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Probiotic and biotechnological potential of the microbiota from Brazilian native bees: A comprehensive review of the literature

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Abstract

Microorganisms found in stingless native bee hives have been studied for their functional potential and applicability in probiotic products and bioinputs. This review aims to compile the main scientific evidence on the microorganisms present in these symbiotic systems and discuss their applications in the food, health, and agriculture sectors. The research was conducted using PubMed and ScienceDirect databases, covering publications from 2015 to 2025. A bibliometric analysis with the VOSviewer software was used to map scientific trends and knowledge gaps. The studies analyzed reveal that hives of native bees harbor a diverse microbiota—composed of lactic acid bacteria, sporulated bacilli, actinobacteria, and yeasts—with antioxidant, antimicrobial, immunomodulatory, and fermentative properties. These strains show promising potential for use in functional foods, supplements, symbiotics, and biofertilizers. The microbiota of native bees therefore represents a strategic frontier for technological innovation based on Brazilian sociobiodiversity.

Keywords: stingless bees; natural probiotics; symbiotic microbiota; agri-food innovation; microbial biodiversity.

Practical Application: Native Brazilian bee microbiota can be used in probiotics and functional foods.

1 INTRODUCTION

Native Brazilian bees (*Meliponini*) represent one of the most important pollinator lineages in tropical ecosystems, contributing significantly to plant diversity and food security in rural communities. In contrast to the exotic and abundant *Apis mellifera*, stingless bee species such as *Melipona scutellaris* and *Tetragonisca angustula* produce and store honey, fermented pollen, and geopropolis within waxy microenvironments that support specialized microbial communities (Paula et al., 2021).

The microenvironments formed within the hives of native bees, such as honey, fermented pollen, and geopropolis, favor the natural selection of lactic acid bacteria, actinobacteria, and spore-forming bacilli, which are highly adapted to tropical conditions. These microorganisms act in symbiotic consortia, performing relevant functions such as the biosynthesis of antimicrobial compounds, environmental acidification, and protection against pathogens (Rodríguez-Hernández et al., 2019; Zulkhairi Amin et al., 2019).

Recent studies have highlighted that microorganisms associated with bee products, particularly those from stingless bees, exhibit relevant biochemical and bioactive properties—including the production of antimicrobial substances, organic acids, and antioxidant compounds. These attributes indicate their potential application in the development of functional foods and biotechnological innovations based on native microbiota (Silva et al., 2024).

While traditional probiotics are obtained from fermented dairy matrices, such as yogurts and cheeses, microorganisms isolated from stingless bee hives represent a robust alternative adapted to regional food systems. These strains demonstrate remarkable tolerance to environmental stressors and show metabolic versatility, including antioxidant activity, enzyme production, and adhesion capacity to biological matrices (Silva et al., 2024; Zulkhairi Amin et al., 2019). The functional characteristics of these bacteria support applications that go beyond human health supplements, encompassing the development of bioinputs aimed at restoring soil quality, strengthening agricultural systems, and promoting agroecological sustainability.

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In light of the progress of research and the emergence of regulatory frameworks on the use of Brazilian genetic resources (Brazil, 2015), it becomes strategic to systematize the accumulated knowledge about these strains, particularly given the growing interest of industry in natural, sustainable, and territorially grounded solutions. Moreover, the assessment of recent scientific production allows the identification of thematic gaps and opportunities for innovation based on native resources.

This work aims to systematize the available scientific evidence on the microbiota of native Brazilian bee hives, highlighting their functional characteristics, potential biotechnological applications, and regulatory challenges. The approach includes an integrative review and a bibliometric analysis of scientific publications indexed in the main databases, supported by VOSviewer software for the visualization of the most recurrent themes.

1.1. Relevance of the work

This study systematizes current knowledge on the microbiota of Brazilian native bee hives, emphasizing its biotechnological potential in functional foods, health, and sustainable agriculture. By combining an integrative review with bibliometric analysis, it highlights scientific advances, identifies thematic gaps, and points to innovation opportunities based on native resources. It also addresses regulatory and technical challenges, crucial for introducing these strains into strategic markets. Thus, it contributes to valuing Brazilian sociobiodiversity, guiding future research, and supporting policies for the sustainable and safe use of autochthonous microorganisms.

