FERMENTABLE SUGARS AND THEIR INFLUENCE ON THE SENSORY PROFILE OF MEAD

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Fermentable sugars play a decisive role in fermentation dynamics and the formation of mead's sensory profile. This study conducted a bibliometric review using the Bibliometrix package in the R programming language, employing the search strategy "sugar" AND "honey" AND "fermentation". The analysis identified scientific trends, collaboration networks, and knowledge gaps, highlighting the relationship between fermentable substrates and the beverage's sensory quality.

Keywords: Sensory analysis; Reducing sugars; Bioconversion; Fermentation.

INTRODUCTION

Honey is a natural product produced by bees from flower nectar, featuring a complex chemical composition that varies according to botanical origin, climatic conditions, beekeeping practices, and processing methods. It consists predominantly of fructose and glucose, alongside minor compounds such as sucrose, maltose, proteins, amino acids, minerals, vitamins, phenolic compounds, and enzymes. Thus, honey represents a matrix rich in fermentable substrates and bioactive compounds (Kiran *et al.*, 2026).

These characteristics of honey have contributed to growing interest within both the food industry and the scientific community, driven by its high nutritional value and potential application in fermentation processes for the production of beverages and other biotechnological products (Sawant *et al.*, 2025).

Fermentation is a metabolic process carried out by microorganisms capable of converting carbohydrates into a variety of end products; it is widely employed in food and beverage production. During alcoholic fermentation, fermentable sugars serve as the primary source of carbon and energy, being metabolized via different biochemical pathways that result in the formation of ethanol, carbon dioxide, and various secondary metabolites (Siddiqui *et al.*, 2023).

Fermentation efficiency is influenced by factors such as substrate composition, nutrient availability, temperature, pH, and the physiological characteristics of the microorganisms, all of which determine fermentation dynamics and process yield (Mengesha *et al.*, 2022).

In addition to primary fermentation products, the synthesis of secondary metabolites plays a crucial role in defining the sensory quality of fermented beverages. Compounds such as esters, higher alcohols, organic acids, aldehydes, ketones, and volatile sulfur compounds are produced in varying concentrations, depending on fermentation conditions and microbial metabolism (He *et al.*, 2026).

The interaction among these fermentation-derived compounds imparts attributes related to aroma, flavor, body, taste balance, and sensory persistence, making the sensory profile a key indicator of the product's final quality and consumer acceptance. In this context, the composition of fermentable sugars and their metabolism are determining factors in the formation of these compounds and the sensory complexity of fermented beverages. The significant growth in scientific literature regarding fermentation, carbohydrate metabolism, and the formation of sensory compounds highlights the need to systematize existing knowledge. Accordingly, a bibliometric review offers a quantitative approach to characterizing the evolution of a scientific field, identifying high-impact authors, institutions, journals, and countries, as well as mapping collaboration networks, thematic trends, and knowledge gaps (Li *et al.*, 2025; Chica-Wojciechowicz *et al.*, 2024).

When combined with the Bibliometrix package, developed for the R programming language, this methodology provides robust indicators regarding the structure and dynamics of scientific output, helping to guide future research and support technological advancements in the field (Aria et al., 2026; Reitenbach et al., 2025).

Against this backdrop, the present study aimed to conduct a bibliometric review of the scientific literature concerning fermentable sugars and their influence on the sensory profile of honey-based fermented beverages. The study sought to identify publication trends, key authors, journals, collaboration networks, and research directions, thereby contributing to an understanding of the state of the art and identifying future prospects in this field of inquiry.

MATERIALS E METHODS

A comprehensive bibliometric search was conducted in the Scopus database on July 3, 2026, covering publications indexed between 1962 and 2026. The search strategy employed the Boolean operators "Sugar" AND "honey" AND "fermentation," with terms searched within the documents title, abstract, and keyword fields. The search was performed without language restrictions, and only scientific articles were included in the analysis. Retrieved records were exported in BibTeX format for subsequent bibliometric processing.

Prior to analysis, the dataset was carefully inspected and standardized to identify duplicate records, metadata inconsistencies, and formatting errors. Bibliometric analyses were performed using the Bibliometrix® package via the Biblioshiny graphical interface to the R programming language (version 4.5.1). These tools were employed to assess key bibliometric indicators, including annual scientific output; the most productive authors, journals, institutions, and countries; as well as citation patterns, co-authorship networks, co-citation analysis, bibliographic coupling, keyword co-occurrence, thematic evolution, and international scientific collaboration networks (Aria *et al.*, 2017).

