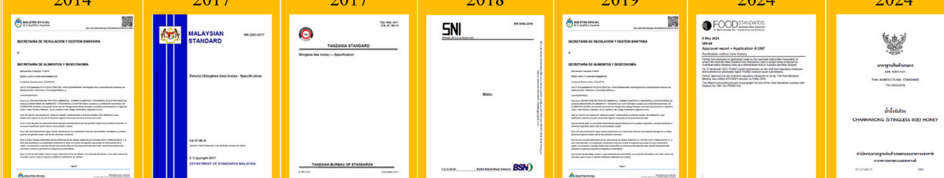
Chemical quality factors	Suggested standards for pantropical SBHs														
	CODEX STAN (2022) honey standards	Neotropical					Paleotropical								
		Guatemala, Mexico, Venezuela (Vit et al., 2004)			Ecuador (Vit, 2017)	Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Venezuela (Vit, 2023b)	Australia (Persano Oddo et al., 2008)	Malaysia (Zawawi et al., 2022 and Chuttong et al., 2024)		Australia (Zawawi et al., 2022)		Tanzania (Mduda, 2023; Mduda et al., 2023a)	Thailand (Chuttong et al., 2024)	China (Zheng et al., 2024)	
Bee taxa	*Apis mellifera*	*Melipona*	*Scaptotrigona*	*Trigona*	*Scaptotrigona vitorum*	*Tetragonisca angustula*	*Tetragonula carbonaria*	*Geniotrigona thoracica*	*Heterotrigona itama*	*Tetragonula carbonaria*	*Tetragonula hockingsi*	*Axestotrigona ferruginea*	*Tetragonula*	*Lepidotrigona*	*Tetragonula*
n		25	12	8	38	93	8	5	10	11	10	32	70	79	13
Water (g/100g honey)	Maximum 20.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 30.0	Maximum 35.0	Maximum 30.0	Maximum 30.0	Maximum 30.0
Reducing sugars (g/100g honey)	Minimum 65.0	Minimum 50.0	Minimum 50.0	Minimum 50.0	Minimum 40.0	Minimum 50.0	Minimum 60.0[a]	Minimum 40.0[b]	Minimum 35.0[b]	Minimum 35.0[b]	Minimum 35.0[b]	Minimum 40.0	Minimum 15.0[a]	Minimum 20.0[b]	Minimum 30.0[b]
Sucrose (g/100g honey)	Maximum 5.0	Maximum 6.0	Maximum 2.0	Maximum 6.0	Maximum 2.0	Maximum 5.0	Maximum 2.0	N.D.[c]	N.D.[c]	N.D.[c]	N.D.[c]	Maximum 1.0	Maximum 5.0	Maximum 1.0	Maximum 1.0
Free acidity (mEq/100g honey)	Maximum 40.0	Maximum 70.0	Maximum 85.0	Maximum 75.0	Maximum 100.0	Maximum 70.0	Maximum 160.0	Maximum 340.0	Maximum 315.0	Maximum 200.0[d]	Maximum 170.0[d]	Maximum 110.0	Maximum 180	*L. flavibasis*, Maximum 260.0 *L. terminata*, *L. arcifera* Maximum 200.0	*T. gressitti* Maximum 280.0 *T. pagdeni* Maximum 105.0
Ash (g/100g honey)	Maximum 0.5	Maximum 0.5	Maximum 0.5	Maximum 0.5	Maximum 0.5	Maximum 0.5	Maximum 0.5	Maximum 0.2	Maximum 0.2	Maximum 0.5	Maximum 0.5	Maximum 1.0	Maximum 1.0	Maximum 0.5	Maximum 0.5
Hydroxymethylfurfural (mg/kg honey)	Maximum 40.0	Maximum 40.0	Maximum 40.0	Maximum 40.0	Maximum 30.0	Maximum 40.0	Maximum 20.0	–	–	–	–	Maximum 40.0	Maximum 40.0	Maximum 10.0	Maximum 10.0
Diastase activity (DN)	Minimum 8.0	Minimum 3.0	Minimum 3.0	Minimum 7.0	Minimum 2.0	Minimum 8.0	Minimum 0.1	–	–	–	–	–	–	N.D.[a]	N.D.[a]
Trehalulose (g/100g honey)	–	–	–	–	–	–	–	Minimum 40.0	Minimum 15.0	Minimum 15.0	Minimum 15.0	-	-	Minimum 4.0	Minimum 5.0

