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REVIEW ARTICLE

Active metabolites of stingless bee nest materials used for meliponitherapy: Bibliometrics, impact of biodiversity in conservation, and emerging microbiome

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ABSTRACT

Stingless bees (Hymenoptera: Apidae: Apinae: Meliponini) collect biotic and abiotic resources from nature to be transformed into nest materials with diverse functions such as structural, immune, defense, and nutritional. The 605 species of stingless bees collecting natural resources processed with associated microbiota are a spectacular biodiversity forming pot-honey, pot-pollen, cerumen and propolis valued in meliponitherapy. The bioactive metabolites have botanical, entomological, and microbial origins. Only pot-honey has been regulated since 2014 in Bahia, Brazil and further national standards. Forecasts of climate change affect stingless bee distribution, their productivity, and may influence the diversity of active metabolites in the nest. A sequence of researches serving meliponitherapy illustrated the ancient use of pot-honey eye drops to the latest cerumen components, reducing oxidative stress, and recent synergism with antibiotics to overcome antimicrobial resistance. Besides the chemical composition, the antioxidant and antimicrobial activities are fundamental added values, supporting a medicinal approach for both nutritional and pharmaceutical applications. Increased aliphatic organic acid contents in fermented pot-honey is not a defect, but a microbial biotransformation to preserve their wet honey with active metabolites. Characterizing the microbiome of stingless bees and their nest materials assists in identifying potential active biomolecules of microbial origin. Authenticity and chemical variability were discussed for quality control. Bibliometrics complemented this review for medicinal stingless bees (2004–2023) and stingless bees in climate change (2010–2023). Neotropical biodiversity of stingless bees was evidenced with the 259 stingless bee species richness in Brazil, 95 of them used in meliponiculture. Nest materials of 64 stingless bee taxa in 14 countries were reviewed for their flavonoid and polyphenol contents, and 13 biological activities. Conservation of stingless bees' biodiversity has been addressed in the face of climate change and the chemical pool represented for meliponitherapy. Active metabolites from the stingless bee nest are not envisaged to be extracted but to be used in their original matrices: pot-honey, pot-pollen, cerumen, or propolis. A synthesis of most active metabolites could be an option for pharmaceutical developments to reproduce a bioactive chemical repertoire of stingless bees in nature, with a role on Sustainable Development Goals SDG2 food security and SDG3 good health and well-being.

Keywords: antimicrobial resistance, biological activity, cerumen, climate change, flavonoids and polyphenols, medicinal, meliponitherapy, microbiome, pot-honey, pot-pollen, propolis, stingless bee.

1. Introduction

As the largest Neotropical country, Brazil has been leading conservation policies to protect biodiversity, and meliponine conservation is one example of that[1]. The first official standard for stingless bee honey was approved in the state of Bahia for *Melipona* honey[2]. Promoting nutraceutical uses of stingless bee pot-honey, pot-pollen, cerumen, and propolis, considers rational exploitation protecting natural resources for a sustainable meliponine industry. The diversity of active metabolites for meliponitherapy rely on the bee flora; the bees harvesting and transporting resources to the nest; colony and microbial processing; and chemical transformations.

The global decrease in rainforests[3] has adverse impact on biodiversity of stingless bees and plants used as nesting sites, nest materials, and food sources for their colonies. Particularly, Brazilian deforestation in the Neotropical region[4], and the greatest 2020 deforestation rate of the Brazilian Amazon in a decade[5] need our attention. Rocha et al. (2020)[6] analyzed the loss of functional diversity. Knowing the vital role of honeydew, nectar, pollen, oil, and resin use of plant resources by stingless bee colonies, any altered tree landscape would affect bee density and performance. Having diverse requirements and food preferences, different stingless bee species would adapt better than others to the deforestation stress[7] in a dynamic forest community, causing shifts in abundance and diversity. Bees and forests have a vital synergism. Therefore, distinctive conservational objectives are linked to the utilization of stingless bee products. The Atlantic Forest is the second largest tropical rainforest in the American continent after the Amazon, home of stingless bees, their nest products, and communities exploiting these natural resources managed for meliponiculture.

Stingless bee keepers harvest pot-honey, pot-pollen, cerumen, and propolis from stingless bee nests (Fig. 1) for their unique sensory attributes and beneficial medicinal values. Stingless bee studies have become a hotspot in the international bee product research, with a progressive expansion to characterize their entomological biodiversity, and to propose therapeutic applications.

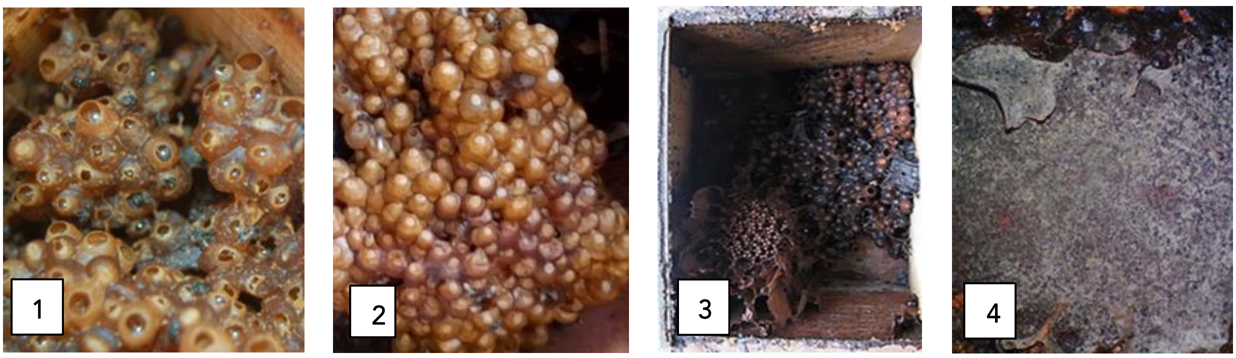


Fig. 1 Four major materials harvested from the stingless bee nest:
1. Honey pots of *Austroplebeia australis*, Australia Photo: ©M. Halcroft; 2. Pollen pots of *Hypotrigona ruspolii*, Tanzania Photo: ©C. Mduda; 3. Cerumen and propolis of *Tetragonula iridipennis*, India Photo: ©U. Layek; and 4. Propolis of *Tetragonisca angustula*, Venezuela Photo: ©P. Vit.

Main topics of the Apitherapy section in the Apimondia Congress held in Santiago de Chile, September 2023, were: 1. Scientific-based evidence supporting the nutritional, physiological, and health claims of bee products, 2. Preclinical research - safety, pharmacology, and toxicology of bee products. Guidelines for medical applications, 3. Clinical trials in apitherapy – doses, interactions, side effects (human and veterinary medicine). Update on the use of apitherapy in infectious diseases, and 4. Regulatory issues and clinical ethics related to the integration of apitherapy as TCM in healthcare systems. The first topic on bee products, particularly stingless bee nest materials, was reviewed because diverse nest materials have different chemical composition and added values on bioactive properties for pharmaceutical design. Their attributes caused by the botanical origin is an investigation initiated with *Apis mellifera*, and further variations caused by the entomological origin were mandatory for the meliponine biodiversity—Engel et al. (2023)[8] recognize 605 stingless bee species—scientific attention was more recently addressed to the microbial origin of

The support of traditional knowledge, such as to *Scaptotrigona mexicana* pot-honey by ethanolic fermentation[9] was demonstrated with *Tetragonisca angustula* pot-honey in Venezuela[10], and recent studies exploring the meliponine rich microbiome[11] producing pot-honey metabolites of microbial origin quantified by targeted[1] H-NMR[12].

Another approach to differentiate nest materials is using non-invasive techniques to study volatile organic compounds (VOCs) with diverse chemical structures, ecological roles, and origins. For example, a diversity of 95 VOCs in *Tetragonisca angustula* cerumen types and propolis was detected, identified by HS-SPME/GC-MS, and grouped in chemical classes: 1. Acids (11), 2. Alcohols (16), 3. Aldehydes (7), 4. Esters (16), 5. Ketones (8), 6. Monoterpenes (17), 7. Oxides (5), 8. Sesquiterpenes (11), and 9. Others (4) by Betta et al. (2024)[13], Their transformations are fascinating, waiting for suggested biochemical and microbial pathways. The acetic acid accumulated in the cerumen of empty honey pots, was esterified into methyl acetate in the entrance tube, and five acetates in the *Tetragonisca angustula* honey pots. Microbial metabolites of stingless bee nest materials were reviewed by Vit (2024)[14] for alcohols (ethanol, glycerol, isoamylic), aliphatic organic acids (AOA) (acetic, gluconic, lactic, oxalic, succinic, tartaric), amino acids (phenylalanine, proline, pyroglutamic acid), antibiotics (meliponamycin A, B, recently discovered as microbial metabolites in *Melipona scutellaris*), diphenylether (asterric acid), polyketide pigments (monascin), phenolic acids (3-phenyllactic acid), polyols (2,3-butanediol), statins (lovastatin), steroids (ergosterol), sugars (dihydroxyacetone, maltose, raffinose, trehalulose, turanose), surfactants (suspected sophorolipids), and vitamins (ascorbic acid). Surprisingly, a honey authenticity test revealed suspected microbial associations with the *Scaptotrigona vitorum* pot-honey from Ecuador[15].

These studies are beneficial for multifactorial medicinal stingless bee science and applications in integrative medicine as a good source of bioactive natural compounds with therapeutic and nutritional value. Salomon et al.[16] observed significant reduction of cotton pellet-induced granuloma weights at all doses tested (27.34%, 35.53% and 47.53% granuloma inhibition) in Wistar rats treated daily with injected intravenously *Tetragonisca fiebrigi* honey (1000 mg/kg b.w.) for a week. In contrast, significant reduction in hind paw edema (44.44%) was achieved with *Tetragonisca fiebrigi* honey oral administration, causing analgesic responses in the three models used (acetic acid, formalin, tail immersion). Antioxidant activity, melissopalynological, physicochemical, phenolics, and sugars HPLC assessments of the honey were provided.

The tropical uses of pot-honey, pot-pollen, cerumen and propolis in meliponitherapy are traditional knowledge/constitute traditional knowledge gaining scientific interest for their biological activities and the most studied flavonoids and polyphenols active biomolecules. The scientific literature was tabulated for that approach, and additionally complemented with bibliometrics on medicinal stingless bees, and a further evaluation of stingless bees and climate change to understand the impact on biodiversity conservation. Protection of stingless bee and associated microbiome biodiversity is considered vital for chemical diversity of nest materials used in meliponitherapy.

This wide-ranging review integrates the chemical, biological, ecological, and therapeutic dimensions of stingless bee nest materials within the framework of meliponitherapy. It encompasses a detailed exploration of the diversity of active metabolites originating from botanical, entomological, and microbial sources found in pot-honey, pot-pollen, cerumen, and propolis of stingless bees. The review includes a bibliometric analysis of global research on medicinal stingless bees and their relationship with climate change, highlighting publication trends, collaborative networks, and research impact. It further synthesizes current evidence on the antioxidant, antimicrobial, and pharmacological activities of these bioactive compounds and their implications for nutraceutical and pharmaceutical development. It also assesses the importance of biodiversity conservation and related microbiomes, as well as their promising medical applications. The primary objective is to establish a science-based framework to promote the rational and sustainable use of these natural products for pharmaceutical and nutraceutical applications, considering the potential effects of environmental changes on their chemical composition and availability. Our aim is to provide a sound background on the science supporting meliponitherapy, to propel discoveries on microbial biomolecules as potential medicinal natural resources for health, alone or combined with drugs.

2. Bibliometrics

Science mapping from the citation network[17] and a tool to visualize bibliometric networks such as Bibliometrix[18] are needed to describe structures of research. This section has two bibliometric reviews on stingless bees, one on their medicinal uses (107 documents) in the period 2004 to 2023, and another on climate change (25 documents) in the period 2010 to 2023. The annual growth rate of both datasets is compared in Fig. 2. There is a tendency to increase the number of documents with time. The annual growth of medicinal stingless bees recorded with the first paper in 2004, escalated in 2012 and 2013, with a sudden drop followed by a second peak in 2018, and a further drop with a steady growth in the last three years up to 15 documents in 2023. The annual growth of stingless bees and climate change shows the first paper in 2010, the second in 2015, a yearly paper from 2017 to 2019, growing interest reaching a peak of 7 papers in 2022. However, production decreased to 3 documents in 2023, that may recover in two weeks before the end of the year.

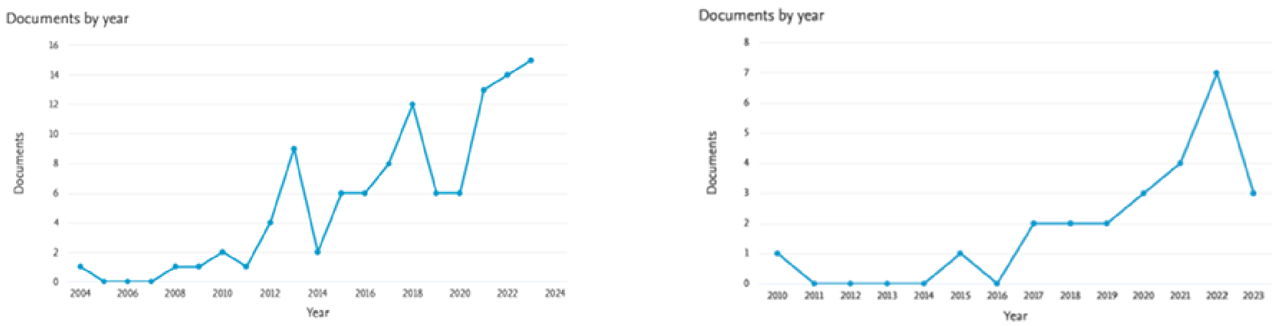


Fig. 2 Annual growth of publications on medicinal stingless bees (2004–2023) and stingless bees' climate change (2010–2023)

2.1 METHODOLOGY AND RESULTS OF THE BIBLIOMETRIC REVIEW ON MEDICINAL STINGLESS BEES

The Scopus database was used to review the scientific literature on medicinal stingless bees. Other words were used in the query string but the number of retrieved documents was lower; for example, using apitherapy only 16 documents, and 37 documents using pharmaceutical. Therefore, we selected medicinal for the search done on the 1st December 2023.

TITLE-ABS-KEY (stingless bee AND medicinal)

The main information of bibliometric descriptors is presented in Table 1 including publications from the first retrieved document since 2004 to 2023, almost two decades. The 107 documents of the dataset were published in four languages: English (100),

Portuguese(3), Spanish(3), and Chinese(2). Note that the addition gives 108 documents, possibly one was bilingual or considered bilingual by the dataset.

Table 1. Bibliometric descriptors of medicinal stingless bee research (2004–2023)

Main information of the dataset bibliometric descriptors	Counts of all documents
Timespan	2004:2023
Sources (Journals, Books, etc)	80
Documents	107
Annual Growth Rate %	15.32
Document Average Age	4.84
Average Citations per Document	18.63
References	5419
Document Contents	
Keywords Plus (ID)	869

Main information of the dataset bibliometric descriptors	Counts of all documents
Author's Keywords (DE)	327
Authors	
Authors	489
Authors of Single-Authored Documents	6
Authors Collaboration	
Single-Authored Documents	6
Multi-Authored Documents	101
Co-Authors per Document	4.97
International Co-Authorships %	24.3
Document Types	
Article	73
Book	1
Book chapter	12
Conference paper	4
Editorial	1
Note	1
Review	15
No. of languages	4
English	100
Portuguese	3
Spanish	3
Chinese	2

The first document of this dataset was *Quality standards for medicinal uses of Meliponinae honey in Guatemala, Mexico and Venezuela*, which was cited 132 times since 2004. The International Honey Commission was not supporting the proposal of medicinal stingless bee honey, but honey eye drops were sold in pharmacies before we started our research, and more recently online pharmacies offer the familiar eye drops, pot-honey, supplements with pot-honey, pot-pollen, and stingless bee propolis. The Vit et al.[9] article was published the same year of the Apidologie special number for European honey, with the seminal article *Main European unifloral honeys: Descriptive sheets* by Livia Persano-Oddo and Roberto Piro[19] on more than 35,000 unifloral, multifloral and honeydew honeys. The next document on this topic had to wait until 2008, *Composition and antioxidant activity of Tetragonula carbonaria honey from Australia*, cited as *Trigona carbonaria* at that time[20], *Medicinal animals as therapeutic alternative in a semi-arid region of Northeastern Brazil*[21], *Properties of honey from Tetragonisca angustula fiebrigi and Plebeia wittmanni of Argentina*[22] and *Antimicrobial activity of honey from the stingless bee Tetragonula carbonaria determined by agar diffusion, agar dilution, broth microdilution and time-kill methodology*[23], *Cerumen of Australian stingless bees (Tetragonula carbonaria): Gas chromatography-mass spectrometry fingerprints and potential anti-inflammatory properties*[24]. The annual growth of medicinal research of stingless bees is plotted in Fig. 2. The topic took flight in 2012 with four documents and a prolific peak in 2013 with the book *Pot-honey. A legacy of stingless bees*[25], and a further peak of productivity with the second book *Pot-pollen in stingless bee melittology*[26]. A drop of productivity was observed, the following year of each book publication, and a possible effect of the COVID-19 pandemic in 2020. A spectacular recovery in 2021 shows the inner motivation of authors, with a steady growth in 2022 and 2023, a merit of the multidisciplinary teams of worldwide experts with scientific interest embracing medicinal research of tropical stingless bees.

2.1.1 Most productive authors

The top ten authors in Table 2 are from Argentina, Australia, Brazil, Malaysia, and Venezuela. Hilgert publishes on ethnomedicinal uses of stingless bees, Brooks is microbiologist of cerumen and propolis, Mustafa and Ahmad are veterinarians with papers in multiple subjects, and Vit is a biologist interested in quality control of pot-honey, pot-pollen, and propolis.