2 MATERIAL AND METHODS

This integrative review was conducted through a bibliographic search in the *PubMed* and *ScienceDirect* databases. The time frame covered the period from 2015 to 2025, considering publications in Portuguese, English, and Spanish. The descriptors used included: “stingless bees,” “native bees,” “Meliponini,” “probiotics,” “bee microbiota,” “biotechnology,” “bioactive compounds,” and “biodiversity.”

The combination of terms was performed using the Boolean operators “*OR*” and “*AND*,” and filters were applied to retrieve articles focused on microorganisms isolated from native bee hives, their functional properties, and technological applications. Original articles and systematic reviews with microbiological or biotechnological evidence were included.

To ensure the comprehensiveness of the research, the searches were carried out in two main stages: (i) Identification and screening of titles and abstracts; (ii) Full-text analysis of the selected articles.

After screening, the extracted data were organized by microorganism type, isolation method, functional tests, source matrix (honey, pollen, geopropolis), and biotechnological application.

In addition, a bibliometric analysis was performed using the *VOSviewer software* (version 1.6.20), with files exported from the *PubMed* and *ScienceDirect* databases. The term co-occurrence analysis was based on the authors’ keyword fields, with a minimum threshold of one occurrence per term. The generated maps were visually interpreted by thematic clusters, highlighting the most recurrent, less explored terms and their possible correlations.

3 RESULTS AND DISCUSSION

3.1 Microbial diversity in native bee hives

Stingless bee hives in Brazil, particularly from genera such as *Melipona*, *Scaptotrigona*, and *Tetragonisca*, host a highly diverse microbial community. Larval food, known as “bee bread,” contains bacteria from the phyla *Firmicutes*, *Proteobacteria*, and *Actinobacteria*, as well as fungi from *Ascomycota*, *Basidiomycota*, *Mucoromycota*, and *Mortierellomycota* (Cerqueira et al., 2021; Santos et al., 2023).

Gut analyses reveal nine dominant bacterial families, including *Acetobacteraceae*, *Bifidobacteriaceae*, *Lactobacillaceae*, and *Enterobacteriaceae*, accounting for roughly 97% of sequences identified via 16S rRNA analysis (Sarton-Lohéac et al., 2023).

Microbial composition on nest surfaces varies with construction materials. Resin-based nests are dominated by *Pseudomonas* and *Sphingomonas*, whereas nests built with soil or feces show higher abundance of coliforms such as *Escherichia coli* and *Alcaligenes faecalis* (Sousa, 2021).

Comparative studies indicate that stingless bee hives maintain more diverse and balanced microbial communities than other bee groups, with greater richness and evenness across dry and rainy seasons (Kueneman et al., 2023).

Metagenomic analyses further show that *Melipona* hives lack typical Apini symbionts, such as *Snodgrassella* and *Gilliamella*, but host other groups, including *Lactobacillus*, *Bifidobacteriaceae*, *Acetobacteraceae*, and yeasts like *Starmerella*, *Zygosaccharomyces*, and *Lachancea*, reflecting adaptations to their specific ecosystem (Cerqueira et al., 2021).

3.2 Probiotic and functional potential of strains

Native bee hives, especially those of the genus *Melipona*, constitute habitats rich in microorganisms with functional properties of great interest to the food, pharmaceutical, and agricultural industries. Recent studies have identified a predominant bacterial diversity in *Melipona*, including genera such as *Bifidobacterium*, *Lactobacillus*, *Apilactobacillus*, and *Floricoccus*, which are recognized for their probiotic properties and therapeutic potential (Cerqueira et al., 2024; Luca et al., 2024; Sarton-Lohéac et al., 2023).

Moreover, the gut microbiota of these stingless bees has been associated with the production of bioactive compounds, such as short-chain fatty acids and antimicrobial peptides, which play essential roles in host health and protection against pathogens (Motta & Moran, 2024; Tilocca et al., 2024). These properties suggest a promising potential for the development of functional products derived from these microbial communities.