RESULTS AND DISCUSSION

The bibliometric analysis (Figure 1) covered the period from 1962 to 2026, totaling 301 documents indexed across 195 publication sources. The scope of the analysis encompassed 1,316 authors, of whom only 23 published single-authored works, highlighting the predominance of collaborative research. This scenario is corroborated by an average of 4.98 co-authors per document and an international co-authorship rate of 13.29%. Scientific output showed an average annual growth rate of 4.87%, indicating a continuous expansion of the literature over recent decades.

Furthermore, 985 author keywords and 38,992 bibliographic references were identified, with a mean document age of 7.43 years and an average of 18.73 citations per publication. These indicators highlight a consolidated research field characterized by a high degree of scientific interconnectivity and significant academic impact. Collectively, these results reflect the maturation of the field of study, demonstrating that research related to fermentable sugars, honey, and fermentation processes has shown consistent growth, supported by an extensive researcher collaboration network and a robust bibliographic base, factors that foster the advancement of knowledge and the development of new scientific approaches.

Figure 1. Bibliometric indicators of scientific output retrieved from the Scopus database for the period from 1962 to 2026

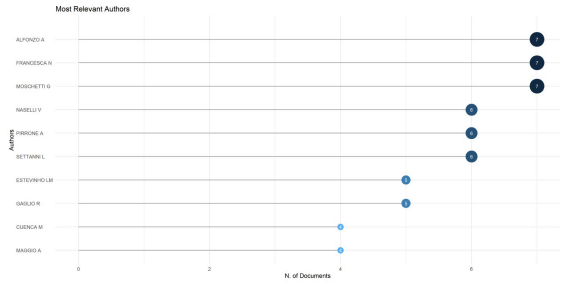
The analysis of author productivity revealed an asymmetrical distribution of scientific output, highlighting that the advancement of knowledge in the field is driven by a small number of highly productive researchers, while the majority of authors contribute only sporadically (Figure 2). This pattern aligns with Lotka's Law, which posits that a small fraction of researchers is responsible for a large share of scientific output in a given field. Antonio Alfonzo, Nicola Francesca, and Giancarlo Moschetti stood out, each with seven publications, followed by Valentina Naselli, Antonio Pirrone, and Lorenzo Settanni, with six publications each; this underscores the existence of a core group of researchers driving key investigations into the subject matter.

The influence of these authors is corroborated by individual bibliometric indicators, which show similar performance among Antonio Alfonzo, Nicola Francesca, and Giancarlo Moschetti. All three have 110 citations, an h-index of five, and an average of 15.7 citations per publication. These results indicate that the scientific relevance of these researchers stems not only from their high volume of published work but also from the impact of their research and their ability to influence subsequent studies.

Furthermore, the concentration of publications within the last decade highlights the scientific community's growing interest in research related to

fermentation, food microbiology, and the development of fermented beverages with superior technological and sensory qualities. This scenario reflects the field's strengthening, driven by the search for new biotechnological strategies capable of optimizing fermentation processes, harnessing the metabolic potential of various microorganisms, and adding value to honey-based fermented beverages.

A)



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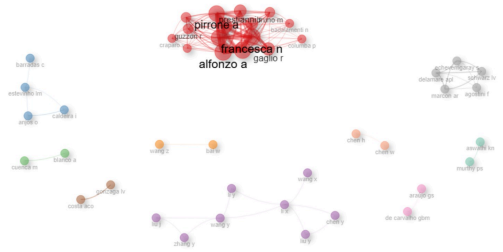


Figure 2. Scientific authorship structure: author productivity (A), and co-authorship network of the analyzed literature (B).

Keyword analysis reveals a high degree of thematic convergence among the most productive researchers, with a predominance of terms related to alcoholic fermentation, *Saccharomyces cerevisiae*, mead, honey, microbiology, volatile compounds, and spontaneous fermentation. This concentration highlights a high level of scientific specialization and suggests that research has evolved from predominantly descriptive approaches to more integrated studies involving microbiology, biochemistry, analytical chemistry, and food technology. This interdisciplinary approach has contributed significantly to the understanding of fermentation processes and to the development of products with superior quality and technological potential.