Table 2. Top ten most productive authors in stingless bee medicinal research since (2004–2023) with their affiliations and countries

Ranking	NP[1]	Stingless bee medicinal research		
		Author	Affiliation, city	Country
1	4	Hilgert, N.I.	Instituto de Biología Subtropical, CONICET, Facultad de Ciencias Forestales, Universidad Nacional de Misiones, Puerto Iguazú	Argentina
2	3	Brooks, P.R.	Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore	Australia
3	3	Mustafa, M.Z.	Hospital Universiti Sains Malaysia, Kubang Kerian 16150, Kelantan	Malaysia
4	3	Vit, P.	Food Science Department, Faculty of Pharmacy and Bioanalysis, Universidad de Los Andes, Mérida	Venezuela
5	2	Ahmad, H.	Department of Veterinary Preclinical Sciences, Faculty of Veterinary Medicine, Universiti Putra Malaysia, Serdang	Malaysia
6	2	Al Hatamleh, M.A.I.	Department of Immunology, School of Medical Sciences, Universiti Sains Malaysia, Kubang Kerian	Malaysia
7	2	Balestieri, J.P.B.	Research group on Biotechnology and Bioprospecting Applied to Metabolism (GEBBAM), Federal University of Grande Dourados, Dourados	Brazil
8	2	Beux, M.R.	Department of Food Engineering, Federal University of Parana (UFPR), Curitiba	Brazil
9	2	Campos, J.F.	Research Group on Biotechnology and Bioprospecting Applied to Metabolism (GEBBAM), Federal University of Grande Dourados, Dourados	Brazil
10	2	Carollo, C.A.	Laboratory of Natural Products and Mass Spectrometry, Federal University of Mato Grosso do Sul, Cidade Universitária, Campo Grande	Brazil

[1]NP number of publications

In Table 3, the author impact metrics of the top ten authors are presented. The h-index for the medicinal stingless bee documents varied between 2 and 4. This is a public index available in the Google scientific citation database. The g-index and m-index are less used than the h-index. The h-index in this dataset was the same as g-index. The total citations (TC) varied between 57 and 236. The total number of publications (NP) varied between 2 and 4. The top author Mustafa MZ started to publish in this topic recently, and already has 4 important contributions since 2018. The most cited author has the oldest paper published in 2004. A team from Brazil and Portugal has two articles and 57 citations, sharing all other metrics too.

Table 3. Impact factor of top ten authors of stingless bee medicinal documents (2004–2023)

Top ten authors	h-index	g-index	m-index	TC	NP	PY start
Mustafa MZ	4	4	0.667	134	4	2018
Brooks PR	3	3	0.231	85	3	2011
Vit P	3	3	0.150	236	3	2004
Ahmad H	2	2	0.667	31	2	2021
Al-Hatamleh MAI	2	2	0.500	73	2	2020
Balestieri JBP	2	2	0.286	57	2	2017
Campos JF	2	2	0.286	57	2	2017
Carollo CA	2	2	0.286	57	2	2017
Dos Santos CM	2	2	0.286	57	2	2017
Dos Santos EL	2	2	0.286	57	2	2017

The most productive institutions worldwide in Table 4 show the Universiti Putra Malaysia in the top position with 7 publications, Instituto Tecnólogico de Mérida with 6, Universidad de Los Andes, School of Medical Science, Universiti Sains Malaysia, and Universidad Nacional de Misiones with 5, as the top five institutions.

Table 4. Number of documents on stingless bee medicinal research (2004–2023) ranking top ten most productive institutions worldwide

Ranking	NP[1]	Stingless bee medicinal research	
		Institution	Country
1	7	Universiti Putra Malaysia	Malaysia
2	6	Instituto Tecnólogico de Merida	Mexico
3	5	Universidad de Los Andes	Venezuela
4	5	School of Medical Science, Universiti Sains Malaysia	Malaysia
5	5	Universidad Nacional de Misiones	Argentina
6	5	Universiti Sains Malaysia	Malaysia
7	5	Universiti Sultan Zainal Abidin	Malaysia
8	3	Universiti Kebangsaan Malaysia	Malaysia
9	3	Universiti Teknologi Malaysia	Malaysia
10	3	Universidad Nacional Autónoma de México	Mexico

[1]NP number of publications

The top ten countries engaging with stingless bee medicinal research have 4 to 29 publications (Table 5) in the period (2004-2023), with Malaysia at the top (29), Brazil (19), Mexico (14), Australia and India (7), as the top five.

Table 5. Number of documents in the ten countries most productive on stingless bee medicinal research (2004–2023)

Ranking	NP[1]	Stingless bee medicinal research
		Country
1	29	Malaysia
2	19	Brazil
3	14	Mexico
4	7	Australia
5	7	India
6	6	Argentina
7	5	Venezuela
8	4	Indonesia
9	4	Kenya
10	4	United Kingdom

[1]NP number of publications

The most globally cited countries in the Bibliometrix plot (Fig. 3) were Brazil (480), Malaysia (403), Venezuela (236), Australia (195), India (113), Ethiopia (59), Mexico (51), Bulgaria (50), Argentina (47), and Indonesia (38).

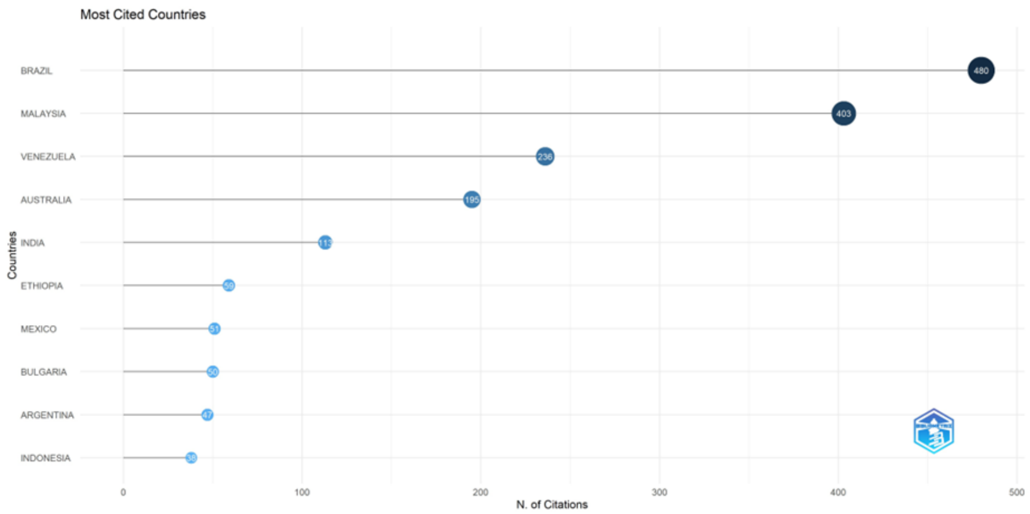


Fig. 3 Most cited countries of stingless bee medicinal research (2004–2023)
The bubble size is proportional to the number of documents, and the color intensity is proportional to the total citations per year.

In Table 6, the ranking of stingless bee medicinal research top ten sources selected by authors, hosted from 2 to 6 documents each. The most productive sources were the book *Pot-Honey. A legacy of Stingless Bees*, followed by the *Journal of Apicultural Research*, the book *Stingless Bee's Honey from Yucatan: Culture, Traditional Uses and Nutraceutical Potential*, *Journal of Ethnobiology, and Ethnomedicine*, and *Estudios de Cultura Maya*, as the top five sources. Journals h-index varied between 8 and 231, 2/8 journals are Quartile 1. The maximum impact score was 5.57 for the *International Journal of Molecular Sciences* ranked in the 10th position; note that alphabetical order is applied for the same number of publications. The metrics used for the journals are not available for the books in Resurchify, but the h-index was used as an impact factor in the following Bibliometrix plot (Fig. 4).

Table 6. Most productive sources hosting stingless bee medicinal research (2004–2023)

Ranking	NP[1]	Stingless bee medicinal research Sources (h-index, Quartile, impact score) Publisher, country[1]
1	6	Pot-Honey: A Legacy OF Stingless Bees Springer, New York, United States
2	5	Journal OF Apicultural Research (h 66, Q2, 2.08) Taylor and Francis Ltd., United Kingdom
3	4	Stingless Bee's Honey From Yucatan: Culture, Traditional Uses AND NutraceuticaL Potential
4	3	Journal OF Ethnobiology AND Ethnomedicine (h 84, Q1, 4.27) BioMed Central Ltd., UK
5	2	Estudios DE Cultura Maya (h 8, Q2, 0.20) UNAM, Instituto de Investigaciones Filologicas, Mexico
6	2	Ethnobiology AND Conservation (h 18, Q2, 1.54) Universidade Federal Rural de Pernambuco, Brazil
7	2	Food Research (h15, Q3, 1.03) Malaysia
8	2	Indian Journal OF Traditional Knowledge (h40, Q2, 0.92) National Institute of Science Communication and Information Resources (NISCAIR), India
9	2	Interciencia (h 39, Q3, 0.40) Interciencia Association, Venezuela
10	2	International Journal OF Molecular Sciences (h 230, Q1, 5.57) Multidisciplinary Digital Publishing Institute (MDPI), Switzerland

[1]NP number of publications
[2]https://www.resurchify.com

In the Bibliometrix plot, the local impact of medicinal stingless bee sources by h-index shows the highest impact (6) for the book *Pot-Honey. A Legacy of Stingless Bees* detached from the nine journal's impacts (2) of the dataset. Table 6 corresponds with the most relevant sources Bibliometrix plot, not shown here. Note that the top ten Scopus-ranked sources by number of publications in Table 6 differ from the Bibliometrix-ranked sources by h-index in Fig. 4.

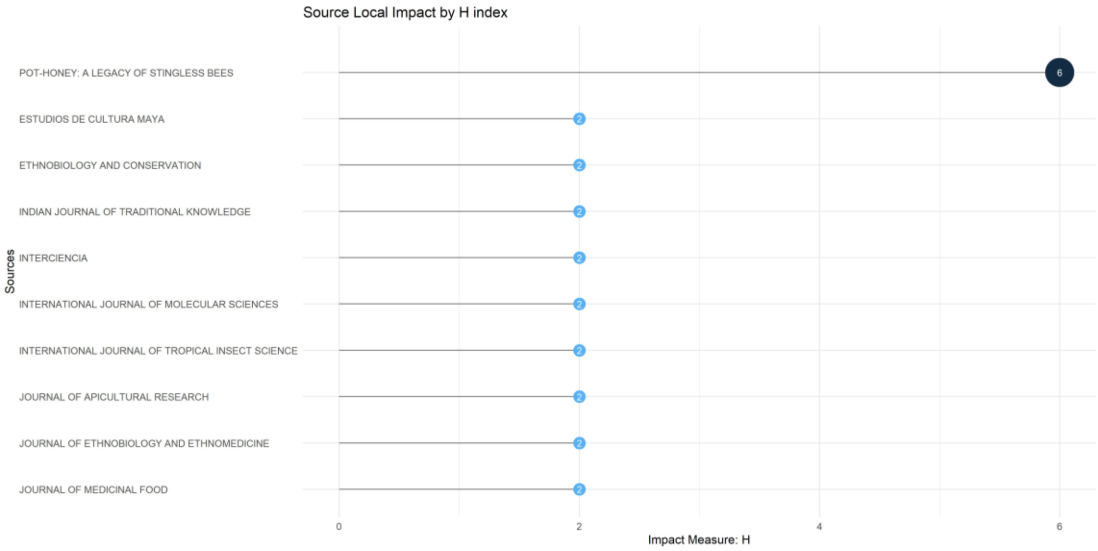


Fig. 4 Local impact of sources on stingless bee medicinal research (2004–2023)

Bibliometrix produced the most locally cited sources of top ten authors and number of articles Table 7. In this table, authors are considered sources. Local citations measure how many times an author (or a document) included in the dataset collection have been also cited by other authors in the dataset collection. Further Scopus search was done for each author to know the topic (stingless bee AND medicinal), total number of publication (NP), and total number of citations (NC). Six of these ten authors have zero topical publications, and therefore zero citation in this topic. The number of articles cited by other authors of the dataset (local collection) were lower than the topical citations in the Scopus database for Vit (89/234), Bankova (25/51), and Alves (19/21). Biluca had more citations from other authors in the dataset, than in the Scopus database (32/12), as well as other authors with zero topical citations.

Table 7. Most locally cited sources (2004–2023)

Sources	Document cited by another document of the dataset	NP[1] Scopus database (topical/total)	NC[2] Scopus database (topical/total)
Vit P	89	3/66	234/1 698
Biluca FC	32	1/26	12/741
Bogdanov S	26	0/43	0/5 518
Michener CD	26	0/86	0/1 975
Bankova V	25	1/204	51/12 276
Roubik DW	24	0/138	0/6 297
Crane E	20	0/34	0/326
Alves RRN	19	1/266	21/7 917
Kek S P	17	0/6	0/365
Cortopassi-Laurino M	16	0/4	0/250

[1]NP Number of publications
[2]NC Number of citations

In Table 8, the funding sponsors for the stingless bee medicinal research are from Argentina (1), Australia (1), Austria (1), Brazil (2), Bulgaria (1), El Salvador (1), Malaysia (3). Up to 8 projects received support from two Brazilian funding agencies, from two Malaysian Ministry (7) and University (4), and the National Council of Science and Technology from El Salvador (3), as the top five funding sponsors.

Table 8. Most supportive funding sponsors of research projects on stingless bee medicinal research (2004–2023)

Ranking	NP[1]	Stingless bee medicinal research	
		Funding sponsor	Country
1	8	Conselho Nacional de Desenvolvimento Científico e Tecnológico	Brazil
2	8	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior	Brazil
3	7	Ministry of Higher Education, Malaysia	Malaysia
4	4	Universiti Kebangsaan Malaysia	Malaysia
5	3	Consejo Nacional de Ciencia y Tecnología	El Salvador
6	3	Consejo Nacional de Investigaciones Científicas y Técnicas	Argentina
7	3	Universiti Sains Malaysia	Malaysia
8	1	Australia and New Zealand Banking Group Limited	Australia
9	1	Austrian Development Agency	Austria
10	1	Bulgarian Academy of Science	Bulgaria

[1]NP number of publications

The Scopus database covers 4 broad supergroup areas (health sciences, life sciences, physical sciences, and social sciences) categorized into 27 subject areas that are automatically scrutinized in the left side menu by number of publications, and plotted as percentages of documents of a pie chart in the analyzed results report. In Table 9, the top ten studied subject areas on stingless bee medicinal research (2004–2023) had the following top five: Agricultural and Biological Sciences (30.6%), Biochemistry, Genetics and Molecular Biology (10.9%), Medicine (10.4%), Environmental Science (7.8%), and Social Sciences (5.7%).

Table 9. Most studied subject areas on stingless bee medicinal research (2004–2023)

Ranking	NP[1]	%	Stingless bee medicinal research
			Subject area
1	59	30.6	Agricultural and Biological Sciences
2	21	10.9	Biochemistry, Genetics and Molecular Biology
3	20	10.4	Medicine
4	15	7.8	Environmental Science
5	11	5.7	Social Sciences
6	10	5.2	Chemistry
7	10	5.2	Pharmacology, Toxicology and Pharmaceutics
8	8	4.1	Chemical Engineering
9	5	2.6	Earth and Planetary Sciences
10	5	2.6	Engineering

2.1.2 Other visualizations of stingless bee medicinal publications using Bibliometrix

2.1.2.1 Author's keywords

Compared with a word cloud, the tree map is structured in fields with visualized descending order of frequent keywords, both representations use bright colors. The frequencies of author's keywords, and their percentages in the Fig. 5 tree map are visible: stingless bee (21, 11%), honey (17, 9%), stingless bees (17, 9%), propolis (14, 7%), meliponini (7, 4%), antioxidant (6, 3%), antioxidant activity (6, 3%), chemical composition (6, 3%). Meliponiculture (6, 3%), antibacterial (5, 3%), antimicrobial activity (5, 3%), stingless bee honey (5, 3%), natural products.

Fig. 5 Tree Map medicinal stingless bee research (2004–2023)

2.1.2.2 Country collaborative map

The collaboration between countries sharing publications on medicinal stingless bee research in the period 2004 to 2023 was visualized in Fig. 6 using red connectors in a worldwide map. The frequencies of collaboration between two countries are available in the corresponding Excel file. The highest collaborative frequency was between Brazil and Portugal with 3 documents, and for Jordan and Malaysia with two documents.

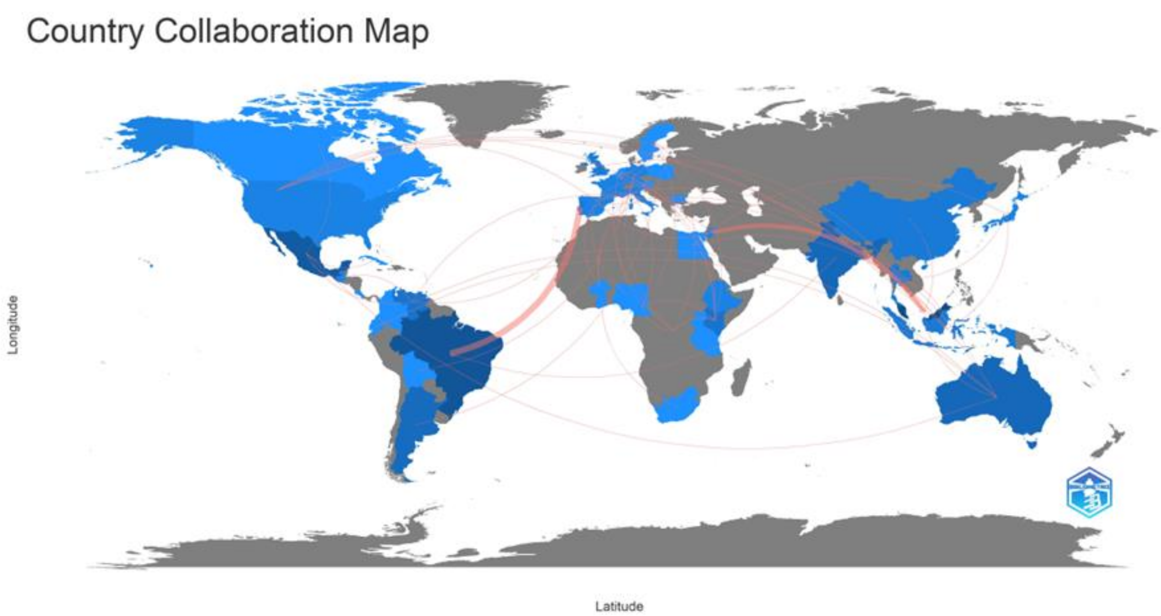


Fig. 6 Worldwide map with country collaboration for medicinal stingless bee research (2004–2023). Dark blue countries are more productive than light blue countries. Thicker collaboration red lines were visualized between Brazil and Portugal (3 or more shared documents), and between Jordan and Malaysia (2 documents). Thin lines connect many countries sharing one document. Connecting countries increase line thickness with most frequently shared publications

2.1.2.3 Most globally cited documents

The plot of most globally cited documents in Fig. 7, shows the top ten documents cited from 147 to 50 times in publications of medicinal stingless bees (2004–2023), silva iaai 2013 food chem (147 citations), vit p 2004 bee world (132), boorn kl 2010 j appl microbiol (110), oddo lp 2008 j med food (101), avila s 2018 trends food sci technol (89), zulkhairi amin fa 2018 adv pharmacol sci (82), choudhari mk evid-based complement altern med 2013 (74), al-hatamaleh mai 2020 biomolecules (64), popova m 2021 phytomedicine (50), and massaro cf 2011 naturwissenschaften (50). The journal types were on food (2), medicine (2), a combined medicinal food (1), bees (1), biomolecules (1), microbiology (1), natural science (1), and pharmacy (1). All these documents were distributed in two clusters of the conceptual structure by factorial analysis in the next plot (Fig. 8).