Functional characterization of the microbiota also revealed the presence of *Lactobacillaceae* and *Saccharomycetaceae*, bacterial families that play crucial roles in modulating the intestinal microbiome and host immune defense (Grinn-Gofroń et al., 2025; Todorov et al., 2024). Studies on stingless bee honey, such as Rosli et al. (2020), have demonstrated significant antibacterial activity against human pathogens, highlighting its potential as a source of natural antimicrobials.

From a technological perspective, strains isolated from these hives have shown good stability during industrial processes, such as freeze-drying and microencapsulation, which are essential for their application in functional foods, nutritional supplements, and agro-food formulations. Maintaining viability and metabolic activity after these processes expands their potential use in various food matrices, including juices, honey, and plant-based products (Toutiaee et al., 2022).

In summary, bacteria isolated from Brazilian native bee hives exhibit a set of functional attributes that position them as promising sources for the development of biotechnological solutions applicable to human health, sustainable agriculture, and the food industry.

3.3 Applications in food, health, and agriculture

Microbial communities present in native bees, particularly those of the genus *Melipona*, demonstrate significant potential for applications in functional foods, human health, and sustainable agriculture. Recent studies have shown that bacterial strains isolated from these colonies can act as starter or adjunct cultures in fermentations of tropical products, such as juices, yogurts, and plant-based beverages, promoting synbiotics with a distinct territorial identity. The combination of raw honey and autologous strains from the colony confers antimicrobial and antioxidant properties superior to those of synthetic products (Cerqueira et al., 2024; Santini et al., 2025).

In the context of human health, these strains have been evaluated as ingredients in probiotic supplements, showing promising effects on immune modulation and gut health. Research indicates that microorganisms derived from *Melipona* colonies contribute to the balance of the intestinal microbiota, presenting potential for the prevention of gastrointestinal infections and improvement of digestive parameters (Alves et al., 2024; Tariq et al., 2025).

In agricultural systems, species such as *Bacillus subtilis*, *Paenibacillus polymyxa*, and *Streptomyces griseus* have been applied as biofertilizers and biocontrol agents against phytopathogenic pathogens. The introduction of these bacteria into agroecological systems contributes to increased soil productivity, reduced use of chemical pesticides, and the promotion of sustainable farming practices (Langendries & Goormachtig, 2021; Li et al., 2024; Liu et al., 2021; Sun et al., 2020; Zalila-Kolsi et al., 2025).

3.4 Regulatory and technical challenges

Despite their promising potential, the commercial use of microorganisms isolated from Brazilian native bee hives faces significant regulatory and technical barriers. A major limitation is the absence of these strains from key international food safety lists, such as the GRAS (Generally Recognized As Safe) designation by the U.S. Food and Drug Administration and the QPS (Qualified Presumption of Safety) by the European Food Safety Authority (EFSA). Without these certifications, direct application of the strains in foods and supplements requires extensive toxicological dossiers and robust scientific safety studies (EFSA Panel on Biological Hazards et al., 2025, 2026).

In Brazil, the National Health Surveillance Agency (ANVISA) and the Ministry of Agriculture, Livestock, and Supply (MAPA) impose strict requirements for probiotic registration. These include proof of functional efficacy, stability studies during storage, full genomic characterization, and often clinical trials to validate safety and health benefits (ANVISA, 2021; Brazil, 2018).

In addition, the recent Resolution of the Collegiate Board—RDC No. 839, of 12/14/2023 (Brazil, 2023b) establishes specific criteria for the authorization of new foods and ingredients, including microorganisms that do not have a history of safe use in Brazil. This standard requires the submission of complete genomic identification data, assessment of virulence and antimicrobial resistance factors, absence of pathogenicity genes, and proof of a history of safe use, in addition to characterization of purity and composition (Brazil, 2023b). In addition, RDC 843/2024 and IN 281/2024 (Brazil, 2024a, 2024b) update the procedures for registration and prior assessment of the safety and efficacy of probiotics in foods and supplements, reinforcing the need for a formal petition to ANVISA prior to commercialization (Brazil, 2024a).