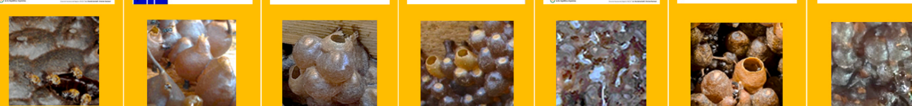
[a] Persano Oddo et al. (2008) and Chuttong et al. (2024) detected a peak near to maltose that was identified as trehalulose by Fletcher et al. (2020), thus considered as trehalulose.
[b] Minimum reducing sugars were estimated adding fructose + glucose + trehalulose (MT Fletcher, personal communication).
[c] N.D. Not detected in any SBH.
[d] After original data availability, the second highest value for *T. carbonaria* was 202.4 then 190.8 mEq/kg. The second highest value for *T. hockingsi* was 166.3 then 156.4 mEq/kg (NL Hungerford, personal communication). We considered that possibly the highest values of the ranges could be outliers (*T. carbonaria* 212.3 and *T. hockingsi* 202.0), and selected the second highest values for both stingless bee species.

7.2. Differences and similarities between the first Bahia state norm, and the five national norms for stingless bee honey

Seven official standards to regulate stingless bee honey were compared in Fig. 4, comprising the first state norm from Bahia, Brazil (ADAB, 2014), and the six national norms for Malaysia (Department of Standards Malaysia, 2017), Tanzania (Tanzania Bureau of Standards, 2017, pp. 1–18), Indonesia (Indonesian National Standard, 2018), Argentina (Secretaría de Regulación y Gestión Sanitaria y Secretaría de Alimentos y Bioeconomía, 2019), Australia (Australia New Zealand Food Standards, 2024), and Thailand (Thai Agricultural Standard, 2024). Our priority is to compare them with the CODEX STAN (2022) parameters chosen as honey quality indicators for the commercial honeybee *Apis mellifera*. However, some countries modified that by inclusion of additional indicators such as the recently discovered sugar trehalulose (Fletcher et al., 2020). Others decided to replace the classic free acidity by the pH, but considering the fermented nature of pot-honey (Vit et al. 2004, 2013; de Paula et al., 2021; Alves et al., 2024), this idea is not acceptable because free acidity is a powerful descriptor differentiating stingless bee honey types. Moreover, free acidity of honey can be estimated from the content of aliphatic organic acids, some of them of microbial origin (Vit and Simova, 2023), but not the pH. Additionally, the diastase activity so important to assess heating and aging in *Apis mellifera* honey, loses this application in some types of pot-honey with a natural very low or not detected diastase activity. Each stingless bee honey board had particular geographic and cultural reasons for their choices that succeeded in the administrative procedure conducing to the official registration of the norm. Here, we have the opportunity to prepare for the international norm, assimilating lessons learned along the process, attempting a harmonized proposal for such a complex challenge of 605 extant species of stingless bees (Engel et al., 2023) still growing as new taxa are described by taxonomists.