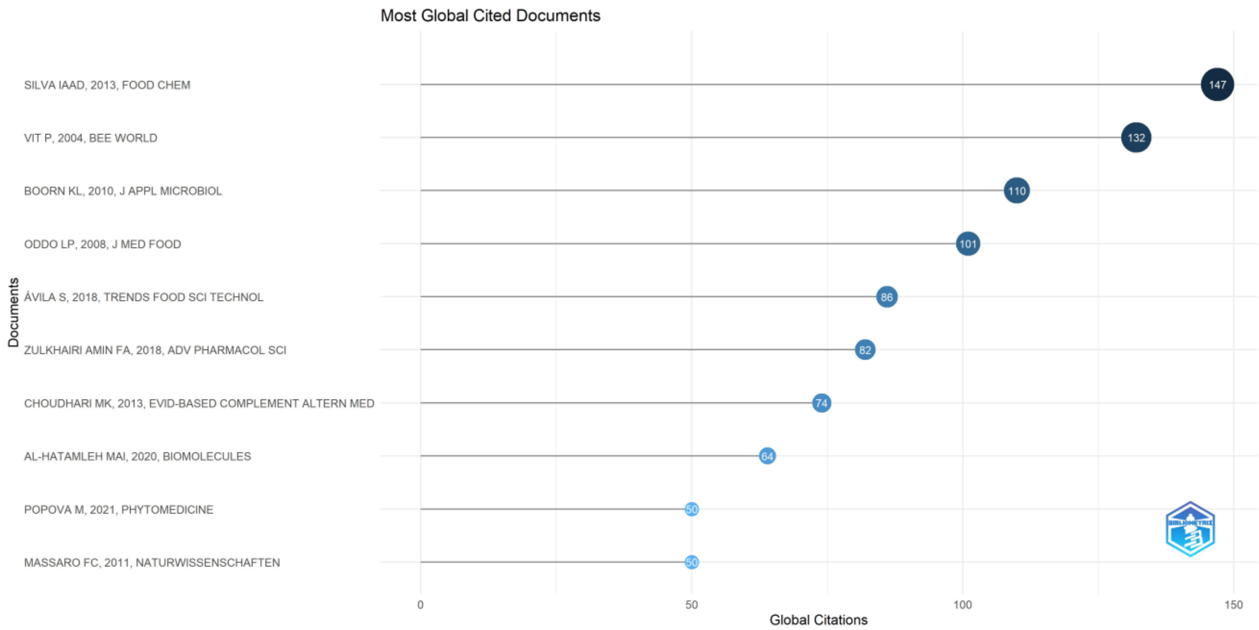


Fig. 7 Most globally cited documents of stingless bees medicinal research (2004–2023)

2.1.2.4 The conceptual structure for most cited articles

Concepts are embedded in a network of associations and contexts, having partial meaning based on links formed between them. Bibliometrix uses factorial analysis of correspondence analysis (CA) as a graphical method to compare variables. Scientific researchers use a conceptual framework to understand a problem and develop the analytical approach, a roadmap to conceptualize an outline that connects different ideas, concepts, and theories within a scientific field.

In this plot of research impact, the most cited medicinal stingless bee documents of the dataset (2004–2023) plotted in Fig. 7 generated two clusters like principal component analysis (PCA) in a CA factorial map Fig. 8, clustering bipartite network of terms extracted from closeness of keyword, title or abstract fields. Factorial analysis is a data reduction technique. CA is used to represent the rows and columns of a two-way dimensional space, with Dim 1 explaining 61.21% of the variations, and Dim 2 explaining 15.81%. A red cluster 1 for boorn kl 2010, choudhari mk 2013, zulkhairi amin fa 2018, andualem b 2013, and vit p 2004 was separated by the second dimension in the upper quadrants except vit p 2004. A blue cluster 2 for popova m 2021, silva iaad 2013, al-hatamleh mai 2020, oddo lp 2008, and massaro fc 2011. This cluster was separated by Dim 1 in the right quadrant except massaro fc 2011 located to the left, all of these documents were separated by Dim 2 in the lower quadrants.

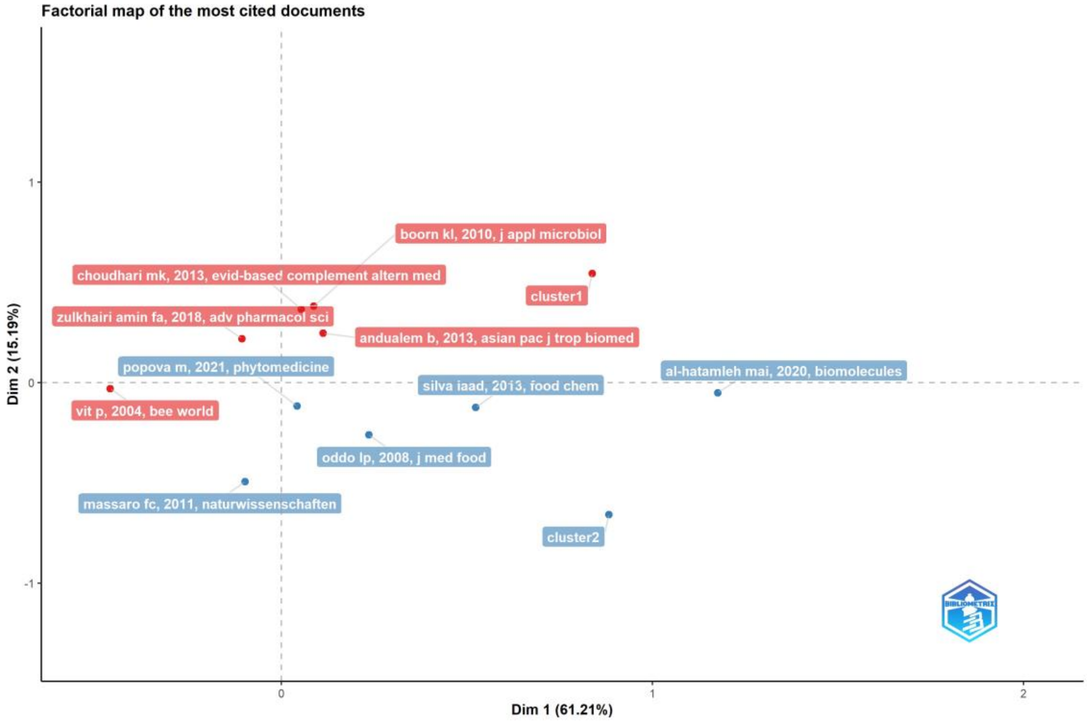


Fig. 8 Factorial map of the stingless bee medicinal documents with most cited articles (2004–2023)

2.1.2.5 Simple and multiple country publications

Publications based on two categories of corresponding author simple country publication (SCP) and multiple country publication (MCP), are represented with bars of two colors for 19 countries in Fig. 9 Bibliometrix plot. Argentina, India, China, Ethiopia, Brunei, Bulgaria, and Colombia publications of the dataset were intra-country SCP. Malaysia (24) and Brazil (19) published major number of documents with most SCP. Australia and Mexico also had more SCP than MCP, and Indonesia was balanced SCP-MCP in four documents. Kenya and Venezuela had more MCP than SCP in three documents. Austria, Bolivia, Japan, Jordan, and Nigeria had one document MCP, indicating compulsory multiple country interaction.

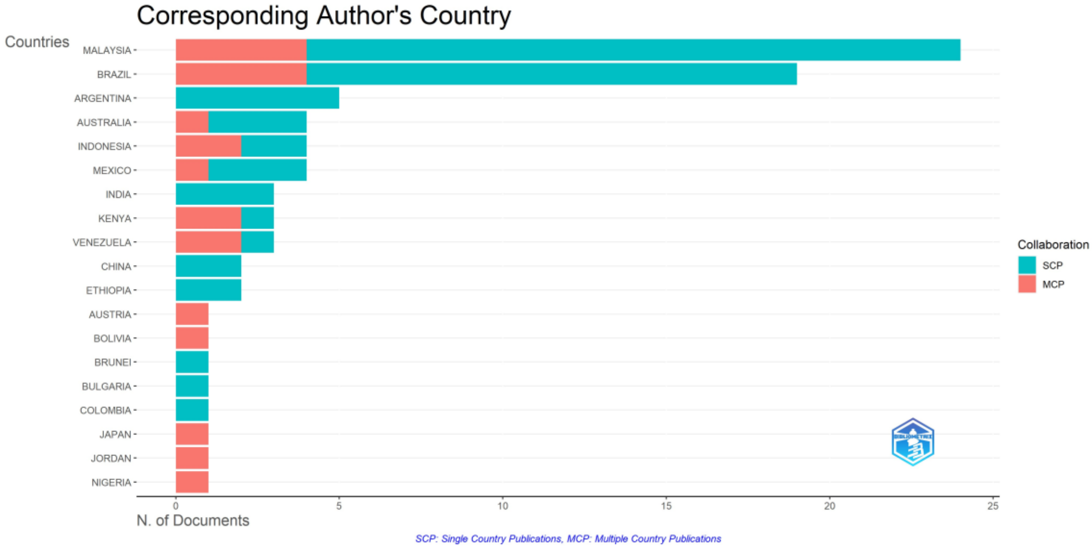


Fig. 9 Corresponding author's countries of stingless bee medicinal documents (2004–2023) Intra-country (single country publication SCP) and inter-country (multiple country publication MCP) corresponding author's collaborations.

According to a Bibliometrix, the most relevant top ten words of this dataset included plurals, stingless bee (21), honey (17), stingless bees (17), propolis (14), meliponini (7), antioxidant (6), antioxidant activity (6), chemical composition (6), meliponiculture (6), and antibacterial (5). These words retrieved from the medicinal stingless bee dataset are more related with the quality control because all medicinal studies rely in the chemical composition, and the standard antimicrobial, referred to as antibacterial—most frequently assessed compared to antifungal and antiviral—and antioxidant bioactivities.

2.2 METHODOLOGY AND RESULTS OF THE BIBLIOMETRIC REVIEW ON STINGLESS BEES IN CLIMATE CHANGE

A second bibliometric review focused for a search of stingless bees in climate change. After reviewing the retrieved documents, we found that three of them only used climate change in the abstract, in general sentences such as: "Ecosystem services provided by such communities may be more greatly affected by environmental changes (anthropogenic activities and climate change) than are services provided by communities with greater functional redundancy"; "Used in folk medicine as antiseptic, antioxidant and antimicrobial agent, the composition is due to bee species, climate changes, local flora, and soil type"; and "Basic ecological knowledge is essential to inform agricultural management policies and to foresee preventable food scarcity problems, especially in view of climate change scenarios that predict drastic alterations in plant geographical distributions". The dataset was retrieved with the Scopus database in the "TITLE-ABS-KEY" field query string the 1st December 2023. The operator AND was used for stingless bee AND climate change, with the operator AND NOT for guild, chayote and geopropolis, as follows.

TITLE-ABS-KEY (stingless bee AND climate change AND NOT guild AND NOT chayote AND NOT geopropolis)

The first and most cited document of stingless bees and climate change was by Batalha-Filho et al.[27], it was used to explain the Pleistocene estimated divergence time of *Melipona quadrifasciata* subspecies in Brazil, in a period of climatic and geomorphological changes in the Neotropics, causing subspecies distribution of *Melipona quadrifasciata quadrifasciata* to the south, and *Melipona quadrifasciata anthidioides* to the north. The second document was on the same species of stingless bee, a key pollinator of the Atlantic flora in Brazil, and approach to mitigate the effect of climate change in habitat fragmentation by identifying key conservation areas and strategies after a forecast to year 2080[28]. A projection of habitat suitability for *Melipona quadrifasciata* was forecasted in a study area of four Brazilian states São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul, from 2015 towards 2030-2050-2080 in Fig. 10, using a species distribution model based on abiotic and biotic factors to predict climate change scenarios[28].

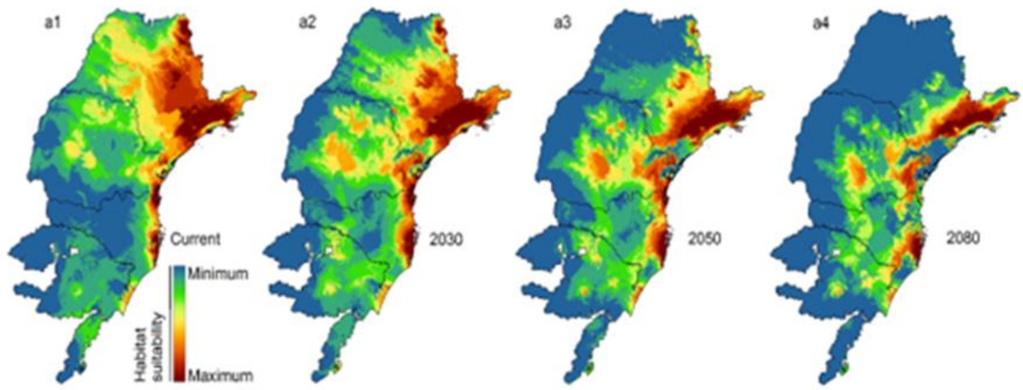


Fig. 10 Habitat suitability for the pollinator *Melipona quadrifasciata* in a study area of four Brazilian states São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul, Brazil from 2015 (a1) towards model predictions to forecast effects of climate change in 2030-2050-2080 (a2, a3, a4) with a visual contraction of northern and western distribution.

From: Giannini et al. [28]

The main information of bibliometric descriptors is presented in Figure **11.1** including publications from the first retrieved document since 2010 to date in 2023, almost two decades. The 25 documents of the dataset were published in English. Three documents were excluded with the AND NOT operator because although climate change was in the abstracts, the investigations were not about climate change.

A total of 19 sources were used to disseminate the research on stingless bees and climate change. The metrics and publishers of the most prolific journals were *Apidologie* (5 documents, *h*-index 96, Quartile 1, impact factor 2.41, Springer Science + Business Media, United States), PLoS ONE (2 documents, *h*-index 404, Quartile 1, impact factor 3.75, Public Library of Science, United States), and Regional Environmental Change (2 documents, *h*-

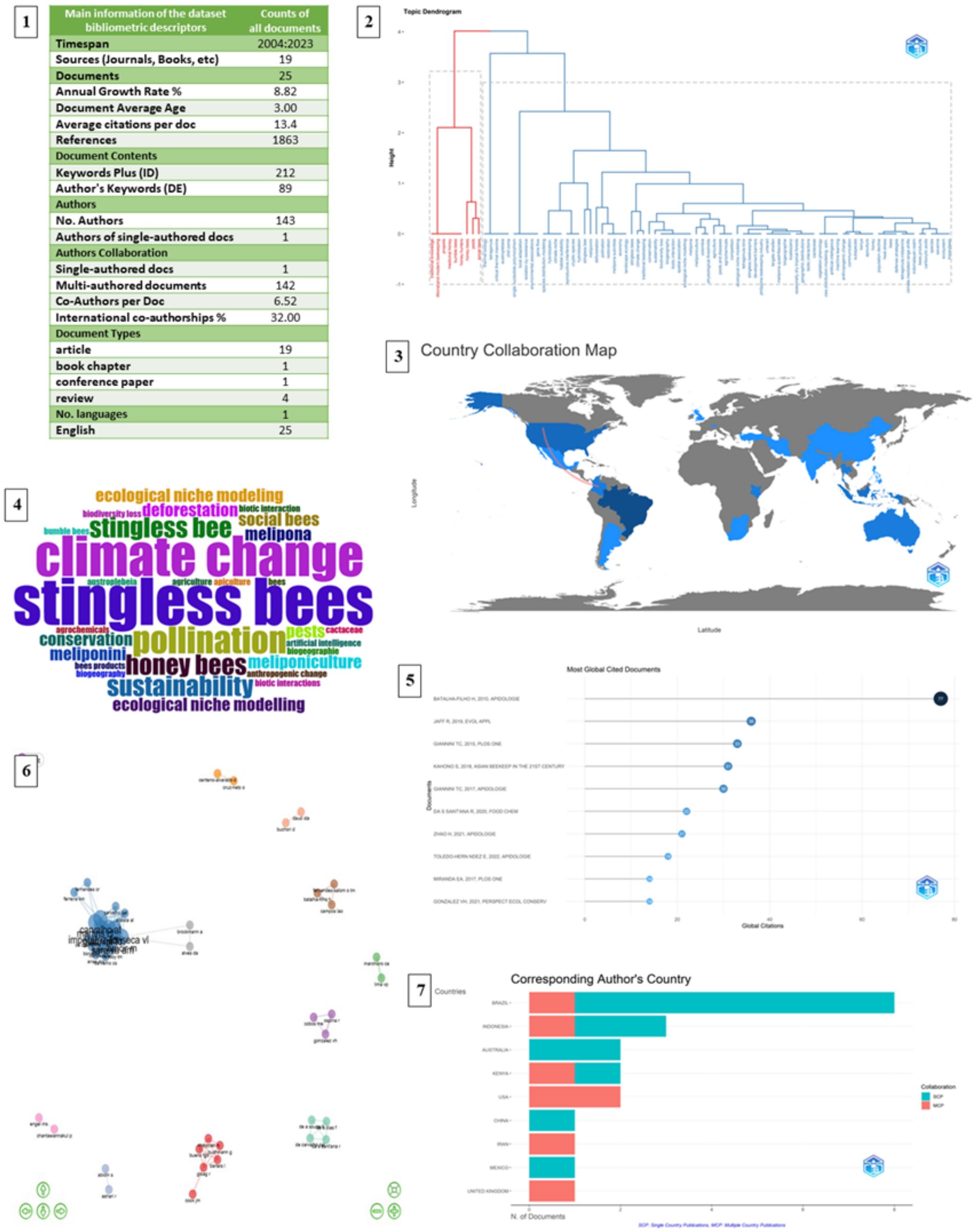
index 82, Quartile 2, impact factor 4.30, Springer Verlag, Germany).