The provisions of RDC 243/2018 and IN 28/2018 (Brazil, 2018a, 2018c) also apply, regulating the composition, limits of use, and labeling of dietary supplements containing probiotics (Brazil 2018a; 2018c). MAPA, in turn, requires the registration of biotechnological products for veterinary or agricultural use containing microorganisms, based on dossiers that include data on characterization, stability, efficacy, and environmental safety (Brazil, 2020, 2023a).

Additionally, access to genetic resources and benefit-sharing obligations under Law No. 13.123/2015 (Brazil, 2015), regulated by the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SISGEN), present further challenges. Compliance with these rules affects research projects, new strain registration, and the development of products derived from native microorganisms (Brazil, 2015).

The absence of structured microbial strain banks that adequately represent Brazil's native biodiversity remains a major obstacle to the industrial and technological advancement of bioproducts derived from native microorganisms. This limitation hinders the reproducibility of studies, delays regulatory validation processes, and reduces competitiveness in the global biotechnology market. Moreover, the lack of infrastructure for safe long-term preservation of native strains and restricted access to registered collections under SISGEN regulations further discourage private investment and technology transfer (Brazil, 2015).

At the production level, technical demands such as optimization of cultivation parameters, lyophilization, stability testing, and strict cross-contamination control significantly increase operational costs, complicating industrial scale-up and market entry (ANVISA, 2025a, 2025b). These combined regulatory and technical bottlenecks emphasize the urgent need for coordinated public policies that integrate biodiversity conservation, innovation, and industrial biotechnology development in Brazil.

3.5 Bibliometric analysis of scientific production

To complement the integrative review with a quantitative perspective, a bibliometric analysis was conducted to map thematic trends, most frequent terms, and research gaps in the literature on the microbiota of Brazilian native bees with probiotic and biotechnological potential. Searches were performed in *PubMed* and *ScienceDirect* using the thematic filter "(*stingless bees OR native bees OR Meliponini) AND microbiota AND probiotic,*" covering the period from 2015 to 2025.

Visualizations were generated using *VOSviewer* (version 1.6.20), employing a keyword co-occurrence analysis based on author-provided keywords, with full counting and a minimum occurrence threshold of one term, to capture both established and emerging topics. Data were analyzed separately by database to allow comparison and identification of thematic specificities.

In *PubMed*, 35 distinct clusters were identified (Figure 1), with prominent terms including "*stingless bees,*" "*pollination,*" "*phylogeny,*" "*diversity,*" and "*taxonomy*" reflecting the predominance of studies focused on ecology, diversity, and classification of stingless bees. Emerging terms such as "*biotechnology,*" "*metabolomics,*" and "*fructophilic lactic acid bacteria*" indicate a gradual shift from ecological studies toward more functional and applied approaches. The map structure reveals thematic organization around conservation, taxonomy, pollination, and bioprospecting, highlighting both established knowledge areas and opportunities for further research.

In the ScienceDirect database, the analysis identified *27 clusters* (Figure 2), with a predominance of terms such as "*probiotics,*" "*honey,*" "*microbiota,*" "*gut microbiota,*" and "*health benefits.*" These results indicate a more applied focus, emphasizing microbial functionality, human health, food safety, and the use of hive products as symbiotic or therapeutic agents. The clusters highlight connections between bioactive compounds (*phenolic acids, propolis*), gut metabolism, microbiota modulation, and sustainable agrofood applications.

The comparison between databases reveals two complementary research profiles. *PubMed* predominantly reflects an ecological and descriptive approach, focusing on bee biodiversity and natural symbiotic systems, whereas *ScienceDirect* emphasizes biotechnological applications of microorganisms associated with these systems. Both databases converge on emerging themes related to gut health, antimicrobial compound production, and potential agro-industrial applications.