The co-authorship network displays a modular structure composed of distinct collaboration groups; the primary cluster consists of Nicola Francesca, Antonio Alfonzo, Antonio Pirrone, Rosaria Gaglio, and Giancarlo Moschetti, who exhibit a high density of connections. From the perspective of scientific network analysis, these researchers occupy central positions, acting as key hubs for knowledge generation and dissemination, thereby fostering the exchange of methodologies, infrastructure, and multidisciplinary expertise. Conversely, the existence of independent clusters involving researchers from Portugal, China, Brazil, Argentina, and India demonstrates that, although mead research is undergoing increasing internationalization, a certain degree of geographic fragmentation in scientific output persists.

Overall, the results demonstrate that scientific development in this field is driven by a small core of highly productive researchers with significant academic impact, capable of establishing and strengthening collaborative networks. The coexistence of a highly connected central group and various peripheral clusters characterizes a scientific field in the process of consolidation, where strengthening international collaborations offers an opportunity to expand knowledge dissemination, diversify methodological approaches, and accelerate innovation in research concerning fermentation processes and the quality of honey-based fermented beverages. Analysis of the temporal evolution of research topics reveals a progressive transformation in lines of inquiry throughout the study period, reflecting the scientific maturation of the field (Figure 3). Initial studies focused on the physicochemical and nutritional characterization of honey, with a predominance of themes related to food composition, carbohydrates, proteins, and nutritional value. From the 2010s onwards, a shift in research focus is evident, incorporating investigations into fermentation, yeasts, *Saccharomyces cerevisiae*, microbiology, and volatile organic compounds. This transition demonstrates an expansion of the research scope, moving beyond the mere characterization of raw materials to explore the microbiological and biochemical processes involved in the production of honey-based fermented beverages.

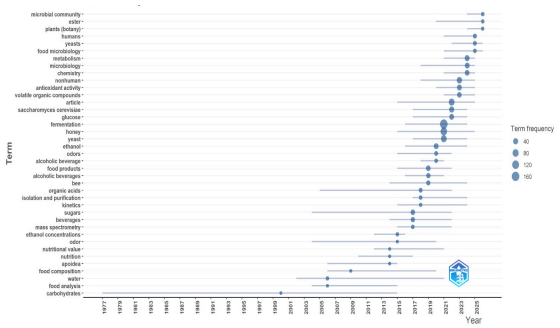


Figure 3. Temporal evolution of the main research topics in the scientific literature on honey.

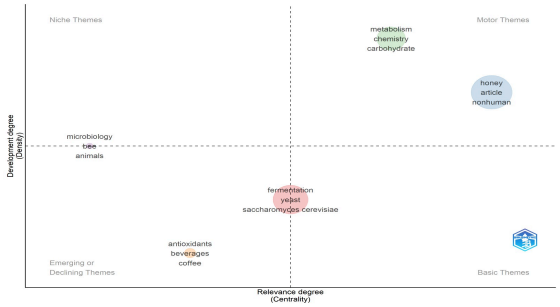


Figure 4. Thematic map of scientific production on honey, based on the centrality and density of descriptors.

In recent years, themes related to metabolism, metabolomics, microbial communities, botany, pollination, and esters have emerged, signaling a shift toward more integrated approaches of greater analytical complexity. This trend parallels the adoption of modern chemical and molecular analysis techniques, enabling a deeper understanding of metabolic pathways, microbial community dynamics, and the formation of compounds responsible for the sensory and technological characteristics of mead. Thus, the field is continuously evolving toward the integration of microbiology, biochemistry, analytical chemistry, and food science.

The thematic map (Figure 4) illustrates varying levels of development and importance among the research lines. Themes related to metabolism, chemistry, and carbohydrates exhibit high centrality and density, characterizing them as driving themes within the field. These results indicate that these subjects play a fundamental role in structuring scientific output, underpinning a significant portion of the research conducted. Similarly, the cluster comprising the terms "honey" and "nonhuman" shows high centrality, highlighting that honey remains the primary focus of investigation and continues to guide studies on raw material characterization, quality, fermentation, and technological development. In contrast, the themes of fermentation, yeast, and *Saccharomyces cerevisiae* are positioned near the center of the thematic map, classified as basic and transversal themes. Although they exhibit lower density compared to the driving themes, their high centrality demonstrates that these research lines connect with virtually all other areas of knowledge within the scientific field. This positioning reinforces the role of fermentation as an integrating element among microbiology, biochemistry, and food technology, forming the foundation for the development of new production strategies, quality control measures, and technological innovations in mead production.