The types of retrieved documents were 15 articles, one book chapter, one conference papers, and 4 reviews, all published in English. The first and most cited document was published by Batalha-Filho et al.[27] in the journal *Apidologie*. Leading countries were Brazil (12), United States (4), Indonesia (3); Australia, Colombia, Kenya, and Thailand with 3 documents each, and one document for Argentina, Botswana, and China. The top seven authors published three documents each, and two the last three authors. Universidade de São Paulo led with 5 publications, five institutions with three, and two publications for the last in the top ten list. The top five Scopus subject areas of research on stingless bees and climate change were Agricultural and Biological Sciences (44.4% of the documents), Environmental Sciences (19.4%), Biochemistry, Genetics and Molecular Biology (13.9%), Multidisciplinary (8.3%), Earth and Planetary Sciences (5.6%), followed by Chemistry (2.8%), Computer Science (2.8%), and Engineering (2.8%). Research for publications was sponsored by ten top agencies: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior CAPES (Brazil), Conselho Nacional de Desenvolvimento Científico e Tecnológico CNPq (Brazil), Australian Research Council (Australia), Fundacao de Amparo a Pesquisa do Estado de Sao Paulo FAPESP (Brazil), National Science Foundation (United States), University of Kansas (United States), Bayer CropScience (Germany), Biotechnology and Biological Sciences Research Council (United Kingdom), Department of Atomic Energy, Government of India (India), and Direktion fur Entwicklung und Zusammenarbeit (Switzerland).

Correlations and classifications of authors' keywords were investigated with multivariate graphical tools. Metrics of scientific literature and other Bibliometrix plots, such as topical dendrograms by Hierarchical Cluster Analysis (HCA), word clouds, country collaboration maps, most global cited documents, co-authors networks, and corresponding authors country publications were illustrated in Fig. 11.

The metrics for 25 documents in the scientific literature of stingless bees and climate change (2010:2023) cited 1863 references, showed an average citation per document of 13.4%, used 89 author's keywords, had an average author number of 6.52, and had 32.00% international coauthorship (Fig. 11.1). Two clusters were produced in the topical dendrogram by HCA after factorial analysis of author's keywords. The red cluster grouped traditional knowledge, traditional and recent beekeeping, propolis, medicinal honey, bumble bees, honey hunters, honey bees, pests, and social bees. The large blue cluster was visualized with two smaller clusters. The left blue cluster was mainly based on thermal biology, tetragonula, critical.therma.maxima, austroplebeia, chill.coma, from[30] and further branches with keywords from other papers; for example, single.nucleotide.polymorphism, local.adaptation, isolation.by.resistance; and environmental.associations, gene.flow, species.distribution.modelling, hybridization, climate.niche, habitat.suitability (Fig. 11.2). The country collaborative map showed red line interactions with at least two papers shared between Colombia and the United States (Fig. 11.3). A word cloud plot visualized higher frequencies of author's keywords with larger letters in central positions (Fig. 11.4), stingless bees (7) was the most frequent, then, climate change (6), pollination (4), honey bees (3), stingless bee (3), sustainability (3), conservation (2), deforestation (2), ecological niche modeling (2), meliponiculture (2), meliponini (2), pests (2), melipona (2), social bees (2), and one for the remaining 35 keywords of the plot, anthropogenic change, biodiversity loss and biotic interaction among others. The most global cited documents (Fig. 11.5) were ten documents cited from 77 times (batalha-filho 2010) to 14 (gonzalez 2021), in five different journals *Apidologie*, *Food Chemistry*, *Evol Appl*, *Perspect Ecol Conserv*, *PLoS ONE*, and one book chapter *Asian Beekeeping in the 21st Century*. Namely, Batalha-Filho H, 2010, Apidologie (77), Jaffe R, 2019, Evol Appl (36), Giannini TC, 2015, PLoS ONE (33), Kahono S, 2018, Asian Beekeep in the 21st Century (31), Giannini TC, 2017, Apidologie (30), Da S Sant'Ana R, 2020, Food Chem (22), Zhao H, 2021, Apidologie (21), Toledo-Hernandez E, 2022, Apidologie (18), Miranda EA, 2017, PLoS ONE (14), and Gonzalez VH, 2021, Perspect Ecol Conserv (14). Brazil, Australia, and the United States, were the three countries originating the documents of the top ten authors in the Scopus dataset, with Brazil ranking from 1 to 8.

The author's collaborative network consisted in 11 clusters of working groups (Fig. 11.6). Cluster 1 (red) gloag r, bartels l, buchmann g, bueno fgb, chapman n, cook jm from Australia and United States; Cluster 2 (blue) carvalho at, giannini tc, hrncir m, imperatriz-fonseca vl, jaff r, martins cf, saraiva am, acosta al, alves r, andrade scs, arias mc, bonatti v, carvalho cal, carvalho cs, contrera fal. de castro ms, fernandes cr, ferreira km, francoy tm, this is the largest cluster from Brazil; Cluster 3 (green) lima vp, marchioro ca; Cluster 4 (violet) gonzalez vh, ospina r, cobos me) from United States; Cluster 5 (orange) centeno-alvarado d, cruz-neto o; Cluster 6 (brown) batalha-filho h, campos lao, fernandes-salom o tm from Brazil; Cluster 7 (pink) chantawannakul p, engel ms from United States; Cluster 8 (grey) alves da, brockmann a); Cluster 9 (aquamarine) da s sant'ana r, de a souza b, de carvalho cal, de s dias; Cluster 10 (peach) buchori d, daud ida; and Cluster 11 (pale blue) abidin s, ashari r. In Fig. 11.7, corresponding authors are represented with turquoise bars for simple (SCP) and orange bars for multiple (MCP) country publications for nine countries. Australia, China, and Mexico publications of the dataset were intra-country SCP. Brazil (7) and Indonesia (2) published most documents with SCP. Kenya was balanced SCP-MCP in two documents. United States, Iran, and the United Kingdom produced MCP.



Main information of the dataset bibliometric descriptors	Counts of all documents
Timespan	2004:2023
Sources (Journals, Books, etc)	19
Documents	25
Annual Growth Rate %	8.82
Document Average Age	3.00
Average citations per doc	13.4
References	1863
Document Contents	
Keywords Plus (ID)	212
Author's Keywords (DE)	89
Authors	
No. Authors	143
Authors of single-authored docs	1
Authors Collaboration	
Single-authored docs	1
Multi-authored documents	142
Co-Authors per Doc	6.52
International co-authorships %	32.00
Document Types	
article	19
book chapter	1
conference paper	1
review	4
No. languages	1
English	25

Fig. 11 Metrics and plots from the dataset of stingless bees and climate change (2010–2023) visualized with Bibliometrix.

1. Main metric information, **2**. Dendrogram of author's keywords by HCA. The red cluster grouped nine words on traditional and recent bee keeping, medicinal honey, pests, honey bees. The blue cluster grouped more words including all those related with climate change, **3**. Word cloud of author's keywords with larger stingless bees, climate change and pollination positioned in the center, **4**. Country collaboration map showing interactive red lines between countries with two shared documents between Colombia and the United States, **5**. The most globally cited documents published between 2010 and 2023. **6**. Networks of co-authors, and **7**. Corresponding authors simple (SCP) and multiple (MCP) country publication.

To continue with stingless bees and climate change, information here is an excerpt from the dissertation by Halcroft.[29] It could be expected that an overall increase in ambient temperatures may see an extension of the southern distribution of *Austroplebeia australis*. Under these conditions, the temperature threshold for 'sub-optimal foraging' activity (≥ 20°C) is reached earlier in the day, resulting in increased foraging opportunities (Fig. 12). The 'optimal foraging' activity (≥ 26°C) is also achieved earlier in the day, thus increasing opportunities to forage at optimal levels. In spring, a period when a greater variety and abundance of floral resources are likely to be available, temperatures are predicted to shift from 'sub-optimal' (i.e., 20 – 25°C) to 'optimal foraging' conditions. It is also predicted that there will be a 10% reduction in spring rain in southern QLD and northern NSW, thus increasing opportunities for foraging.

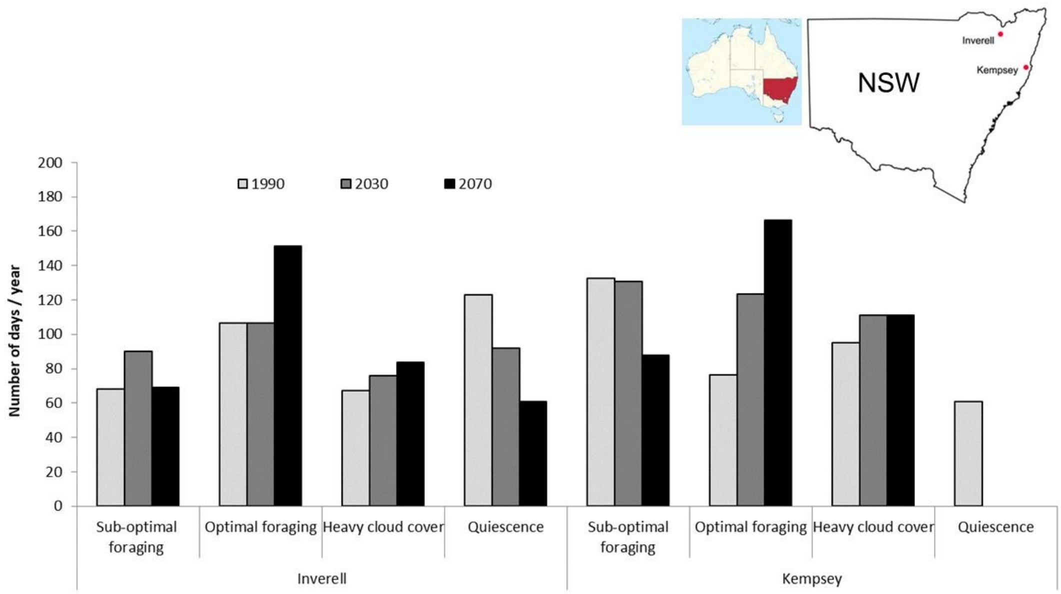


Fig. 12 Predicted changes in *Austroplebeia australis* foraging opportunities, between 1990, 2030, and 2070, as a result of climate change in Inverell and Kempsey, NSW, Australia.
Sub-optimal foraging = days where ambient temperature ≥ 20°C but < 26°C, with < 6 oktas of cloud in the sky; Optimal foraging = days where ambient temperature ≥ 26°C, with < 6 oktas of cloud in the sky; Heavy cloud cover = days where ambient temperature ≥20°C, with ≥ 6 oktas of cloud in the sky resulting in foragers being unable to leave the nest; Quiescence = days where ambient temperature < 20°C, thus reducing the colony's metabolism. Predicted temperature increases were based on 50th percentile and medium emissions [CSIRO, Commonwealth Scientific and Industrial Research Organisation. (2007). Climate change in Australia. http://www.climatechangeinaustralia.com.au/index.php]. Cloud cover data were based on averages for over 38 years [BOM, Bureau of Meteorology. (2012). Climate data online. http://www.bom.gov.au/climate/data/index.shtml.

Under this scenario, if floral resources are within proximity, colonies will be able to increase their food storage during this time. Utilization of increasing stored resources will result in an overall increase in colony populations. Brood production will increase, as periods of quiescence and inactivity decrease, and ontogenic times shorten with improved brood incubation, driven by increased ambient temperatures. All of these factors would be expected to result in more frequent nest crowding and increasing incidence of reproductive swarming. Increasing temperatures may see a gradual broadening of the southern distribution of this species, and probably others.

The scenario described above appears to be true for populations near Kempsey, the most southerly coastal location for *Austroplebeia australis* in NSW. This region will experience a 13% increase in 'optimal foraging' conditions by 2030 and this will continue to increase to 25% by 2070 (Fig. 1). While the climate predictions appear to positively impact colonies of *Austroplebeia australis* at Kempsey, the reverse is likely to be true for colonies located in NSW inland areas such as Inverell, the most southerly inland location for *Austroplebeia australis*. Conditions predicted for Inverell in 2030 will result in a 6% increase in 'sub-optimal foraging' opportunities, where food consumption exceeds incoming food, but with no concurrent increase in 'optimal foraging' conditions. This situation is further compounded by a 2% increase in conditions where foragers cannot leave the nest due to 'heavy cloud cover', resulting in more times when food consumption exceeds incoming food.

Together with an 8% decrease in periods of 'quiescence', annual food requirements of colonies will increase, and may not be met under the predicted conditions of decreased foraging. As a result, colonies may fail to thrive, leading to starvation and shrinkage of distribution in this region.

Ten years later, further Australian stingless bee research was related to climate change examined critical thermal maxima (CTmax) temperature to understand thermal tolerance for predicting resilience to extreme heat events of climate change. *Austroplebeia australis* had the highest CTmax of 44.5°C, while the CTmax of *Tetragonula carbonaria* and *Tetragonula hogkingsi* was ~43.1°C. After a 1-h heat exposure, *T. carbonaria* foragers mortality rate was 95% at 42°C, and 100% at 45°C; their larvae and pupae were more resistant to heat exposure than foragers[30]. These authors suggest nest site insulation and habitat preservation to manage colony survival under repeated heating events of climate change.

3. Scanning medicinal stingless bee resources, research, and efforts for wellness

3.1 SIGNIFICANCE OF THE ENTOMOLOGICAL BIODIVERSITY OF STINGLESS BEES IN APITHERAPY

3.1.1 Richness of stingless bees in Brazil as resources for meliponiculture

The conservation of stingless bee biodiversity is of paramount importance for this natural resource with medicinal traditional uses. Brazil has a great wealth of stingless bees, which makes this country stand out from the rest of the Neotropical region, since the last survey carried out by Nogueira,[31] counted a total of 259 species, distributed in the five regions of this country (Fig. 13), the Amazon region with 197 of these species, 128 of which occur in the Amazonas state. Although there are many species in Brazil, the most familiar for management are used for honey production, the vast majority belonging to the genus *Melipona* Illiger, 1806, as *M. seminigra* Friese, 1903, *M. interrupta* Latreille, 1811, *M. flavolineata* Friese, 1900, *M. subnitida* Ducke, 1910, *M. scutellaris* Latreille, 1811 and *M. quadrifasciata* Lepeletier, 1836. Species from other genera that also deserve to be highlighted in terms of productivity for Brazil are *Tetragonisca angustula* (Latreille, 1811), *Tetragona clavipes* (Fabricius, 1804), and species of *Scaptotrigona* Moure, 1942.

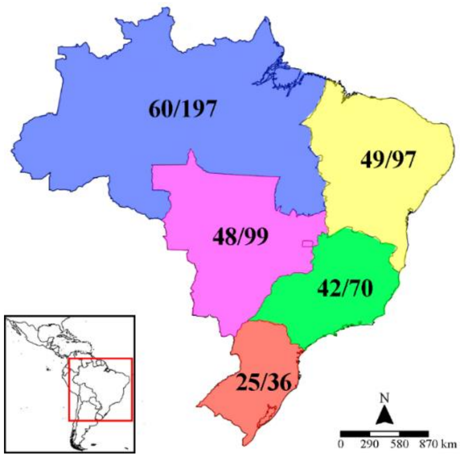


Fig. 13 Proportion of Brazilian stingless bees managed for meliponiculture [1], related to total stingless bee species richness per region in Brazil [31]. **1.** North 60/197 (blue), **2.** Northeast 49/97 (yellow), **3.** Central-West 48/99 (pink), **4.** Southeast 42/70 (green), and **5.** South 25/36 (red). Map: ©DS Nogueira.

In a proportion of 95 managed stingless bees[1] over the total of 259 species of stingless bees in Brazil[31], around half of these species are used for meliponiculture in the Northeast and Central-West regions, and a little more than half in the Southeast and South regions. On the contrary, the richest North region uses a third of these resources, with the remaining 137 species of stingless bees unexploited or not selected for meliponiculture, or which do not have data about nesting.

3.1.2 Managed stingless bee species in Brazil

Good practices of sustainable stingless bee keeping do not represent a risk for the stingless bee biodiversity conservation, on the contrary, more colonies are kept, and divided to increase productivity. However, feral nest hunting is a common practice in rural areas; moving colonies from their natural substrates to stingless bee hives. On the other hand, pot-honey hunting is more destructive, its intensity may affect the natural populations of stingless bees, but is the traditional method especially for non-domesticated underground species. For example, developing conventional stingless bee farming is an opportunity to increase availability of pot-honey in demand for ethnomedicinal use in Baringo County, Kenya. Some Brazilian stingless bee species used in meliponiculture are illustrated with the images and size of the Brazilian Association of Bee Studies[33] in Fig. 14.

			
Cephalotrigona capitata	*Frieseomelitta varia*	*Leurotrigona muelleri*	*Melipona quadrifasciata*
9.5 mm	5.5 mm	3.0 mm	10.0 mm
			
Melipona scutellaris	*Melipona seminigra*	*Nannotrigona testaceicornis*	*Paratrigona lineata*
10.5 mm	10.5 mm	4.0 mm	4.5 mm
			
Plebeia droryana	*Scaptotrigona polysticta*	*Tetragona clavipes*	*Tetragonisca angustula*
3.5 mm	6.0 mm	6.5 mm	4.0 mm

Fig. 14 Images and size of some Brazilian stingless bee species used in meliponiculture
https://abelha.org.br/fichas-catalograficas-das-especies-relevantes-para-a-meliponicultura-2/

The Brazilian Ministry of Environment has documented the stingless bee species used for meliponiculture in each state for conservation of biodiversity, listed in Table 10[1]. Brazil has 26 states distributed in the 5 regions of the map (Fig. 13).