Overcoming the hurdle of 259 species of stingless bees in Brazil –half of them in the Amazonas state– (Nogueira, 2023), the Bahia state





Stingless bee **Quality Factors** Codex Alimentarius Commission Standard for honey CXS 12-1981	**One state and six national stingless bee honey standards**						
	Bahia, Brazil 2014	Malaysia 2017	Tanzania 2017	Indonesia 2018	Argentina 2019	Australia 2024	Thailand 2024
	Melipona scutellaris ©C.A.L. Carvalho	*Heterotrigona itama* ©M.Z. Mustafa	*Axestotrigona ferruginea* ©C.A. Mduda	*Tetragonula laeviceps* ©Agussalim	*Tetragonisca fiebrigi* ©Y. Aquino	*Tetragonula carbonaria* ©T. Smith	*Tetragonula laeviceps* ©B. Chuttong
Stingless bee taxa	*Melipona*	All species	All species	All species	*Tetragonisca fiebrigi*	*Austroplebeia & Tetragonula*	All species
Ethnic name	–	Kelulut	–	–	Yateí	–	Channarong
Moisture (g/100 g)	Maximun 35	Maximum 35	Maximum 28	Maximum 27.5	Maximum 26	Maximum 28	Maximum 35
Reducing sugars (g/100 g)	Minimum 60	Maximum 85	Minimum 50	Minimum 55	Minimum 40	Minimum 50	Maximum 65[2]
Sucrose (g/100 g)	Maximum 6.0	Maximum 7.5	Maximum 6.0	Maximum 5	Maximum 6.0	–	Maximum 5.0
Free acidity (mEq/kg)	Maximum 50	–	Maximum 85	Maximum 200	Maximum 70	–	Maximum[3] 30 – 350
Ash (g/100 g)	Maximum 0.6	Maximum 1.0	Maximum 0.5	Maximum 0.5	Maximum 0.7	–	Maximum 1.0
Hydroxymethylfurfural (mg/kg)	Maximum 10	Maximum 30	Maximum 40	Maximum 40	Maximum 21	–	Maximum 40
Diastase activity (Schade units)	Maximum 3[1]	–	Minimum 3.0	Minimum 1	Minimum 2.0	–	–
Insoluble solids (g/100 g)	Maximum 0.1	–	–	Maximum 0.7	Maximum 0.1	–	–
Trehalulose (g/100 g)	–	–	–	–	–	Minimum 2	–

[1]Diastase activity is low in *Melipona* honey. Therefore, a maximum value was suggested to prevent admixtures with honeybee honey, instead of the minimum value of CODEX STAN established to detect heated and aged honey. [2]For unknown reasons, Thailand assigned a maximum reducing sugars instead of the minimum reducing sugars value of CODEX STAN. [3]For unknown reasons, Thailand assigned a maximum total acidity instead of maximum free acidity value of CODEX STAN.

Fig. 4. Comparative approach of official standards to regulate stingless bee honey (2014–2024).

focused on the *Melipona* genus for their Melipona honey norm (ADAB, 2014), which was followed by other four Brazilian states (Vit et al., 2023a) with further established state standards for stingless bee honey in Amazonas (ADAF, 2016), Paraná (ADAPAR, 2017, pp. 1–9), Espírito Santo (IDAF, 2019, pp. 1–7), and Santa Catarina (SAR, 2020, pp. 16–24). *Melipona* is the richest genus in the Meliponini Tribe, with 70 species, and 10 subspecies (Vit and Yurrita-Obiols, 2024). They are large stingless bees, which build the largest honey pots in the storage area of the nest, and thus, have top honey yields (Alves, 2013) with the maximum for *Melipona scutellaris* producing 2–15 kg/year (RMO Alves, Personal observation).