Finally, topics related to antioxidants, beverages, coffee, microbiology, bees, and animals are classified as niche or emerging themes, characterized by lower density or connectivity within the thematic network. However, recent growth in research involving bioactive compounds, functional microbiota, and the sustainability of the beekeeping supply chain suggests that these areas hold significant potential for expansion in the coming years. Overall, the results demonstrate that the literature has evolved from studies focused primarily on honey characterization to broader research integrating advanced analytical tools and multidisciplinary approaches, thereby consolidating a more robust scientific foundation for technological development and innovation in mead production.

The keyword co-occurrence network (Figure 5) reveals the thematic organization of the literature into four main clusters, indicating the multidisciplinary nature of research on honey and fermentation. Node size reflects term frequency, while connection intensity represents the strength of the association between terms. In this context, the terms "fermentation" and "honey" stand out as the network's primary hubs, reflecting their central role in the conceptual structure of the analyzed publications.

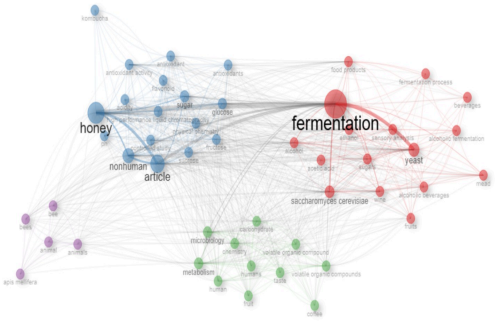


Figure 5. Structure of the keyword co-occurrence

network from the scientific literature on honey and fermentation processes.

The red cluster focuses on studies related to the fermentation process, grouping keywords such as yeast, *Saccharomyces cerevisiae*, ethanol, alcoholic fermentation, and mead. This configuration highlights that the production of fermented beverages, particularly mead, remains a significant area of research, emphasizing yeast activity, the conversion of sugars into ethanol, and the technological factors influencing the final product's quality.

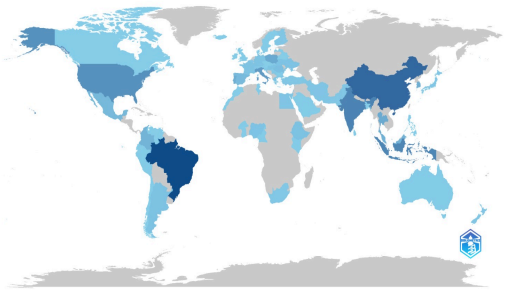
The blue cluster is associated with honey characteristics and chemical composition, incorporating terms such as glucose, fructose, sucrose, antioxidants, flavonoids, and high-performance liquid chromatography. This grouping demonstrates that the physicochemical and bioactive characterization of honey is a fundamental step in understanding its fermentative potential, given that the composition of sugars and phenolic compounds directly influences microbial metabolism, the formation of secondary metabolites, and the sensory properties of the fermented beverages.

The green cluster gathers terms related to microbial metabolism, microbiology, and volatile organic compounds, highlighting a growing interest in understanding the biochemical mechanisms responsible for shaping the aromatic and sensory profile during fermentation. Meanwhile, the small purple cluster focuses on terms related to bees and Meanwhile, the small purple cluster focuses on terms related to bees and the species *Apis mellifera*, demonstrating that a portion of the literature also investigates the biological origin of honey and the factors determining its quality as a raw material.

Overall, the high density of connections between the clusters demonstrates that current studies integrate knowledge regarding honey composition, microbiology, fermentative metabolism, and sensory analysis. This interrelationship reinforces the trend of research aimed at understanding the factors that determine the technological and sensory quality of mead, highlighting that the interaction between honey composition and yeast metabolism represents one of the field's primary scientific directions.

Comparing the scientific output map with the international collaboration map reveals a direct relationship between publication volume and the intensity of partnerships established between countries. The nations with the highest scientific output, represented by darker shades on the blue map, also occupy central positions within the collaboration network, standing out as key drivers of international research in this field. This pattern suggests that high scientific productivity is linked to the ability to establish extensive cooperation networks, thereby fostering the exchange of knowledge, infrastructure, and resources.