Table 10. Stingless bee species with initiatives of management in diverse Brazilian states

No.	Stingless bee species	Brazilian states[1]
1	*Trigonisca pediculana*	CE, MA, PB, PA, BA, PI, AM, RO, RR, PE, MG
2	*Trigonisca duckei*	AM, PA, CE, MA, MT, RR
3	*Trigona pallens*	AC, AM, AP, PA, RO, RR, TO, MA, GO, CE, DF, MT, PI
4	*Trigona cilipes*	AC, AM, AP, PA, RO, MT, RR, MA, GO
5	*Tetragonisca weyrauchi*	AC, RO, MT
6	*Tetragonisca fiebrigi*	MS, RS, SP, PR, SC, MT
7	*Tetragonisca angustula*	AM, AP, PA, RR, BA, CE, MA, PB, PE, GO, MS, MT, ES, MG, RJ, SP, PR, RS, SC, TO, DF, AC, PI, RO
8	*Tetragona quadrangula*	GO, MA, MG, MT, PA, TO, MS
9	*Tetragona kaieteurensis*	AM, PA, RR
10	*Tetragona goettei*	AC, AM, PA, MT, RO, MA, RR
11	*Tetragona essequiboensis*	AM, RO
12	*Tetragona clavipes* (syn. *T. elongata*)	AC, AM, RO, AP, RR, PA, MA, PI, MT, TO, BA, GO, DF, MG, MS, ES, RJ, SP, PR, SC, RS
13	*Schwarziana quadripunctata*	BA, GO, ES, MG, RJ, SP, PR, RS, SC, DF
14	*Scaura longula*	AM, AP, PA, MA, GO, MT, MG, SP, AC, BA, MS, RO, RR
15	*Scaura latitarsis* (syn. *Scaura tenuis*)	AC, AM, MT, PA, RO, RR
16	*Scaptotrigona xanthotricha*	BA, ES, MG, SP, SC, PR, RJ
17	*Scaptotrigona tubiba*	SP, MG
18	*Scaptotrigona tricolorata*	RO, MT, AM
19	*Scaptotrigona postica*	PA
20	*Scaptotrigona polysticta*	AC, PA, RO, TO, MA, GO, MT, MG, SP, AM, DF, PI
21	*Scaptotrigona depilis*	MS, MG, SP, RS, GO, DF, SC, PR
22	*Scaptotrigona bipunctata*	MG, PR, RS, SC, SP, RJ
23	*Plebeia wittmanni*	RS
24	*Plebeia saiqui*	MG, RJ, SP, PR, RS, SC
25	*Plebeia remota*	ES, MG, SP, PR, RS, SC
26	*Plebeia poecilochroa*	BA, ES
27	*Plebeia nigriceps*	SP, PR, RS, SC
28	*Plebeia mosquito*	MG, RJ, BA, SP
29	*Plebeia minima*	AC, AM, AP, MT, PA, MA, GO, RO, RR, DF, TO
30	*Plebeia lucii*	ES, MG
31	*Plebeia julianii*	PR, SC
32	*Plebeia flavocincta*	AL, BA, PB, PE, PI, SE, CE, RN, MG
33	*Plebeia emerina*	SP, PR, RS, SC
34	*Plebeia droryana*	BA, ES, MG, SP, PR, SC, RJ, RS, DF, MS
35	*Plebeia alvarengai*	AM, PA, RO, MT, TO, MA
36	*Partamona seridoensis*	CE, MA, PB, PE, RN, PI, TO
37	*Partamona cupira*	DF, GO, MS, MG, SP, TO
38	*Paratrigona subnuda*	BA, MG, RJ, SP, PR, RS, SC, ES
39	*Paratrigona peltata*	PA, MA
40	*Paratrigona lineata*	PA, BA, CE, MA, PB, PI, GO, MT, MG, SP, DF, MS, PE, RO, RJ, TO, PR
41	*Nannotrigona testaceicornis*	BA, GO, MS, ES, MG, RJ, SP, PR, RS, SC, DF, MT, TO
42	*Nannotrigona punctata*	AP, PA
43	*Nannotrigona melanocera*	AC, AM, RO
44	*Nannotrigona chapadana*	GO, MT, AC, RO, MS
45	*Melipona tumupasae*	AC
46	*Melipona torrida* (syn. *Melipona obscurior*)	SP, PR, RS, SC, MS, MT

No.	Stingless bee species	Brazilian states[1]
47	*Melipona subnitida*	AL, BA, CE, PB, PE, PI, RN, MA, SE
48	*Melipona seminigra*	AC, AM, PA, RO, RR, TO, MA, MT
49	*Melipona scutellaris*	AL, BA, PB, PE, RN, SE, CE
50	*Melipona rufiventris*	GO, MG, SP, BA, DF, MS
51	*Melipona quinquefasciata*	CE, DF, GO, MS, MT, ES, MG, RJ, SP, PR, SC, BA, PE, PI, RS, TO
52	*Melipona quadrifasciata*	AL, BA, PB, PE, SE, GO, MS, ES, MG, RJ, SP, PR, RS, SC
53	*Melipona puncticollis*	AM, PA, MA
54	*Melipona paraensis*	AM, AP, PA, RR
55	*Melipona orbignyi*	MS, MT, TO
56	*Melipona ogilviei*	AM, PA, AP, TO
57	*Melipona nebulosa*	AC, AM, PA, MT
58	*Melipona mondury*	BA, ES, MG, RJ, SP, PR, SC
59	*Melipona melanoventer*	AC, AM, PA, RO, MA, MT
60	*Melipona marginata*	BA, GO, ES, MG, RJ, SP, AL, PR, RS, SC
61	*Melipona mandacaia*	AL, BA, CE, PE, PI, SE
62	*Melipona lateralis*	AM, AP, PA, RR
63	*Melipona interrupta*	AM, AP, PA, MA
64	*Melipona illustris*	AM, RO, MT, AC, AP, MS, PA, RR
65	*Melipona grandis*	AC, AM, RO, MT
66	*Melipona fuscopilosa*	AC, AM, PA, MT
67	*Melipona fulva*	AM, AP, PA, RR
68	*Melipona fuliginosa*	AC, AM, AP, PA, RO, RR, BA, MA, PI, GO, MT, MG, SP, ES, MS
69	*Melipona flavolineata*	PA, TO, MA, AM, PI, CE
70	*Melipona favosa*	RR
71	*Melipona fasciculata*	PA, TO, MA, MT, PI, AM, AP, GO
72	*Melipona eburnea*	AC, AM
73	*Melipona dubia*	RO, AC, AM, PA
74	*Melipona crinita*	AC, AM, RO
75	*Melipona cramptoni*	RR
76	*Melipona compressipes*	AM, AP, RR, AC, MA, MT, PA, TO
77	*Melipona captiosa*	AM, AP
78	*Melipona capixaba*	ES
79	*Melipona bicolor*	ES, MG, RJ, SP, PR, RS, SC, BA
80	*Melipona asilvai*	BA, CE, PB, PI, RN, MG, PE, SE, AL
81	*Melipona amazonica*	AC, AM, PA, RO, MA, MT
82	*Leurotrigona muelleri*	RO, TO, BA, MA, PB, GO, MS, MT, MG, SP, SC, AL, PA, DF, ES, PR, RJ, PE
83	*Geotrigona mombuca*	PA, TO, BA, MA, PI, GO, MS, MT, MG, SP, DF, PR
84	*Geotrigona fulvohirta*	AC, AM
85	*Frieseomelitta varia*	TO, GO, MT, MG, SP. BA, PA, DF, PB, PE
86	*Frieseomelitta silvestrii*	RO, MT, PA, MA, PI, CE, BA, GO
87	*Frieseomelitta meadewaldoi*	BA, PB, ES, SE, PE, CE, RN
88	*Frieseomelitta longipes*	PA, AM, MA, TO, MT, RR
89	*Frieseomelitta languida*	BA, GO, MG, SP, DF
90	*Frieseomelitta flavicornis*	AM, AP, PA, MT, RO, GO, RR
91	*Frieseomelitta doederleini*	BA, CE, MA, PB, PE, PI, RN, MG, DF, TO, PA

No.	Stingless bee species	Brazilian states[1]
92	*Friesella schrottkyi*	ES, MG, SP, PR
93	*Duckeola ghilianii*	AM, AP, PA, MT, RO
94	*Cephalotrigona femorata*	AM, PA, RO, MA, AC, AP, MT, TO
95	*Cephalotrigona capitata*	AP, PA, CE, MT, ES, MG, SP, PR, SC, BA, RJ, MS, AL, GO, RO

[1]**North region**: Acre (AC), Amazonas (AM), Amapá (AP), Pará (PA), Rondônia (RO), Roraima (RR) and Tocantins (TO). **Midwest region**: Distrito Federal (DF), Goiás (GO), Mato Grosso (MT) and Mato Grosso do Sul (MS). **Southeast region**: Espírito Santo (ES), Minas Gerais (MG), Rio de Janeiro (RJ) and São Paulo (SP). **Northeast region**: Alagoas (AL), Bahia (BA), Ceará (CE), Maranhão (MA), Paraíba (PB), Pernambuco (PE), Piauí (PI), Rio Grande do Norte (RN) and Sergipe (SE). **South region**: Paraná (PR), Santa Catarina (SC) and Rio Grande do Sul (RS).

Source: BRASIL[1]

Some stingless bee species like *Scaptotrigona postica* (PA), *Plebeia wittmanni* (RS), *Melipona tumupasae* (AC), *Melipona favosa* (RR), *Melipona cramptoni* (RR), and *Melipona capixaba* (ES) were managed only in one state, in contrast with *Tetragonisca angustula* and *Tetragona clavipes* widely selected for meliponiculture in 24 and 21 of the 26 Brazilian states respectively.

This list of managed stingless bees was a document proposed based on the process of assessing the risk of extinction of Brazilian fauna species[1]. It was prepared through long discussions and by expert teams, and although there is no consensus on some taxonomic identifications and occurrence records, see the occurrence of the same species in Nogueira[31], it shows promise in trying to organize the biodiversity to prevent the illegal transport of species outside the political boundaries of their occurrence, as is the case in states (Table 15). The illegal transport of nests to places where they do not naturally occur can cause a series of problems such as the transmission of diseases, increased competition for resources with native species, and genetic modification of wild and managed populations, which can compromise the permanence and maintenance of both native species of this new location, as well as species that came from a different location[34] In the long term, these environmental imbalances may harm both bee biodiversity and local stingless beekeepers, as species extinction may occur, especially when there is hybridization between species due to the disturbance of ecological barriers promoted by human action[35,36]. The dangers of interbreeding are well-known threats to wildlife[37], both for bees and extinction of rare plant species[36].

Direct and online interviews were focused on bees and beekeepers of 25 Indonesian provinces with traditional stingless bee keeping in and cultural practices. Data of 272 beekeepers revealed 19 species of stingless bees are reared, mostly *Tetragonula laeviceps*, and climate change was one of the obstacles besides pesticides, demanding a strategy for stingless bee keeping and bee conservation to adapt and mitigate environmental changes on climate and land-use[38].

3.2 FLORAL AND EXTRAFLORAL NECTAR, FLORAL POLLEN, RESIN, GUM AND LATEX PLANT NATURAL RESOURCES

Tropical stingless bees nest, feed and interact with tropical plants. Tropical bee flora is represented by biodiverse Fabaceae, Asteraceae, Rubiaceae, Malvaceae, Lamiaceae, Euphorbiaceae, Arecaceae, Poaceae, Apocynaceae, and Melastomataceae as the most visited of 221 plant families[39]. Stingless bee preferences of available tropical resources, pollen create enormous combinations of pot-honey, pot-pollen, cerumen and propolis variables, explained by natural history[40] and investigated as a healing matrix. For example, secondary metabolites like flavonoids originate from the foraged plants, and having luteolin derivatives as active phytochemicals in ocular cataract models[41] have a significance for the nature of the stingless bee material, the biomolecular richness, the relationship with the environmental resources, and its biodiverse conservation.

Standard terminology for palynology is used for morphological descriptions of pollen grains[42] and the major pollen grains in the pollen spectrum[43]. Pollen identifications at plant family, genus and even species, are assigned after comparisons with pollen atlases and pollen reference collections. The taxonomic status of botanical taxa is systematically updated by consulting Tropicos Missouri Botanical

Garden database available online[44]. Extrafloral nectar causes poor pollen spectra of honey because it contains less pollen than floral nectar.

Plant resins sometimes comprise gums, latex and resin exudates from different parts of plants: bark like *Dalbergia ecastaphyllum* Fabaceae, and *Schinus terebinthifolia* Anacardiaceae; buds like *Populus* spp. Salicaceae; flowers like *Clusia major* and *Clusia minor*, Clusiaceae, and *Dalechampia* spp. Euphorbiaceae; fruits like *Corymbia torelliana* Myrtaceae, and *Coussapoa asperifolia* Cecropiaceae; and whole plant like *Artocarpus heterophyllus* Moraceae, *Merremia umbellate* Convolvulaceae. Anacardiaceae and Fabaceae are two plant resin source families for stingless bees in Brazil, China, Colombia, and India; Euphorbiaceae is common in Brazil, Colombia, and India; and Clusiaceae is a Neotropical source in Brazil, Colombia, and Venezuela[45].

Plant resins use has an evolutionary meaning of sociality in stingless bees[46]. Diverse plant resin-based functions such as social immunity, cuticular hydrocarbon chemical profiles, defense, and microbial communities are associated with stingless bees[40,46]. Cerumen is a vital material in stingless bee nest architecture, composed by admixtures of beeswax and plant resins. For this reason, stingless bee foragers prioritize resin collection and reduce pollen foraging after hive splitting, as observed for the Australian *Tetragonula carbonaria*[47].

In Fig. 14, acetolyzed pollen grains used to identify the *Coffea arabica* unifloral *Tetragonisca angustula* honey from Costa Rica are illustrated[48]. Taxa were identified as nectariferous sources, and polleniferous, considered contaminants of honey because they do not secrete nectar, the raw material transformed into honey.

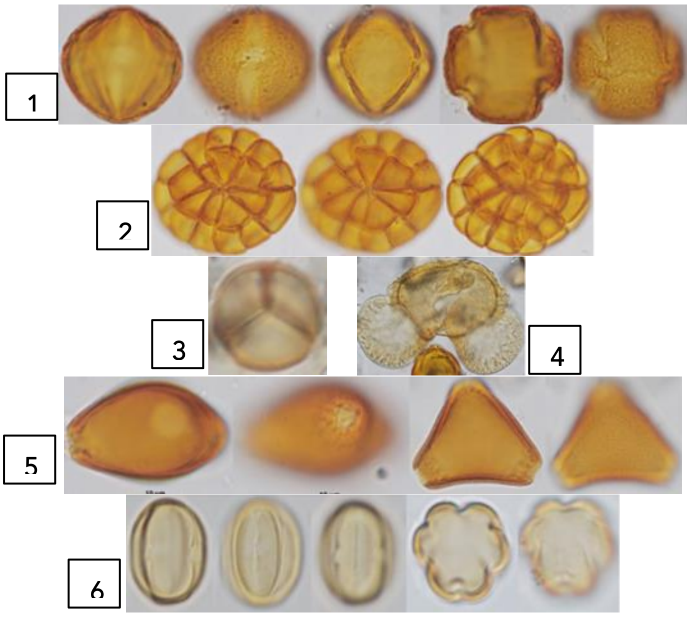


Fig. 14 Pollen grains of a unifloral pot-honey with nectariferous and polleniferous taxa.Nectariferous 1. *Coffea arabica*, Rubiaceae produces nectar. A frequency of 54.3% of the pollen spectrum featured this as unifloral coffee honey [48]. Polleniferous 2. Polyads of *Inga* sp. Fabaceae-Caesalpinioideae, 3. *Mimosa* sp., Fabaceae–Caesalpinioideae, and single grains or monads of 4. *Pinus* sp. Pinaceae, 5. *Paullinia* sp. Sapindaceae, and 6. *Miconia* sp. Melastomataceae. Pollen from nectarless plants is considered contaminant pollen in melissopalynology. Photos: ©E. Moreno *After*: Moreno et al.[48]

A unifloral honey has 45% pollen of one taxa, with exceptions for over-represented and under-represented pollen types[49]. Floral pollen, *Apis mellifera* bee-bread and stingless bee pot-pollen are obviously pollen grains. A recent controversy has raised for a traditional palynological analysis of propolis, the pollen landed on plant resins, latex or gums, collected and processed into propolis or bee glue. Layek et al.[50] found that the pollen spectra of *Tetragonula iridipennis* from India are not accurate to identify the plant resin or latex sources of cerumen and propolis, because this nest material is not seasonal like floral nectar and floral pollen when in bloom.

3.3 DEMONSTRATED BIOMOLECULES, BIOLOGICAL ACTIVITIES, AND PUTATIVE THERAPEUTIC PROPERTIES OF POT-HONEY, POT-POLLEN, CERUMEN AND PROPOLIS OF THE STINGLESS BEE NEST

Table 11 presents a screening of scientific literature for the most studied bioactive molecules —

flavonoids and polyphenols— and biological activities —antimicrobial and antioxidant— added values to the medicinal uses of stingless bee products, expanding with the putative therapeutic actions that would deserve more bioassays and clinical trials to support apitherapy. The stingless bee species were carefully retrieved for each study. It is recommended to inform the species in the abstracts. The corresponding entomological authority, institution, and collection where the entomological specimens are deposited, is mandatory in the materials and methods. Continuous updating of names arises with research, and this fact also deserves the attention of melittologists. Valid names should be informed as suggested by M. Engel (P. Vit, personal communication). For example, *Axestotrigona ferruginea* (cited as *Meliponula ferruginea* by Popova et al.[51]

It is not our aim to provide ranges of concentrations and IC_{50} for this table, but to summarize the chronological input for studies on biomolecules and biological activities, projecting therapeutic properties, showing the first and the last publications in each category. Timespan years and (number of publications/number of nest materials) varied as follows for the alphabetical order used in Table 11: *Biomolecules* Flavonoids 1993–2023 (16/2), Polyphenols 1993–2023 (16/1); *Biological activities* Anti-atherogenic 2019–2022 (3/2); Anticancer 2013–2020 (9/4); Anticataract 1997–2008 (4/1); Antihyperglycemic 2015–2023 (8/2); Antimicrobial 2013–2023 (10/4); Antioxidant 2006–2023 (22/4); Anti-inflammatory 2011–2023 (15/4); Antinociceptive 2014–2022 (3/2); Antiproliferative 2016–2018 (2/3); Chemopreventive 2016 (2/3), Hypocholesterolemic 2021 (1/3); and Modulator of gut microbiota 2019–2022 (3/1).