Camargo et al. (2023) report the ethnic names of the stingless bee species in the Meliponini Lepeletier, 1836 chapter. The names used by people to call their stingless bees are important in the honey standards to be aware of the cultural heritage. Both the scientific name and the ethnic name should be included, and visibility is given in the labels of packed honey. In Fig. 4, the first national standard by Malaysia (Department of Standards Malaysia, 2017) used Kelulut honey, the ethnic name given to all stingless bees in Malaysia. The second national norm by Tanzania (Tanzania Bureau of Standards, 2017, pp. 1–18) is about stingless bee honey specifications. The third national norm by Indonesia (Indonesian National Standard, 2018, pp. 1–27) is different from all others because the title of the norm is *Madu*, honey in Indonesian, and covers three types of honey: 1. *Madu hutan* also known as forest honey which is harvested from the honeybee *Apis dorsata* in the forest. 2. *Madu budidaya* is honey harvested from the honeybees *Apis mellifera* and *Apis cerana* reared by the beekeepers. 3. *Madu Lebah tanpa sengat* is the stingless bee honey, because in Indonesia stingless bee is named *Lebah tanpa sengat* (Agussalim, personal communication). The fourth national norm by Argentina (Secretaría de Regulación y Gestión Sanitaria y Secretaría de Alimentos y Bioeconomía, 2019) opted for the scientific name of one stingless bee species *Tetragonisca fiebrigi*, and its ethnic name Yateí. The fifth is the Australian norm (Australia New Zealand Food Standards, 2024) that did not care for heritage of the culture. Therefore, Carby is not mentioned for *T. carbonaria*, and Sugarbag bee either. Each *Melipona* species in Brazil has an ethnic name, thus impossible to mention all of them in the Bahia norm (ADAB, 2014), but they are available on-line in the Meliponini Lepeletier, 1836 chapter (Camargo et al., 2023). The sixth national norm by Thailand (Thai Agricultural Standard, 2024) Channarong (Stingless Bee) honey, has the ethnic name given to all stingless bees in Thailand.

Regarding the physico-chemical parameters, some norms consider processed honey dehumidified or refrigerated. In Fig. 4, the maximum and minimum values are given only for raw honey. At first glance, the Neotropical norms from Brazil (ADAB, 2014) and Argentina (Secretaría de Regulación y Gestión Sanitaria y Secretaría de Alimentos y Bioeconomía, 2019), are following the Codex Alimentarius guidelines, and were designed by a team of invited stingless bee scientists. On the contrary, the Malaysian norm (Department of Standards Malaysia, 2017) and the Thai norm (Thai Agricultural Standard, 2024), ignored the stingless bee taxonomists and the entomological biodiversity, considering stingless bee honey standards for a putative pull of all stingless bee species, called Kelulut in Malaysia and Channarong in Thailand, despite the scientific literature harvesting and analyzing the honey produced by each Malaysian and Thai species or genus of stingless bees. Standardization for stingless bee honey will benefit from an array of standards for evidenced distinctive taxa in the scientific literature, first proposed by Vit et al. (2004) for the neotropical genera *Melipona*, *Scaptotrigona* and *Trigona* producing pot-honey. It is not compatible to recommend a minimum content of 85% reducing sugars plus a maximum of 35% moisture. Should be a lower value of reducing sugar due to the high moisture of Kelulut honey, and not providing the free acidity standard was a remarkable omission for fermented honey. Seven years later the Thai Channarong (Stingless Bee) Honey did not follow the Codex Alimentarius on the free acidity quality factor, and used total acidity. The positive approach was using a range of 30–350 mEq/kg illustrating the biodiverse physiology and microbial associations with stingless bees causing that variation of a key quality standard in fermented honey. Thai literature should stop reporting total acidity of stingless bee honey, and harmonize with the free acidity additional quality factor selected by the Codex Alimentarius Commission Standard for honey (CODEX STAN, 2022). In 2015, P. Vit was invited to review a manuscript of Thai stingless bee honey, and sent the reviewer report to the editor of Food Chemistry because the internet connectivity was low for their webpage. The use of the Codex quality factor free acidity was recommended instead of the total acidity. However, that report did not reach the authors and Chuttong et al. (2016) was published with total acidity, showing the impact of an editorial omission in time, reflected in the Thai Channarong (Stingless Bee) honey standard (Thai Agricultural Standard, 2024) (P. Vit, personal observation). A paper of Indian stingless bee honey was published without the identification of the stingless bee (Thomas and Kharnaior, 2023), and having sour honey in the title was unnoticed by reviewers and editors of the Journal of Apicultural Research, for a document lacking free acidity.