The combined analysis indicates that, despite growing literature on native bees, significant gaps remain in functional validation and regulatory aspects of microbial strains isolated from these environments. Few studies report in vivo experiments or translational approaches, and discussions on regulatory frameworks with ANVISA (for food probiotics) or MAPA (for agricultural bioinputs) are scarce. Furthermore, the intersection of microbiota, biodiversity, and innovation remains an emerging field, with low methodological standardization and disciplinary fragmentation.

ibliometric data highlight the potential of native bee hive microbiota as a strategic frontier for sustainable innovation. Frequently recurring keywords—such as *probiotics*, *health*, *pollination*, *biotechnology*, and *diversity*—indicate a fertile scientific field that could be advanced through interdisciplinary research, functional assays, registration of native strains in recognized microbial collections, and development of symbiotics integrated with hive products. These initiatives may promote human health, sustainable agriculture, and ethical valorization of Brazil's sociobiodiversity.

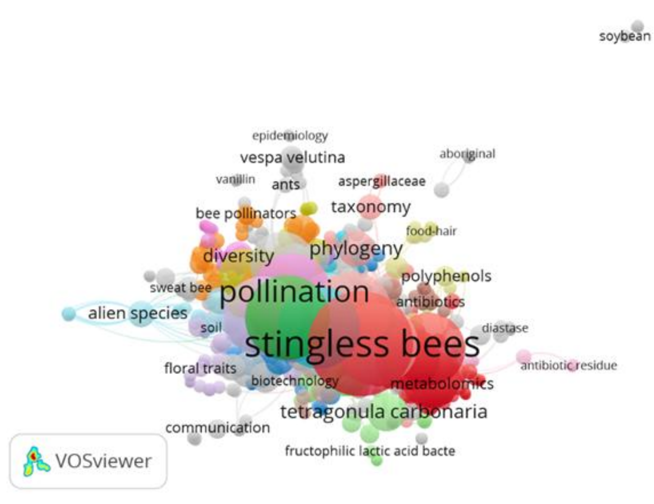

Figure 1. Co-occurrence map of author keywords in the PubMed database from 2015 to 2025.

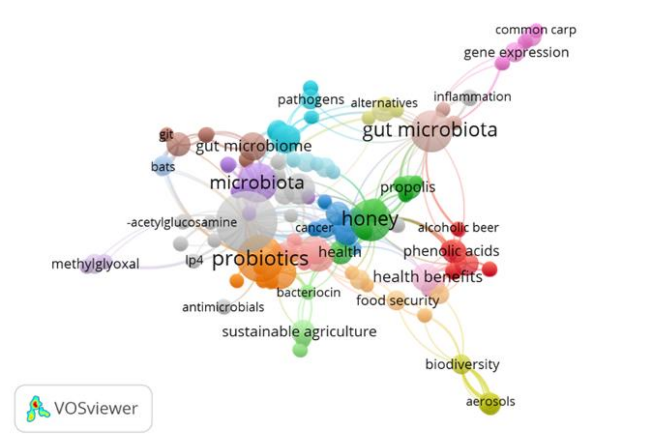

Figure 2. Author keyword co-occurrence map in the ScienceDirect database between 2015 and 2025.

4 CONCLUSIONS

The symbiotic microbiota of Brazilian native bee hives exhibits unique ecological and functional characteristics, reflecting the coevolution of insects, plants, and microorganisms in tropical environments. Microorganisms isolated from these systems demonstrate potential for applications in functional foods, probiotic supplements, biofertilizers, and biocontrol agents.

Despite the demonstrated diversity and technological potential, challenges remain, such as the lack of regulatory recognition for native strains, the absence of adapted industrial production protocols, and legal barriers to safe and ethical commercial exploitation. Integration between academic research, strain banks, and public innovation policies is essential to transform this microbiological heritage into technological assets.

Finally, a bibliometric analysis highlighted the recent growth of scientific interest in this area, while also revealing important thematic gaps. Strategic future directions include the exploration of tropical symbiotics, the incorporation of these microorganisms into agroecological systems, and the standardization of Brazilian regulatory frameworks.

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