Table 11. Selected stingless bees from some studies on active biomolecules and biological activities, first and last publications

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
Flavonoids	*Frieseomelitta varia, Melipona compressipes, Melipona favosa, Paratrigona anduzei, Scaptotrigona depilis*	Venezuela	1993	-	-	-	Tomás-Barberán et al.[52]
	Geotrigona sp., *Tetragonisca fiebrigi*	Ecuador	2023	-	-	Ferreira et al.[53]	-
Polyphenols	*Frieseomelitta varia, Melipona compressipes, Melipona favosa, Paratrigona anduzei, Scaptotrigona depilis*	Venezuela	1993	-	-	-	Tomás-Barberán et al.[52]
	Geotrigona sp., *Tetragonisca fiebrigi*	Ecuador	2023	-	-	Ferreira et al.[53]	-
Biological activities							
Anti-atherogenic	*Heterotrigona itama*	Malaysia	2019	-	Othman et al.[54]	-	-
	Heterotrigona itama	Malaysia	2022	-	Zakaria et al.[55]	-	-
Anticancer	*Tetragonula* spp.	India	2013	-	-	-	Choudhari et al.[56]
	Heterotrigona itama	Malaysia	2020	Mahmood et al.[57]	-	-	-
Anticataract	*Melipona favosa*	Venezuela	2002	Vit[58]	-	-	-
	Commercial flavonoids present in honey[1]	Wales, UK	2008	-	-	-	-
Antihyperglycemic	*Lepidotrigona ventralis, Lepidotrigona*	Thailand	2015	-	-	-	Vongsak et al.[59]

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
	terminata, Tetragonula pagdeni						
	Heterotrigona itama	Malaysia	2023	Cheng et al.[60]	-	-	-
	Tetragonula sapiens	Indonesia	2023	-	-	-	Farida et al.[61]
Anti-inflammatory	*Tetragonula carbonaria*	Australia	2011	-	-	Massaro et al.[24]	-
	Tetragonula biroi	Indonesia	2023	-	-	-	Arung et al.[62]
	Heterotrigona itama, Tetragonula reepeni, Tetragonula testaceitarsis, Tetragonula fuscobalteata, Tetragonula iridipennis, Tetragonula pagdeni	Indonesia	2023	-	Naibaho et al.[63]	-	-
Antimicrobial	*Melipona seminigra*	Brazil	2013	da Silva et al.[64]	-	-	-
	Axestotrigona ferruginea, Axestotrigona togoensis, Meliplebeia beccarii, Hypotrigona gribodoi, Dactylurina schmidti, Plebeina armata	Tanzania	2023	Mduda et al.[65]	-	-	-
Antinociceptive	*Melipona subnitida*	Brazil	2014	-	-	-	Silva et al.[66]
	Tetragonisca fiebrigi	Argentina	2022	Salomon et al.[16]	-	-	-
Antiproliferative	*Tetragonula carbonaria*	Australia	2013	Vit et al.[67]	-	-	-
	Melipona fasciculata Melipona rufiventris, Melipona scutellaris Melipona subnitida Scaptotrigona polysticta	Brazil					
	Frieseomelitta nigra Melipona beecheii, Melipona fasciata Melipona solani, Scaptotrigona hellwegeri, Scaptotrigona mexicana	Mexico					
	Melipona favosa,	Venezuela					
	Geniotrigona thoracica, Heterotrigona itama	Malaysia	2018	Ismail et al.[68]	Ismail et al.[68]	-	Ismail et al.[68]
Antioxidant	*Melipona subnitida*	Brazil	2006	-	Silva et al.[69]	-	-
	Geotrigona sp., Tetragonisca fiebrigi	Ecuador	2023	-	-	Ferreira et al.[53]	-

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
	Axestotrigona ferruginea, Axestotrigona togoensis, Meliplebeia beccarii, Hypotrigona gribodoi, Dactylurina schmidti, Plebeina armata	Tanzania	2023	Mduda et al.[70]	-	-	-
Chemopreventive	*Lepidotrigona terminata*	Malaysia	2016	-	Omar et al.[71]	-	-
	Tetragonula spp.	Malaysia	2016	Yazan et al.[72]	-	-	-
Hypocholesterolemic	*Melipona seminigra*	Brazil	2021	-	Rebelo et al.[73]	-	-
Modulator of gut microbiota	*Heterotrigona itama*	Malaysia	2019	Zulkhairi Amin et al.[74]	-	-	-
	Tetragonula sarawakensis, Heterotrigona itama, Tetragonula testaceitarsis Tetragonula minangkabau, Geniotrigona thoracica, Tetrigona binghami	Indonesia	2022	Melia et al.[75]	-	-	-

[1]Vit and Jacob[76]

The complete revision from authors collection of selected literature is presented in Table 12

Table 12. Active biomolecules and biological activities of pot-honey, pot-pollen, cerumen, and propolis.

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
Flavonoids	*Frieseomelitta varia, Melipona compressipes, Melipona favosa, Paratrigona anduzei, Scaptotrigona depilis*	Venezuela	1993	-	-	-	Tomás-Barberán et al.[52]
	Melipona subnitida	Brazil	2006	-	Silva et al.[69]	-	-
	Melipona spp.	Venezuela	2011	Truchado et al.[137]	-	-	-
	Tetragonisca angustula	Venezuela	2013	Pérez-Pérez et al.[138]	-	Pérez-Pérez et al.[138]	Pérez-Pérez et al.[138]
	Melipona seminigra	Brazil	2013	da Silva et al.[64]	-	-	-
	Melipona quadrifasciata, Tetragona clavipes, Scaptotrigona spp.	Brazil	2017	-	-	-	Pazin et al.[139]
	Melipona subnitida	Brazil	2018	-	-	-	de Souza et al.[140]
	Geniotrigona thoracica, Heterotrigona itama,	Malaysia	2018	Tuksitha et al.[141]	-	-	-

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
	Heterotrigona erythrogastra						
	Tetrigona apicalis, Heterotrigona itama, Geniotrigona thoracica	Malaysia	2019	-	-	-	Asem et al.[80]
	Tetragonula biroi	Phillipines	2019	-	Belina-Aldemita et al.[142]	-	-
	Melipona quadrifasciata, Melipona asilvai, Melipona subnitida, Melipona scutellaris	Brazil	2019	-	Oliveira et al.[143]	-	-
	Scaptotrigona bipunctata, Melipona marginata, Tetragonisca angustula, Trigona hypogea, Melipona quadrifasciata, Tetragona clavipes	Brazil	2020	Biluca et al.[144]	-	-	-
	Heterotrigona itama	Malaysia	2020	Majid et al.[145]	-	-	-
	Melipona seminigra	Brazil	2021	-	Rebelo et al.[73]	-	-
	Tetrigona apicalis, Tetrigona binghami, Homotrigona fimbriata	Malaysia	2021	-	-	-	Syed Salleh et al.[82]
	Geotrigona sp,	Ecuador	2023	-	-	Ferreira et al.[53]	-
	Tetragonisca fiebrigi	Brazil		-	-		-
Polyphenols	*Frieseomelitta varia, Melipona compressipes, Melipona favosa, Paratrigona anduzei, Scaptotrigona depilis*	Venezuela	1993	-	-	-	Tomás-Barberán et al.[52]
	Tetragonula carbonaria	Australia	2011	-	-	Massaro et al.[24]	
	Tetragonisca angustula	Venezuela	2013	Pérez-Pérez et al.[138]	-	Pérez-Pérez et al.[138]	Pérez-Pérez et al.[138]
	Melipona seminigra	Brazil	2013	da Silva et al.[64]	-	-	-
	Melipona fasciculata	Brazil	2014	-	-	-	Dutra et al.[106]
	Melipona quadrifasciata, Tetragona clavipes, Scaptotrigona spp.	Brazil	2017	-	-	-	Pazin et al.[139]
	Melipona subnitida	Brazil	2018	-	-	-	de Souza et al.[140]
	Geniotrigona thoracica, Heterotrigona itama, Heterotrigona erythrogastra	Malaysia	2018	Tuksitha et al.[141]	-	-	-
	Tetrigona apicalis, Heterotrigona itama, Geniotrigona thoracica	Malaysia	2019	-	-	-	Asem et al.[80]
	Melipona quadrifasciata, Melipona asilvai,	Brazil	2019	-	Oliveira et al.[103]	-	-

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
	Melipona subnitida, Melipona scutellaris						
	Scaptotrigona bipunctata, Melipona marginata, Tetragonisca angustula, Trigona hypogea, Melipona quadrifasciata, Tetragona clavipes	Brazil	2020	Biluca et al.[144]	-	-	-
	Heterotrigona itama	Malaysia	2020	Majid et al.[145]	-	-	-
	Melipona seminigra	Brazil	2021	-	Rebelo et al.[73]	-	-
	Tetrigona apicalis, Tetrigona binghami, Homotrigona fimbriata	Malaysia	2021	-	-	-	Syed Salleh et al.[82]
	Geotrigona sp., *Tetragonisca fiebrigi*	Ecuador	2023	-	-	Ferreira et al.[53]	-
	Tetragonula laevicpes	Thailand	2023	-	-	Iesa et al.[147]	-
Biological activities	Stingless bee taxa						
Anti-atherogenic	*Heterotrigona itama*	Malaysia	2019	-	Othman et al.[54]	-	-
	Geniotrigona thoracica	Malaysia	2020	-	-	-	Mohd Suib et al.[148]
	Heterotrigona itama	Malaysia	2022	-	Zakaria et al.[55]	-	.
Anticancer	*Tetragonula* spp.	India	2013	-	-	-	Choudhari et al.[56]
	Homotrigona apicalis, Tetragonilla fuscibasis, Tetragonula fuscobalteata, Wallacetrigona incisa	Indonesia	2014	Kustiawan et al.[149]	Kustiawan et al.[149]	-	Kustiawan et al.[149]
	Tetragonula laeviceps	Thailand	2015	-	-	Nugitrangson et al.[150]	-
	Lepidotrigona terminata	Malaysia	2016	-	Omar et al.[71]	-	-
	Melipona orbignyi	Brazil	2017	-	-	-	dos Santos et al.[151]
	Heterotrigona itama	Malaysia	2019	Ahmad et al.[152]	-	-	-
	Tetragonula biroi	Phillipines	2019	-	-	-	Desamero et al.[153]
	Heterotrigona itama	Malaysia	2020	Mahmood et al.[59]	-	-	-
	Homotrigona fimbriata, Heterotrigona itama, Heterotrigona bakeri, Tetragonula sarawakensis, Tetragonula testaceitarsis, Tetragonula fuscobalteata, Tetragonula laeviceps	Indonesia	2021	Arung et al.[154]	Arung et al.[154]	-	Arung et al.[154]

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
Anticataract	*Melipona favosa, Tetragonisca angustula,*	Venezuela	1997	Vit[155]	-	-	.-
	Commercial luteolin derivatives present in honey1	Wales, UK	2001				
	Melipona favosa	Venezuela	2002	Vit[58]			
	Melipona favosa, Scaptotrigona mexicana, Tetragonisca angustula Commercial luteolin derivatives present in honey	Brazil, Mexico, Venezuela	2004	Vit et al.[9]	-	-	.-
	Commercial flavonoids present in honey2	Wales, UK	2008	-	-	-	-
Antihyperglycemic	*Lepidotrigona ventralis, Lepidotrigona terminata, Tetragonula pagdeni*	Thailand	2015	-	-	-	Vongsak et al.[59]
	Geniotrigona thoracica	Malaysia	2017	Abdul Aziz et al.[156]	-	-	-
	Heterotrigona itama, Trigona apicalis	Malaysia	2018	-	-	-	Nna et al.[157]
	Tetragonula sapiens	Indonesia	2019	-	-	-	Pujirahayu et al.[158]
	Tetragonula biroi, Tetragonula laeviceps	Indonesia	2019	Rahmawati et al.[159]	-	-	-
	Heterotrigona itama	Malaysia	2020	Ali et al.[160]	-	-	-
	Heterotrigona itama	Malaysia	2023	Cheng et al.[60]	-	-	-
	Tetragonula sapiens	Indonesia	2023	-	-	-	Farida et al.[61]
Anti-inflammatory	*Tetragonula carbonaria*	Australia	2011			Massaro et al.[24]	-
	Tetragonisca fiebrigi	Brazil	2015	-	-	-	Campos et al.[161]
	Tetragonula carbonaria	Australia	2016	-	-	Hamilton et al.[162]	-
	Melipona orbignyi	Brazil	2017	-	-	-	dos Santos et al.[151]
	Tetragonula carbonaria	Australia	2017	-	-	Hamilton et al.[163]	-
	Melipona fasciculata	Brazil	2019	-	Lopes et al.[164]	-	-
	Scaptotrigona bipunctata, Melipona marginata, Tetragonisca angustula, Trigona hypogea, Melipona quadrifasciata, Tetragona clavipes	Brazil	2020	Biluca et al.[144]	-	-	-
	Tetragonula spp.	Malaysia	2020	Badrulhisham et al.[165]	-	-	-
	Melipona fasciculata	Brazil	2020	-	-	-	Barboza et al.[166]

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
	Heterotrigona itama	Malaysia	2020	-	-	-	Zhang et al.[167]
	Heterotrigona itama	Malaysia	2021	Ooi et al.[168]	-	-	-
	Tetragonula carbonaria	Australia	2022	-	Hamilton et al.[169]	-	-
	Tetragonisca fiebrigi	Argentina	2022	Salomon et al.[16]	-	-	-
	Heterotrigona itama, Tetrigona binghami	Malaysia	2022	Wu et al.[170]	-	-	-
	Tetragonula biroi	Indonesia	2023	-	-	-	Arung et al.[154]
	Heterotrigona itama, Tetragonula reepeni, Tetragonula testaceitarsis, Tetragonula fuscobalteata, Tetragonula iridipennis, Tetragonula pagdeni	Indonesia	2023	-	Naibaho et al.[63]	-	-
	Geotrigona sp,	Ecuador	2023	-	-	Ferreira et al.[53]	-
	Tetragonisca fiebrigi	Brazil		-	-		-
Antimicrobial	*Melipona seminigra*	Brazil	2013	da Silva et al.[64]	-	-	-
	Tetragonisca fiebrigi	Brazil	2015	-	-	-	Campos et al.[159]
	Melipona quadrifasciata, Tetragonisca angustula	Brazil	2017	-	-	-	dos Santos et al.[151]
	Geniotrigona thoracica, Heterotrigona itama, Heterotrigona erythrogastra	Malaysia	2018	Tuksitha et al.[141]	-	-	-
	Geniotrigona thoracica, Heterotrigona itama, Tetrigona binghami	Brunei	2020	-	-	-	Abdullah et al.[171]
	Axestotrigona ferruginea	Tanzania	2021	Popova et al.[51]	-	Popova et al.[51]	Popova et al.[51]
	Tetragonisca fiebrigi	Argentina	2022	Dallagnol et al.[172]	-	-	-
	Heterotrigona itama, Tetrigona binghami	Malaysia	2022	Wu et al.[130]	-	-	-
	Axestotrigona ferruginea, Axestotrigona togoensis, Meliplebeia beccarii, Hypotrigona gribodoi, Dactylurina schmidti, Plebeina armata	Tanzania	2023	Mduda et al.[65]	-	-	-
	Heterotrigona itama, Tetragonula reepeni, Tetragonula pagdeni, Tetragonula iridipennis, Tetragonula fuscobalteata Tetragonula testaceitarsis	Indonesia	2023	-	Naibaho et al.[173]	-	-
Antinociceptive	*Melipona subnitida*	Brazil	2014	-	-	-	Silva et al.[66]
	Melipona fasciculata	Brazil	2019	-	Lopes et al.[164]	-	-

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
	Tetragonisca fiebrigi	Argentina	2022	Salomon et al.[16]	-	-	-
Antioxidant	*Melipona subnitida*	Brazil	2006	-	Silva et al.[66]	-	-
	Tetragonisca angustula	Venezuela	2007	Pérez-Pérez et al.[10]	-	-	-
	Melipona sp, *Tetragonisca* sp	Venezuela	2007	Rodriguez-Malaver et al.[174]	-	-	-
	Melipona seminigra	Brazil	2013	da Silva et al.[64]	-	-	-
	Tetragonisca angustula	Venezuela	2013	Pérez-Pérez,[138]	-	Pérez-Pérez,[138]	Pérez-Pérez,[138]
	Melipona fasciculata	Brazil	2014	-	-	-	Dutra et al.[146]
	Tetragonula carbonaria	Australia	2016	-	-	Hamilton et al.[162]	-
	Geniotrigona thoracica, Heterotrigona itama, Tetrigona apicalis	Malaysia	2016	-	Nurdianah et al.[175]	-	-
	Tetragonula carbonaria	Australia	2017	-	-	Hamilton et al.[163]	-
	Tetrigona apicalis, Heterotrigona itama, Geniotrigona thoracica	Malaysia	2017	-	Harif Fadzilah et al.[176]	-	-
	Melipona quadrifasciata, Tetragona clavipes, Scaptotrigona spp.	Brazil	2017	-	-	-	Pazin et al.[139]
	Melipona quadrifasciata, Tetragonisca angustula	Brazil	2017	-	-	-	dos Santos et al.[151]
	Geniotrigona thoracica, Heterotrigona itama, Heterotrigona erythrogastra	Malaysia	2018	Tuksitha et al.[141]	-	-	-
	Tetrigona apicalis, Heterotrigona itama, Geniotrigona thoracica	Malaysia	2019	-	-	-	Asem et al.[80]
	Tetragonula biroi	Phillipines	2019	-	Belina-Aldemita et al.[142]	-	-
	Melipona compressipes	Brazil	2019	-	Carneiro et al.[137]	-	-
	Melipona quadrifasciata, Melipona asilvai, Melipona subnitida, Melipona scutellaris	Brazil	2019	-	Oliveira et al.[143]	-	-
	Geniotrigona thoracica, Heterotrigona itama, Tetrigona binghami	Brunei	2020	-	-	-	Abdullah et al.[171]
	Scaptotrigona bipunctata, Melipona marginata, Tetragonisca angustula, Trigona hypogea, Melipona quadrifasciata, Tetragona clavipes	Brazil	2020	Biluca et al.[144]	-	-	-
	Heterotrigona itama	Malaysia	2020	Majid et al.[145]	-	-	-

Active Biomolecules	Stingless bee species	Country	Year	Pot-honey	Pot-pollen	Cerumen	Propolis
	Tetrigona apicalis, Tetrigona binghami, Homotrigona fimbriata	Malaysia	2021	-	-	-	Syed Salleh et al. [82]
	Axestotrigona ferruginea, Axestotrigona togoensis, Meliplebeia lendliana, Meliponula bocandei, Liotrigona spp., *Plebeina armata*	Kenya	2022	Mokaya et al.[178]	-	-	-
	Heterotrigona itama, Tetrigona binghami	Malaysia	2022	Wu et al.[179]	-	-	-
	Geotrigona sp., *Tetragonisca fiebrigi*	Ecuador	2023	-	-	Ferreira et al.[53]	-
	Tetragonula laevicpes	Thailand	2023	-	-	Iesa et al.[147]	-
	Axestotrigona ferruginea, Axestotrigona togoensis, Meliplebeia beccarii, Hypotrigona gribodoi, Dactylurina schmidti, Plebeina armata	Tanzania	2023	Mduda et al.[70]	-	-	-
Antiproliferative	*Tetragonula carbonaria*	Australia	2013	Vit et al.[67]	-	-	-
	Melipona fasciculata Melipona rufiventris, Melipona scutellaris Melipona subnitida Scaptotrigona polysticta	Brazil			-	-	-
	Frieseomelitta nigra Melipona beecheii, Melipona fasciata Melipona solani, Scaptotrigona hellweheri, Scaptotrigona mexicana	Mexico			-	-	-
	Melipona favosa	Venezuela			-	-	-
	Lepidotrigona terminata	Malaysia	2016	-	Omar et al.[71]	-	-
	Geniotrigona thoracica, Heterotrigona itama	Malaysia	2018	Ismail et al.[68]	Ismail et al.[68]	-	Ismail et al.[68]
Chemopreventive	*Lepidotrigona terminata*	Malaysia	2016	-	Omar et al.[71]	-	.
	Tetragonula spp.	Malaysia	2016	Yazan et al.[72]	-	-	-
Hypocholesterolemic	*Melipona seminigra*	Brazil	2021	-	Rebelo et al.[73]	-	-
Modulator of gut microbiota	*Heterotrigona itama*	Malaysia	2019	Zulkhairi Amin et al.[74]	-	-	-
	Heterotrigona itama	Malaysia	2020	Mohammad et al.[179]	-	-	-
	Tetragonula sarawakensis, Heterotrigona itama, Tetragonula testaceitarsis, Tetragonula minangkabau, Geniotrigona thoracica, Tetrigona binghami	Indonesia	2022	Melia et al.[75]	-	-	-

The list of stingless bee taxa of this revision was tabulated in Table 13 with their Neotropical, Afrotropical, Indo-Malaysian, and Australian geographical distribution. Pot-honey, pot-pollen, cerumen and propolis from 31 Neotropical (Argentina, Brazil, Ecuador, Mexico, and Venezuela), 9 Afrotropical (Kenya and Tanzania), 22 Indo-Malaysian (Brunei, India, Indonesia, Malaysia, Philippines, and Thailand), and 1 Australian stingless bee taxa were studied for their flavonoid and polyphenol contents, and 13 biological activities. In this Table 13, Most biological activities were studied for materials of stingless bee species from Indo-Malaysian *Heterotrigona itama* (9) and *Geniotrigona thoracica* (7), the Neotropical *Tetragonisca angustula* (6) and *Tetragonisca fiebrigi* (6), and the unique medicinal Australian bee *Tetragonula carbonaria* (5) in our search.