Considering that most native bees do not produce honey, it is unfortunate that Food Standards Australia and New Zealand (FSANZ), used native bees in the title of their norm instead of stingless bees (Australia New Zealand Food Standards, 2024). It is confusing along with the text. Apparently, it was a norm designed to trade only Australian stingless bee honey in Australia, where it is produced, and in New Zealand, with no stingless bees. Stakeholders made the choice, not scientists (M. Halcroft, Personal communication). However, the concept of native bees is different: 1. Native bees exist naturally in a particular area, and are not the result of human activity. Therefore, stingless bee keeping is not comprised. 2. According to Dr. Tobias Smith (2023) from Queensland University, there are over 20,700 native bee species worldwide, 1660 of them in Australia, including stingless bee species from two genera, *Austroplebeia* and *Tetragonula*. In the discoverlife interactive checklists of world bees by country (Ascher and Pickering, 2017), these are the 11 Australian stingless bee species 1. *Austroplebeia australis*, 2. *Austroplebeia cassiae*, 3. *Austroplebeia cincta*, 4. *Austroplebeia essingtoni*, 5. *Austroplebeia magna*, 6. *Tetragonula carbonaria*, 7. *Tetragonula clypearis*, 8. *Tetragonula davenporti*, 9. *Tetragonula hockingsi*, 10. *Tetragonula mellipes*, 11. *Tetragonula sapiens*.

The text of the norm uses alternatively native bees and stingless bees, which is wrong, because they are not the same. Stingless honey bees belong to the Meliponini Lepeletier, 1836 tribe. In section 1.2 The application, it says "The applicant seeks to amend the Australia New Zealand Food Standards Code (the Code) to accept honey produced by Australian native stingless bees as a standardised food in Australia and New Zealand—in other words, to permit the sale and use of honey produced by stingless bees native to Australia in these two countries." It seems they mean only honey produced by stingless bees in Australia is permitted for sale. It was a tremendous conquer to include stingless bee honey in the Code, which was exclusive for *Apis mellifera*, but the confusing name causes a temporary situation that should be solved taxonomically wisely for the international standards of stingless bee honey. In section 2.3.3 **Name of the food**, page 21, the applicant requested the term 'native bee honey' to be a prescribed name for the purposes of the name of the food labelling requirement. This seems inadequate, especially considering that most native bees do not produce honey. Only two honey quality indicators, moisture and reducing sugars were chosen from the CODEX STAN (2022), and the lack of analytical references does not evidence discarding the other quality indicators: contents of ash, free acidity, sucrose, hydroxymethylfurfural, and diastase activity from the Australian norm. As mentioned before, trehalulose is a recently discovered sugar in stingless bee honey (Fletcher et al., 2020). It is a good addition to the quality control parameters of the CXS 12–1981 (CODEX STAN, 2022). Possibly food analyst experts in stingless bee honey, and a taxonomist of stingless bees were not consulted by the Honey Board of this norm, otherwise the minimum 50% reducing sugars would not have been adopted, see Zawawi et al. (2022).

However, a minimun 50% reducing sugars was previously suggested for *T. carbonaria* (Persano-Oddo et al., 2008), updated to 60% in Table 1 with the sum of the near to maltose sugar considered the reducing trehalulose after Fletcher (2020), suggesting more data is needed to know if there are environmental factors causing bimodal concentrations. Physicochemical parameters of *Austroplebeia* honey are poorly covered in the scientific literature, wondering how standards could be suggested, especially merging these two genera of Australian stingless bees (Hymenoptera: Apidae: Meliponini).

7.3. An idea to cluster groups of stingless bee honey according to their free acidity

Given the great biodiversity, it is not envisaged the CODEX STAN preparing one norm for each species of stingless bee, as it is for *Apis mellifera*. However, different countries may have different ideas on what they need for the stingless bee industry. Brazil merged all *Melipona* species in the state norm (ADAB, 2014), and Argentina prepared a national norm for a unique species (Secretaría de Regulación y Gestión Sanitaria y Secretaría de Alimentos y Bioeconomía, 2019). Indonesia, Malaysia, Tanzania, and Thailand considered honey produced by all species of stingless bees in each country (Indonesian National Standard, 2018, pp. 1–27; Department of Standards; Malaysia, 2017; Tanzania Bureau of; Standards, 2017; Thai Agricultural Standard, 2024), and Australia selected two genera of stingless bees (Australia New Zealand Food Standards, 2024).

Possibly a reduction to similar stingless bee honey based on their free acidity, may facilitate the proposal of standards for stingless bee honey developed by the Codex Alimentarius Commission. In Table 2, this reduction is based on tentative ranges of free acidity suggested by Vit (2022b) and their corresponding suggested classes free acidity. The two ranges with higher free acidity have fewer stingless bee species; thus, they could possibly merge forming a more heterogeneous class 5 with free acidity ranging from 301 to >500 mEq/kg honey. A further class 4 may comprise class 4 and 5 from Table 2, 201 to >500 mEq/kg, considering that most of the studied pot-honeys have a free acidity above 200 mEq/kg.

Table 2
Suggested free acidity classes and ranges of honey produced by 57 species of stingless bees in 18 countries.

Free acidity		Stingless bee species
Classes	Ranges (mEq/kg honey)	
1	30–60	*Hypotrigona* sp., *Lisotrigona furva*, *Melipona cramptoni*, *Melipona indecisa*, *Meliponula bocandei*, *Axestotrigona ferruginea*, *Plebeiella lendliana*, *Axestotrigona togoensis*, *Nannotrigona chapadana*, *Oxytrigona mellicolor*, *Paratrigona* sp., *Plebeia* sp1., *Scaptotrigona depilis*, *Scaptotrigona polysticta*, *Tetragona* sp., *Tetragonula testaceitarsis*
2	61–100	*Geotrigona acapulconis*, *Heterotrigona itama* fed on Acacia *Acacia mangium Melipona capixaba*, *Melipona grandis*, *Plebeia* sp2., *Scaptotrigona* sp., *Scaptotrigona polysticta*, *Scaura* aff. *latitarsis*, *Tetragonisca angustula*, *Tetragonisca fiebrigi*, *Tetragonula fuscobalteata*, *Tetragonisca silvestriana*, *Tetragonula laeviceps-pagdeni complex*
3	101–200	*Cephalotrigona* sp., *Geniotrigona thoracica A. mangium*, *Geniotrigona thoracica* fed on Gelam *Melaleuca cajaputi*, *Heterotrigona itama M. cajaputi*, *Lepidotrigona doipaensis*, *Lepidotrigona flavibasis*, *Lepidotrigona terminate*, *Plebeina armata*, *Plebeia wittmanni*, *Scaptotrigona pectoralis*, *Tetragonula carbonaria*, *Tetragonula fuscobalteata*, *Tetragonula testaceitarsis*
4	201–300	*Frieseomelitta paupera*, *Geniotrigona thoracica*, *Heterotrigona itama* fed on Starfruit *Averrhoa carambola*, *Liotrigona* sp.
5	301– >500	*Geotrigona* sp., *Homotrigona apicalis*, *Homotrigona fimbriata*, *Homotrigona melanoleu ca*

Note that free acidity of *Heterotrigona itama* honey from Malaysia varied according to the botanical resources foraged by the stingless bees: Class 2 (61–100 mEq/kg) Acacia *Acacia mangium*, class 3 (101–200 mEq/kg) Gelam *Melaleuca cajaputi*, and class 4 (201–300 mEq/kg) Starfruit *Averrhoa carambola* (Shamsudin et al., 2019). Different SB species may respond differently, and would be interesting to compare with *Apis mellifera* too. Persano Oddo and Piro (2004) reported the free acidity in more than 30,000 unifloral *Apis mellifera* honey from Europe. It ranged from 10.3 ± 2.1 mEq/kg Rape *Brassica napus* honey, a yellow sweet and crystallized honey, to 35.1 ± 8.1 mEq/kg Strawberry tree *Arbutus unedo* honey, the most bitter honey we ever tasted.
After: Vit (2022b).