Table 13. Stingless bee taxa of the geographical region (Neotropical, Afrotropical, Indo-Malaysian, Australian) used in medicinal stingless bee research of Table 12.

No.	Geographical Region Stingless Bee Taxa	Country	Biomolecules and Biological Activity
	Neotropical		
1	*Frieseomelitta nigra*	Mexico	Antiproliferative
2	*Frieseomelitta varia*		Flavonoids, Polyphenols
3	*Geotrigona* sp.	Ecuador	Flavonoids, Polyphenols, Antioxidant
4	*Melipona asilvai*		Flavonoids, Polyphenols, Antioxidant
5	*Melipona beecheii*	Mexico	Antiproliferative
6	*Melipona compressipes*	Brazil	Flavonoids, Polyphenols, Antioxidant
7	*Melipona fasciata*	Mexico	Antiproliferative
8	*Melipona fasciculata*	Brazil	Polyphenols, Anti-inflammatory, Antinociceptive, Antioxidant, Antiproliferative
9	*Melipona favosa*	Venezuela	Flavonoids, Anticataract, Antiproliferative, Chemopreventive
10	*Melipona marginata*	Brazil	Flavonoids, Polyphenols, Anti-inflammatory, Antioxidant
11	*Melipona orbignyi*	Brazil	Anticancer, Anti-inflammatory
12	*Melipona quadrifasciata*	Brazil	Flavonoids, Polyphenols, Anti-inflammatory, Antimicrobial, Antioxidant
13	*Melipona rufiventris*	Brazil	Antiproliferative
14	*Melipona scutellaris*	Brazil	Flavonoids, Polyphenols, Antioxidant
15	*Melipona seminigra*	Brazil	Flavonoids, Polyphenols, Antimicrobial, Antioxidant, Antiproliferative, Hypocholesterolemic
16	*Melipona solani*	Mexico	Antiproliferative
17	*Melipona subnitida*	Brazil	Flavonoids, Polyphenols, Antinociceptive, Antioxidant, Antiproliferative
18	*Melipona* spp.		Flavonoids
20	*Paratrigona anduzei*		Flavonoids, Polyphenols
21	*Scaptotrigona bipunctata*	Brazil	Flavonoids, Polyphenols, Anti-inflammatory, Antioxidant
22	*Scaptotrigona depilis*		Flavonoids, Polyphenols
23	*Scaptotrigona hellwegeri*	Mexico	Antiproliferative
24	*Scaptotrigona mexicana*	Mexico	Anticataract, Antiproliferative
25	*Scaptotrigona polysticta*	Brazil	Antiproliferative
26	*Scaptotrigona* spp.	Brazil	Flavonoids, Polyphenols, Antioxidant
27	*Tetragona clavipes*	Brazil	Flavonoids, Polyphenols, Anti-inflammatory, Antioxidant
28	*Tetragonisca angustula*	Brazil	Flavonoids, Polyphenols, Anticataract, Anti-inflammatory, Antimicrobial, Antioxidant
		Venezuela	Flavonoids, Polyphenols, Anticataract, Antimicrobial, Antioxidant
29	*Tetragonisca fiebrigi*	Brazil	Flavonoids, Polyphenols, Anti-inflammatory, Antimicrobial, Antinociceptive, Antioxidant

No.	Geographical Region Stingless Bee Taxa	Country	Biomolecules and Biological Activity
		Argentina	Anti-inflammatory, Antimicrobial
30	*Tetragonisca* sp.	Venezuela	Antioxidant
31	*Trigona hypogea*	Brazil	Flavonoids, Polyphenols, Anti-inflammatory, Antioxidant
		5 countries	
	Afrotropical		
1	*Axestotrigona ferruginea*	Tanzania	Antimicrobial, Antioxidant
		Kenya	Antioxidant
2	*Axestotrigona togoensis*	Tanzania	Antimicrobial, Antioxidant
		Kenya	Antioxidant
3	*Dactylurina schmidti*	Tanzania	Antimicrobial, Antioxidant
4	*Hypotrigona gribodoi*	Tanzania	Antimicrobial, Antioxidant
5	*Liotrigona* sp.	Kenya	Antioxidant
6	*Meliplebeia beccarii*	Tanzania	Antimicrobial, Antioxidant
7	*Meliponula bocandei*	Kenya	Antioxidant
8	*Meliplebeia lendliana*	Kenya	Antioxidant
9	*Plebeina armata*	Tanzania	Antimicrobial, Antioxidant
		Kenya	Antioxidant
		2 countries	
	Indo-Malaysian		
1	*Geniotrigona thoracica*	Malaysia	Flavonoids, Polyphenols, Anti-atherogenic, Antihyperglycemic, Antimicrobial, Antioxidant, Antiproliferative
		Brunei	Antimicrobial, Antioxidant
		Indonesia	Modulator of gut microbiota
2	*Heterotrigona bakeri*	Indonesia	Anticancer
3	*Hterotrigoina erythrogastra*	Malaysia	Polyphenols, Antimicrobial
4	*Heterotrigona itama*	Malaysia	Flavonoids, Polyphenols, Anti-atherogenic, Antihyperglycemic, Anti-inflammatory, Antimicrobial, Antioxidant, Antiproliferative, Modulator of gut microbiota
		Indonesia	Anticancer, Anti-inflammatory, Antimicrobial, Modulator of gut microbiota
		Brunei	Antimicrobial, Antioxidant
5	*Homotrigona apicalis*	Indonesia	Anticancer
6	*Homotrigona fimbriata*	Indonesia	Flavonoids, Polyphenols, Anticancer, Antioxidant
7	*Lepidotrigona terminata*	Malaysia, Thailand	Anticancer, Antiproliferative, Chemopreventive
		Thailand	Antihyperglycemic, Antiproliferative, Chemopreventive
8	*Lepidotrigona ventralis,*	Thailand	Antihyperglycemic
9	*Tetragonilla fuscibasis*	Indonesia	Anticancer
10	*Tetragonula biroi*	Phillipines	Flavonoids, Anticancer, Antioxidant

No.	Geographical Region Stingless Bee Taxa	Country	Biomolecules and Biological Activity
		Indonesia	Antihyperglycemic, Anti-inflammatory
11	*Tetragonula fuscobalteata*	Indonesia	Anticancer, Anti-inflammatory, Antimicrobial
12	*Tetragonula iridipennis*	Indonesia	Anti-inflammatory, Antimicrobial
13	*Tetragonula laeviceps*	Thailand	Polyphenols, Anticancer, Antioxidant
		Indonesia	Antihyperglycemic
14	*Tetragonula minangkabau,*	Indonesia	Modulator of gut microbiota
15	*Tetragonula pagdeni*	Thailand	Antihyperglycemic, Anti-inflammatory, Antimicrobial
16	*Tetragonula reepeni*	Indonesia	Anti-inflammatory, Antimicrobial
17	*Tetragonula sapiens*	Indonesia	Antihyperglycemic
18	*Tetragonula sarawakensis*	Indonesia	Anticancer, Modulator of gut microbiota
19	*Tetragonula testaceitarsis*	Indonesia	Anticancer, Anti-inflammatory, Antimicrobial, Modulator of gut microbiota
20	*Tetragonula* spp.	India	Anticancer
		Malaysia	Anti-inflammatory, Chemopreventive
21	*Tetrigona apicalis*	Malaysia	Flavonoids, Polyphenols, Antihyperglycemic, Antioxidant
22	*Tetrigona binghami*	Malaysia	Flavonoids, Polyphenols, Anti-inflammatory, Antioxidant
		Brunei	Antimicrobial, Antioxidant
		Indonesia	Modulator of gut microbiota
23	*Wallacetrigona incisa,*	Indonesia	Anticancer
	23 taxa	6 countries	
	Australian		
1	*Tetragonula carbonaria*	Australia	Polyphenols, Anti-inflammatory, Antioxidant, Antiproliferative, Chemopreventive
	1 taxon	1 country	

3.4 QUALITY CONTROL OF STINGLESS BEE PRODUCTS. KEY BIOMOLECULES, METHODS AND TECHNIQUES

The developing interest towards use of stingless bee products to support human health makes the issue of their standardization increasingly important and urgent. It is well known that stingless bee honey does not comply with the requirements for honeybee honey in the CODEX Alimentarius[77], which have been created for *Apis mellifera* honey. The growing amount of data on the characteristics of stingless bee honey led to the need of creation of specific quality standard for pot-honey. In general, stingless bee honeys do not meet the CODEX Standard for honey moisture, free acidity, and total fructose plus glucose levels. In addition, is has been suggested to apply the presence and amount of a rare reducing sugar, trehalulose, as a marker of authenticity of pot-honey[78]. However, to produce a universal standard and quality parameters, further information from studies of the chemical composition of stingless bee honey — such as organic acids and polyphenol profiles of pot-honey from stingless bee species from different geographical regions is required. Targeted ^{1}H-NMR is adequate to compare sugars, amino acids, aliphatic organic acids, HMF, ethanol, and botanical markers of pot-honey produced by diverse entomological origins[12].

Concerning stingless bee propolis, the chemical variability is much greater than that observed with *A. mellifera* propolis. This has been a serious hindrance in the case of *Apis mellifera* propolis which now, after decades of intense research, comes to an at least partial solution. The stingless bees' propolis poses a much more difficult problem, due to its greater chemical diversity. It is interesting to note that several molecules with significant bioactivities have been found in pot-propolis (gallic acid, alpha-mangostine, propolin A), some of them new chemical entities, such as sulawesin A, mammein cynnamoyl ester, etc.[79] (Fig. 15).

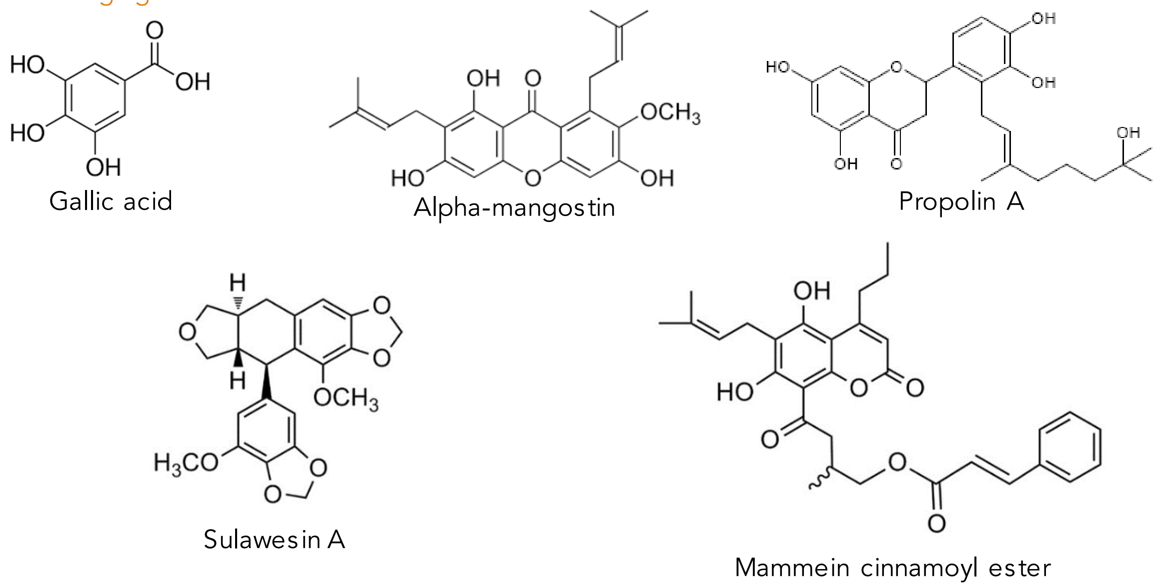


Fig. 15 Important bioactive compounds in stingless bee propolis

The antimicrobial and antioxidant activities of stingless bee propolis are usually reported to depend on its total phenolic content, e.g. Asem et al.[80] However, it is necessary to remember that different stingless bee propolis often contain different phenolic compounds and equal number of observed gallic acid equivalents could correspond to a very different real concentration of phenolics. For this reason, the chemical type of the propolis samples should be observed by LC-MS[81] or GC-MS analyses[82]. As in the case of pot-honey or stingless bee honey, pot-pollen or stingless bee pollen, and cerumen, many more studies have to be conducted on the chemistry and biological activity of stingless bee propolis before any quality control criteria could be formulated.

3.5 INFLUENCE OF THE *MELIPONA* GENUS BAHIA STATE HONEY NORM FROM BRAZIL (2014), AND FURTHER POT-HONEY NORMS IN MEDICINAL USES OF POT-HONEY

In their seminal paper, Gonnet et al.[83] evidenced the higher moisture and free acidity of *Melipona* honey compared to *Apis mellifera* honey. The first proposal for stingless bee honey standards included honey of the *Melipona* from Guatemala, Mexico, and Venezuela.[9] The first Brazilian stingless bee honey norm was created for *Melipona* honey in the State of Bahia.[2] Forthcoming Brazilian State standards were established in Amazonas[84], Paraná[85], Espírito Santo[86], and Santa Santa Catarina[87]. The Philippine honey norm[88] included pot-honey in the last revision, but not the standards. The first National standard was created in 2017 for Kelulut – Malaysian name given to all stingless bees– honey in Malaysia[89], and the second was for the Argentine stingless bee *Tetragonisca fiebrigi* known with the ethnic name Yateí in 2019[90].

Concomitant with the scientific research on medicinal properties of stingless bee products, regulated pot-honey facilitates administrative procedures to launch pharmaceutical products. The diverse state norms in Brazil have promoted presentations of pot-honey, pot-pollen, and propolis of pharmaceutical quality, available online[91].

The facts of standardized pot-materials of the stingless bee nest are promising: 1. More quality products will be produced and will command fair market prices, 2. Regulated products are safe for human and animal health, 3. Support of apitherapy by providing quality raw materials, 4. Best stingless bee-keeping practices should be strictly followed in order to produce quality products, and especially 5. Stingless bee apiaries should backup the volume of marketed stingless bee products, to prevent falsifications.

Potential categorizations of stingless bee materials may include antioxidant activity grading, as suggested for Czech honey using μmoles equivalents Trolox/100 g honey in a scale of pro-oxidant (<1), very low (0-50), low (51–100), moderately low (101–150), medium (151–200), moderately high (201–250), high (251–300), very high (>300) by Vit et al.[92]

A more recent idea of categorization arises after the trehalulose discovery in pot-honey by Fletcher et al., 2020[93] and further analysis[78] could provide useful gradings for entomological origins. This unique sugar needs extensive research and the following trend reveals useful for trehalulose concentrations (g/100g honey) graded for preliminary stingless bee species (10.0–39.9) *Heterotrigona itama*, *Tetragonula carbonaria*, *Tetragonula hogkingsi*, (40.0–49.9) *Geniotrigona thoracica*, *Heterotrigona itama*, and (50.0 59.9) *Geniotrigona thoracica*.

Our *Quality of the beehive for apitherapy* in the VII National Congress of Pharmaceutical Science 2000[94] has focused to *Quality of the stingless bee nest for apitheraphy* in the Apimondia 2023 Central Symposium for Apitherapy, consistent with good practices of stingless bee keeping to achieve great quality of stingless bee products for direct use or in pharmaceutical preparations[95]. Vit and Simova[96] reviewed the aliphatic organic acids (AOA) in honey and proposed updated reference values for *Apis mellifera* and stingless bee honey.