8. A tentative proposal of stingless bee honey types organized according to free acidity classes for maximum free acidity ranges

In Table 3, this reduction is based on tentative ranges of free acidity suggested by Vit (2022b) and their corresponding classes for maximum free acidity ranges. The three ranges with maximum higher free acidity are less frequent and have fewer stingless bee species specialized for such high values of free acidity; thus, they were merged forming a more heterogeneous class 4 with maximum free acidity ranging 201 to >500 mEq/kg honey. The suggested array of stingless bee honey in groups organized according to similar maxima of free acidity classes, may help the development and adoption of the Codex Alimentarius standards for stingless bees. Also, the uses of stingless bee honey may be classified according to their free acidity classes, with class 4 unique strong sour taste, not useful as a sweetener but in gastronomic vinaigrettes or similar sauces.

9. Conclusions

The medicinal properties of stingless bee honey were reviewed for 26 species of stingless bees from 14 countries. Bee, plant, and microbial origin of nutraceutical metabolites present in stingless bee honey were illustrated for the health benefits explained by their chemical components such as aliphatic organic: acids acetic acid and lactic acid, biosurfactants like sophorolipids, the diol 2,3-butanediol, the hydroxiacid 3-phenyllactic acid, flavonoids, polyphenols, trehalulose sugar, and vitamin C. The anticataract, anti-inflammatory, antimicrobial, and antioxidant bioactivities were selected for potential nutraceutical applications of stingless bee honey. The scientific interest in traditional medicinal uses of stingless bee honey have accumulated evidences of their nutraceutical applications as dietary supplement, functional food, medicinal food, and even pharmaceuticals, and to continue further innovative developments for expanded application. The unique characteristics of honey produced by the over 600 species of stingless bees demand tailored standards that reflect their specific properties. The physicochemical indicators were reviewed for 414 stingless bee honey samples participating in papers or congresses, from five genera and seven species in 12 countries, suggesting their standards according to the parameters selected by the CODEX STAN for *Apis mellifera*. The first state norm for *Melipona* honey from Bahia, Brazil (2014), and the six national norms for Kelulut Honey Malaysia (2017); Stingless Bee Honey from Tanzania (2017); Stingless Bee Honey from Indonesia (2018); *Tetragonisca fiebrigi* Yateí from Argentina (2019); *Austroplebeia* and *Tetragonula* from Australia (2024); and Channarong (Stingless Bee Honey) from Thailand (2024) were compared and commented for needed harmonization to proceed with the proposal of Standards for SBH to CODEX STAN. An idea of clustering SBHs according to their free acidity ranges, was proposed to classify the enormous entomological biodiversity according to a parameter so important for fermented pot-honey, related to the microbial origin and also to the botanical origin.

10. Contribution statement

P. Vit Conceptualization, Writing original draft, Writing - Review

Table 3
Stingless bee honey types organized according to suggested free acidity classes for maximum free acidity ranges.