3.6 INTEGRATIVE APPLICATIONS OF STINGLESS BEE NEST METABOLITES TO OVERCOME ANTIBIOTIC RESISTANCE

Antimicrobial resistance (AMR) has become a global health and socioeconomic issue requiring urgent attention[97]. In 2019, an estimated 1.27 million deaths worldwide were attributable to antibiotic-resistant bacterial infections[98]. The World Health Organization (WHO) estimated that by 2050, diseases caused by multidrug-resistant bacteria could lead to 10 million deaths annually, surpassing cancer as the leading cause of death[99]. In 2024, the WHO updated its list of bacterial pathogens considered a priority due to limited treatment options and their significant global health impact. At the top of this list are highly virulent bacteria, including carbapenem-resistant *Acinetobacter baumannii*, carbapenem-resistant *Enterobacter*, and third-generation cephalosporin-resistant *Enterobacterales*[100]. Infections caused by these pathogens are difficult to prevent, highly transmissible, and associated with a high mortality rate, making them a major public health threat[99–101].

The global rise of multidrug-resistant pathogens represents one of the greatest challenges to modern medicine, prompting the search for new therapeutic strategies beyond conventional antibiotics[102]. In this context, stingless bee nest derivatives, such as pot-honey, pot-pollen, cerumen, and propolis, are emerging as promising sources of bioactive compounds for developing effective therapies against resistant microorganisms[103].

Stingless bees produce a wide variety of bioactive substances, including antimicrobial peptides, polyphenols, flavonoids, and enzymes that synergistically inhibit bacterial growth and biofilm formation, modulate immune responses, promote tissue repair, and reduce inflammation[104]. Propolis, in particular, has been extensively studied for its high content of phenolic compounds and flavonoids with potent antioxidant and antimicrobial effects, capable of inhibiting both Gram-positive and Gram-negative bacteria, including multidrug-resistant strains[105]. These compounds act through multiple mechanisms: altering bacterial cell membranes, inhibiting protein synthesis, preventing biofilm formation, and enhancing antibiotic efficacy through proven synergies[106]. Similarly, pot-honey exhibits antimicrobial activity due to the presence of hydrogen peroxide and other compounds that act synergistically with flavonoids and phenolic acids to destabilize bacterial membranes and prevent biofilm formation as key factors in the persistence of chronic resistant infections[103–106].

Beyond the intrinsic antimicrobial properties of stingless bee nest metabolites, numerous studies emphasize the synergistic interactions between bee products and conventional antibiotics[103,107,108]. This synergy not only enhances antimicrobial efficacy and reduces the required antibiotic dosage but also helps prevent the emergence of new resistances and mitigates potential side or toxic effects[102]. Araque and Vit[109] evaluated the synergistic potential of ethanolic extracts of *Tetragonisca angustula* pot-pollen combined with amikacin and meropenem—two frontline antibiotics used against resistant infections. Their results demonstrated strong synergistic interactions in 75% of the bacterial isolates tested, including clinically significant multidrug-resistant strains such as *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Acinetobacter baumannii*. This synergy was evidenced by up to a threefold reduction in the minimal inhibitory concentrations (MICs) of the antibiotics, indicating a potential adjuvant role for pot-pollen in restoring antibiotic susceptibility and reducing therapeutic dosages.

Complementing these findings, Vit et al.[110] examined the volatile compounds in pot-pollen and explored their bioactivity and synergism with antibiotics. In addition to antimicrobial and anti-inflammatory properties, they reported innovative applications of these volatiles in enhancing food flavors, potentially improving the acceptability and clinical application of pot-pollen-derived products. Their bibliometric analysis revealed increasing scientific interest and strong evidence supporting the anti-AMR potential of pot-pollen as a multifunctional natural resource.

From a critical perspective, despite the favorable consensus, the variability in chemical composition due to botanical origin, geographical location, and technical processing presents a challenge in translating findings into standardized and regulated therapeutic applications[111]. Moreover, most studies remain preclinical or in vitro, highlighting the need for robust clinical trials to confirm efficacy and safety in human populations. Nonetheless, advances in the chemical characterization and functional analysis of these natural compounds are paving the way for their inclusion in innovative formulations such as nanoemulsions, gels, and other controlled-release systems[107–112].

The therapeutic promise of stingless bee nest materials extends beyond their capacity to combat bacterial resistance. Their metabolic and cellular protective effects may enhance overall host health and offer potential for managing metabolic and inflammatory diseases that are increasingly prevalent. This integrative perspective underscores the value of stingless bee nest materials as complementary agents in therapeutic management, where responsible and evidence-based utilization could play a pivotal role in the post-antibiotic era.

3.7 GENOMIC AND METAGENOMIC INSIGHTS INTO THE MEDICINAL POTENTIAL OF STINGLESS BEE NEST MATERIALS

Antimicrobial agents biosynthesized for the survival of microbial communities in honey contribute to its well-known antimicrobial properties[113]. Similarly, interactions among microbial populations inhabiting stingless bee nest materials may explain the frequently reported antimicrobial activities of pot-honey[114], pot-pollen[115], cerumen[116,117], and propolis[117]. The wide variety of bioactive molecules of microbial origin has been comprehensively reviewed by Vit (2024)[118] and Alves et al. (2024)[119]. Metabolites generated by the stingless bee nest microbiome represent a vast reservoir of largely unexplored natural compounds that play critical ecological roles and hold strong potential for biotechnological and medicinal applications, including drug discovery. Developing such applications requires understanding the complex microbiota associated with stingless bees to identify and isolate specific bacterial and fungal strains and their metabolites as potential therapeutic agents or dietary supplements. As shown in bumble bees, microbiome assembly and maintenance are dynamic across the lifespan of social bees[120], and likely also in stingless bees and their nest materials, a factor that must be considered when harvesting high-quality materials.

Current research on stingless bee gut microbiomes remains at an exploratory stage. The core microbiome of *Apis mellifera* differs markedly from that of the few stingless bee species studied in Australia[121], Brazil[122,123], Mexico[124], and Thailand[125]. Emerging evidence suggests that host-specific and geographical factors influence microbiome composition in stingless bee nest materials, representing an untapped source of bioactive compounds that may contribute both to colony health and to human health applications. Biotransformations of phytochemicals such as flavonoids and polyphenols by gut microbes involve two-way interactions: microbial degradation reduces molecule size, while phenolics modulate microbial populations[126].

Investigating how microbes transform compounds, communicate with each other within communities, interact with the host, and analyzing their microbial products provides deeper insight into host–microbe interactions and their effects on health and disease.. Knowing the microbiome helps finding potential active biomolecules by using advanced metabolomics to identify and quantify the chemicals microbes produce. Exploring their bioactive properties reveals molecules that can act as therapeutics, drug targets, or function as biomarkers. By deciphering microbiome-mediated transformations of host-derived molecules and xenobiotics, researchers can uncover novel enzymes and biochemical pathways. Understanding metabolic fingerprints of the microbiome connects microbial communities or a unique microbe from food storage, architectural materials of the nest, or the stingless bee itself with a particular function or a set of roles. For instance, in *Scaptotrigona* *depilis*, a Brazilian stingless bee, three microbial populations coordinate during pupal metamorphosis: one produces the steroid ergosterol, two modulate its availability[127], and the symbiotic yeast *Zygosaccharomyces* sp. promotes metamorphic development[128]. Such examples illustrate the intricate interplay between stingless bees and their symbionts. Our particular interest lies in exploring how these associated microbes may contribute to human health by: 1. Modulating host physiology, 2. Influencing disease dynamics, 3. Interacting with immune responses, and 4. Enabling discovery of novel drugs and therapeutic agents.

Genomics and metagenomics are two technologies with complementary approaches to this pursuit. Metagenomics characterizes microbial communities and their functional genes within complex nest environments, while genomics focuses on individual organisms and their genetic composition. Genomics supports applications in drug discovery, whereas metagenomics advances environmental microbiome research and natural product exploration. To fully realize the therapeutic potential of stingless bee nest materials, metagenomics and genomics are needed in tandem.

Instead of morphological identifications of pollen grains by melissopalynology[49], DNA metabarcoding was proposed to characterize the botanical origin of honey[130] but a multi-kingdom resolution is now represented by a major high throughput technology of whole genome shotgun sequencing (WGS) known as shotgun metagenomics[131] covering all DNA instead of primers, unlocking potential applications. A comprehensive view of the entire community of organisms and their genes is achieved by sequencing all DNA from a sample using this powerful tool for studying complex materials, fragmenting all the DNA, sequencing it, and using bioinformatics to identify the organisms present, their functional genes, and metabolic pathways, regardless of whether they are animals, bacteria, fungi, plants or viruses[132,133] Amplicon sequencing and shotgun metagenomics are two platforms used in epidemiological research. Larger microbiome datasets characterize pooled amplicon/shotgun data compared to pure shotgun metagenomic. Usyk et al.[134] harmonized this pooling approach to leverage the exponential amplicon sequencing data produced over two decades.

3.8 FRAUD CONTROL OF STINGLESS BEE PRODUCTS

Stingless bee products have lower yields than *Apis mellifera* because their colonies and nests are smaller, with variable size according to the stingless bee species and environmental factors. Productivity varies with years and some colonies are more propolizers than others. In Table 14, colony size and nest type of some stingless bee species from Brazil[33].

Table 14. Colony size of selected stingless bee species

Stingless bee species Maximum flight distance]	Bee size (mm)	Colony size Average No. workers (min–max)	Type of nest
Cephalotrigona capitata [1.7 km]	9.5	1250 (1000–1500)	Living tree cavities Horizontal brood combs with involucrum Rather large storage pots, with pot-honey and pot-pollen in different sections Permanent deposit of detritus Entrance decorated with plant resins and a hardened cerumen landing platform
Frieseomelitta varia [1.4 km]	5.5	1200 (800–1600)	Tree cavities Horizontal brood combs without involucrum Small spheroidal honey pots, larger pollen-pots slightly elongated Entrance size of worker head
Geotrigona mombuca [unknown]	5.0	2500 (2000–3000)	Underground Cylindrical storage pots, draining gallery a nest bottom, permanent deposits of detritus Underground channel connects the nest with the entrance in the surface.

Stingless bee species Maximum flight distance]	Bee size (mm)	Colony size Average No. workers (min–max)	Type of nest
Leurotrigona muelleri [unknown]	3.0	750 (500–1000)	Tree cavities, rock crevices, iron tubes Horizontal brood combs without involucrum Ovoidal storage cerumen pots light amber color Short dark entrance tube with plant resin drops
Melipona quadrifasciata [2.0 km]	10.0	900 (300–1500)	Tree cavities Horizontal brood combs with involucrum Batumen borders with mud and plant resins Entrance hole in the center of a clay, resin, beeswax patch decorated with furrowed rays
Melipona scutellaris [2.0 km]	10.5	1500 (1000–2000)	Tree cavities Horizontal brood combs with involucrum Batumen borders with mud and plant resins Entrance hole in the center of a clay, resin, beeswax patch decorated with furrowed rays
Melipona seminigra [5.0 km]	10.5	2000 (1000–3000)	Tree cavities Horizontal brood combs with involucrum Batumen borders with mud and plant resins Entrance hole in the center of a clay, resin, beeswax patch decorated with furrowed rays
Nannotrigona testaceicornis [0.9 km]	4.0	2500 (2000–3000)	Tree cavities Horizontal helicoidal brood combs, involucrum Ovoidal storage pots, and plant resin deposits Short entrance nest tube
Paratrigona lineata [unknown]	4.5	(unknown)	Underground, more than 1 m old ant cavities Horizontal brood combs with involucrum Small tower cerumen nest entrance
Plebeia droryana [0.5 km]	3.5	2400 (1070–3000)	Tree cavities Horizontal helicoidal brood combs, involucrum Entrance cerumen nest tube, sometimes two
Scaptotrigona postica [0.9 km]	6.0	8000 (6000–10000)	Tree cavities Horizontal brood combs with involucrum Some colonies share a cavity divided by a batumen layer Large beige entrance nest tube
Scaptotrigona depilis [unknown]	5.5	(>10000)	Tree cavities Horizontal brood combs with involucrum Large entrance nest tube
Tetragona clavipes [unknown]	6.5	7300 (5400–29000)	Tree cavities Horizontal spiral brood combs with involucrum Ovoidal storage pots 3–5 cm height, Variable large nest entrance with hardened resin
Tetragonisca angustula [0.6 km]	4.0	5000 (2000–8000)	Tree cavities, rock cavities or crevices Ovoidal storage pots, with pot-resin and white beeswax resin Entrance nest tube tilted with upper hole
Trigona spinipes [0.8 km]	6.5	13200 (5000–23600)	Exposed aerial nests, with an envelope of plant resins, cerumen, mud, fibers, vertebrate feces Horizontal spiral brood combs, involucrum Spheroidal storage pots, deposits of beeswax and plant resins Large entrance with blades of cerumen

After: A.B.E.L.H.A.[33]

Due to the lower yields of pot-honey, pot-pollen and propolis, stingless bee products are known to have higher costs than *Apis mellifera*, and thus pot-honey has been imitated, mixed with honeybee products, sugars and syrups used in the bee fraud industry (P. Vit, personal observation). Pot-honey yields of *Melipona scutellaris* are 2–15 kg/year (R.M.O. Alves personal observation), *Scaptotrigona* spp 3 kg/year, and *Tetragonisca angustula* 1 kg/year[140] at about 100–200 USD/kg. Pot-pollen yields of *Melipona scutellaris* are 4–5 kg/year, *Scaptotrigona* spp. 5–6 kg/year, and *Tetragonisca angustula* 3–4 kg/year with a value from 32 to 257 USD/kg[141].

Untargeted ^{1}H-NMR studies of sugar profiles of stingless bee honey and chemometrics are particularly useful to detect adulterations[182]. For certain entomological origins, the recently discovered trehalulose[93] is a potential sugar for genuine pot-honey authenticity[78]. Targeted ^{1}H-NMR revealed distinctive composition of pot-honey at genus level[12]. A simple palynological screening would detect absence of pollen spectra in sugar or syrup manufactured fake honey[183]. However, sophistication requires diverse bioanalytical techniques for pot-honey fraud control. For the expert, a simple sensory evaluation uncovers the adulteration, but consumers are not always acquainted with stingless bee nest materials as meliponicultors or a community with stingless bee apiaries or meliponaries. A honey authenticity test based on interface emulsion produced after shaking a honey dilution with diethyl ether, differentiated genuine from fake honey[184], and recently provided a further interpretation on suspected microbial associations with the Ecuadorian *Scaptotrigona vitorum* producing biosurfactants in pot-honey[12].

Conclusions

The biotic materials processed to form pot-honey and pot-pollen have botanical, entomological, and microbial origins, along with plant resins that are essential for producing cerumen, a vital component of stingless bee nests. These nest materials contain diverse compounds and active metabolites that play crucial roles in their biological activities. Their antimicrobial and antioxidant properties contribute significantly to the added value of stingless bee nest materials, supporting their medicinal potential for both nutritional and pharmaceutical applications.

Research on the metabolites present in stingless bee nest materials and their ecological roles provides valuable insights into the complex relationships between stingless bees and their environment. Understanding the chemical composition of these materials may aid conservation efforts targeting both the pollinators and the ecosystems they sustain. The loss of stingless bee biodiversity would also mean the loss of chemical diversity in the bioactive metabolites within their nests, and, consequently, the loss of valuable natural healing molecules.

Our bibliometric analyses evaluated global scientific research on medicinal stingless bees (2004–2023) and stingless bees in climate change (2010–2023), using *Bibliometrix* to visualize datasets retrieved from the Scopus database. The medicinal dataset included 107 documents, showing greater research interest compared with the climate change dataset, which contained 25 documents. Top researchers, institutions, countries, sources, subject areas, and funding sponsors were identified. Hilgert N.I. (Argentina) was the most prolific author in medicinal stingless bee research for her contributions in ethnomedicine, while Martins C.F. (Brazil) led climate change–related studies on habitat loss and pollinator protection, each of them contributing four publications in their respective areas.

Malaysia, Brazil, and Mexico were the top three countries contributing with 62 of 107 documents for medicinal stingless bee research; and for stingless bees in climate change, whereas Brazil, the United States, and Indonesia accounted for 22 of 25 documents on stingless bees and climate change. The most prominent publication sources used to disseminate stingless bee research were the book *Pot-Honey: A Legacy of Stingless Bees* for the medicinal dataset, and the journal *Apidologie* for climate change research. Initiatives promoting pollinator protection within agricultural frameworks benefit both stingless bee conservation and the use of active metabolites of their nests in meliponitherapy.

The role of microbiomes in metabolite transformation, the authenticity and chemical variability of nest materials, and the relevance of stingless bee biodiversity conservation are emphasized as interconnected drivers of medicinal potential and ecosystem sustainability. In bridging ethnomedicine, microbiology, chemistry, and environmental science, this paper provides a multidisciplinary framework that supports meliponitherapy as a promising field contributing to food security, health, and the Sustainable Development Goals (SDG 2 and SDG 3).

Proposals for Future

Bibliometric reviews on the medicinal uses of stingless bee products for the human body systems need to be periodically updated, and medicinal research funded. Studies on medicinal properties should involve interactive collaboration among entomologists, chemists specializing in stingless bee products, melissopalynologists, and sensory scientists to establish standardized characterizations of raw materials and extracts used by experts in health sciences, experimental biology, and molecular biology. This multidisciplinary approach, which should also include statisticians, can provide a strong foundation for elucidating mechanisms of action over time.

Medicinal and climate change approaches interact over the long term. Brazil, which harbors the greatest stingless bee biodiversity for a country (259 of 605 recognized species worldwide), manages 95 species across its five regions, 12 of which are featured in the A.B.E.L.H.A. catalog, with sizes ranging from 3.5 to 10.5 mm. It is important to note that research on stingless bee nest materials remains ongoing. Understanding the specific active metabolites and their potential applications for human health continues to evolve framed in the Sustainable Development Goals SDG2 food security and SDG3 good health and well-being.

Stingless bees yield increasing amounts of medicinal pot-honey, pot-pollen, cerumen, and propolis, and their derivative products are being progressively developed. The conservation of natural ecosystems and the establishment of stingless bee–friendly managed environments are vital strategies for biodiversity preservation and sustainable meliponiculture, particularly in anticipation of shifting geographical distributions caused by climate change.

Reviews focusing on chemical classes are valuable for developing databases, updating bioanalytical methods, and revising reported units in the scientific literature. For instance, After reviewing aliphatic organic acids in honey and pot-honey, Vit and Simova[96] provided updated reference concentration values to replace the underestimated 0.5% AOA content commonly cited in scientific literature. Access to public databases that collect, verify, publish, and maintain DNA sequences globally[135] will be essential for advancing the study of stingless bee nest materials through expert curation, facilitating data exchange, and understanding. Moreover, targeting outer membrane components to enhance antibiotic permeability in Gram-negative bacteria could represent an innovative strategy to curb antimicrobial resistance, similar to recent insights into fungal capsule structures for approaches on novel disease control[136].

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