Free acidity Class[a]	Maximum Free acidity Range (mEq/kg)	Stingless bee taxa	Physicochemical quality factors								n	Country	Authors, Year
			Moisture (g/100g)	Reducing sugars (g/100g)	Sucrose (g/100g)	Free acidity (mEQ/kg)	Ash (g/100g)	HMF (mg/kg)	Diastase activity (Göthe U)	Trehalulose (mg/100g)			
2	61–100	*Melipona*	Maximum 30.0	Minimum 50.0	Maximum 6.0	Maximum 70.0	Maximum 0.5	Maximum 40.0	Minimum 3.0	–	25	Guatemala, Mexico, Venezuela	Vit et al., **2004**
		Scaptotrigona	Maximum 30.0	Minimum 50.0	Maximum 2.0	Maximum 85.0	Maximum 0.5	Maximum 40.0	Minimum 3.0	–	12		
		Trigona	Maximum 30.0	Minimum 50.0	Maximum 6.0	Maximum 75.0	Maximum 0.5	Maximum 40.0	Minimum 7.0	–	8		
		Scaptotrigona vitorum	Maximum 30.0	Minimum 40.0	Maximum 2.0	Maximum 100.0	Maximum 0.5	Maximum 30.0	Minimum 2.0	–	38	Ecuador	Vit, **2017**
		Tetragonisca angustula	Maximum 30.0	Minimum 50.0	Maximum 5.0	Maximum 70.0	Maximum 0.5	Maximum 40.0	Minimum 8.0	–	93	Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Venezuela	Vit, **2023**
3	101–200	*Tetragonula carbonaria*	Maximum 30.0	Minimum 65.0[b]	Maximum 5.0	Maximum 160.0	Maximum 0.5	Maximum 40.0	Minimum 0.1	Minimum 15.0[a]	8	Australia	Persano Oddo et al., **2008**
		Tetragonula carbonaria	Maximum 30.0	Minimum 35.0[b]	N.D.[b]	Maximum 200.0[c]	Maximum 0.5	–	–	Minimum 15.0	11	Australia	Zawawi et al., **2022**
		Tetragonula hockingsi	Maximum 30.0	Minimum 35.0[b]	N.D.[b]	Maximum 170.0[c]	Maximum 0.5	–	–	Minimum 15.0	10		
		Axestotrigona ferruginea	Maximum 35.0	Minimum 40.0	Maximum 1.0	Maximum 110.0	Maximum 1.0	Maximum 40.0	–	–	32	Tanzania	Mduda, **2023**
		Tetragonula	Maximum 30.0	Minimum 15.0	Maximum 5.0	Maximum 180	Maximum 0.7	Maximum 40.0	Maximum 0.2	–	70	Thailand	Chuttong et al., 2024
4	201– >500	*Geniotrigona thoracica*	Maximum 30.0	Minimum 40.0	N.D.[b]	Maximum 315.0	Maximum 0.2	–	–	Minimum 40.0	5	Malaysia	Zawawi et al., **2022**
		Heterotrigona itama	Maximum 30.0	Minimum 35.0	N.D.[b]	Maximum 340.0	Maximum 0.2	–	–	Minimum 15.0	10		
		Lepidotrigona	Maximum 30.0	Minimum 20.0[b]	Maximum 1.0	Maximum 260.0	Maximum 0.5	Maximum 10.0	N.D.[a]	Minimum 4.0	79	China	Zheng et al., 2024
		Tetragonula	Maximum 30.0	Minimum 30.0[b]	Maximum 1.0	Maximum 280.0	Maximum 0.5	Maximum 10.0	N.D.[a]	Minimum 5.0	13	China	Zheng et al., 2024

2Persano Oddo et al. (2008) detected a peak near to maltose that was identified as trehalulose by Fletcher et al. (2020), thus considered as trehalulose.

[a] N.D. Not detected in any SBH.

[b] Minimum reducing sugars were estimated adding fructose + glucose + trehalulose (MT Fletcher, personal communication).

[c] After original data availability, the second highest value for *T. carbonaria* was 202.4 then 190.8 mEq/kg. The second highest value for *T. hockingsi* was 166.3 then 156.4 mEq/kg (NL Hungerford, personal communication). We considered that possibly the highest values of the ranges could be outliers (*T. carbonaria* 212.3 and *T. hockingsi* 202.0), and selected the second highest values for both stingless bee species.

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Data availability

No data was used for the research described in the article, except for the unpublished Thai *Tetragonula*. Data will be made available on request.

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Declaration of competing interest

Authors declare no competing interests.

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Data availability

Data will be made available on request.

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