(A)



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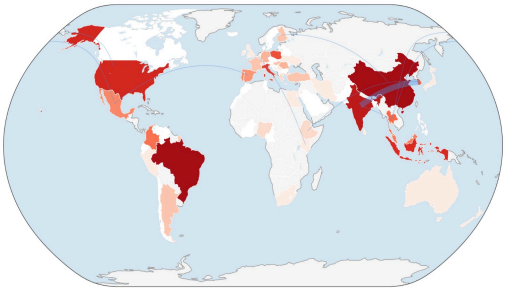

Figure 6. Geographic distribution of scientific production (A) and international collaboration among countries in publications on honey

China, the United States, India, and Brazil stand out both for their high volume of publications and for their strong participation in international collaborations. China and the United States, in particular, act as the field's primary scientific hubs, maintaining connections with numerous countries across different continents. The intense interaction among these research centers highlights their strategic role in shaping scientific agendas and disseminating knowledge regarding fermentation, honey, and fermented beverages.

Brazil deserves special mention for its significant scientific output, comparable to that of leading producing nations, and for its active integration into the international collaboration network. These results demonstrate the strengthening of domestic research in the field and its growing involvement in cooperative projects, particularly with countries in Asia, North America, and Europe. Brazil's high productivity may stem from both the economic importance of beekeeping and the rising interest in

fermentation processes for developing new products and leveraging biodiversity.

Conversely, several countries show moderate or low scientific output and, consequently, participate less actively in collaboration networks. This pattern reinforces the fact that research internationalization tends to concentrate in institutions and countries with greater capacity for investment in science, technology, and innovation. Thus, the relationship between productivity and collaboration highlights that advancing knowledge in this field depends not only on publication volume but also on the consolidation of international networks capable of fostering multidisciplinary research, expanding scientific impact, and accelerating technological innovation.

Table 1 highlights the most influential studies in the field, with citation counts ranging from 155 to 296. The most cited article, Physico-chemical and bioactive properties of different floral origin honeys from Romania (296 citations), emphasizes the importance of physicochemical characterization and the assessment of honey's bioactive properties. These aspects are fundamental to understanding the quality of the raw material used in fermentation processes. Collectively, the most cited publications demonstrate that research on honey composition provides the scientific basis for studies investigating fermented beverages and the influence of fermentable sugars on microbial metabolism.

Table 1. Most cited articles in the literature on fermentable sugars, honey, and fermentation, according to the Scopus database.

Ranking	Year	Article title	citations	Periodical	Periodical Classification
1	**2009**	*Physico-chemical and bioactive properties of different floral origin honeys from Romania*	**296**	*Food Chemistry*	Q1
2	**2013**	*Why are some floral nectars scented?*	**268**	*Ecology*	Q1
3	**2018**	*The sugars of honey—A review*	**236**	*Apidologie*	Q1
4	**2010**	*Characterisation of Spanish thyme honeys by their physicochemical characteristics and mineral contents*	**208**	*Food Chemistry*	Q1
5	**2013**	*Hive-stored pollen of honey bees: Many lines of evidence are consistent with pollen preservation, not nutrient conversion*	**206**	*PLoS ONE*	Q1
6	**2015**	*Fast and global authenticity screening of honey using ^{1}H-NMR profiling*	**155**	*Food Chemistry*	Q1

Another noteworthy finding is the predominance of Q1 journals, including Food Chemistry, Ecology, Apidologie, and PLoS ONE, indicating that the highest-impact studies were published in journals characterized by high visibility and scientific rigor. Notably, Food Chemistry accounts for three of the six most-cited articles, underscoring its pivotal role in disseminating research on the chemical composition, authenticity, quality, and functional properties of honey.

The most-cited articles also reveal considerable thematic diversity. While many studies focus on honey's chemical composition, sugar profile, and bioactive properties, others investigate ecological aspects of nectar production, pollen preservation by honeybees, and advanced analytical techniques, such as proton nuclear magnetic resonance (^{1}H-NMR), for honey authentication. This diversity highlights the multidisciplinary nature of research in this field, integrating food chemistry, microbiology, ecology, and instrumental analytical methods to broaden the understanding of honey and its applications in fermentation.

From a temporal perspective, the most influential publications appeared between 2009 and 2018, demonstrating that studies published over a decade ago continue to shape current research. This pattern is characteristic of well-established scientific fields,

where seminal publications remain widely cited for providing the theoretical and methodological foundation for subsequent investigations. Thus, the most-cited articles constitute the conceptual framework underpinning contemporary research on honey, fermentable sugars, and fermentation processes, reflecting both the maturity and the ongoing evolution of this research area.

CONCLUSION

This bibliometric review demonstrates that research on fermentable sugars and their influence on the sensory profile of honey-based fermented beverages has evolved from descriptive studies of honey composition into a mature, multidisciplinary field integrating microbiology, biochemistry, metabolomics, analytical chemistry, and food technology. The continuous growth of scientific output, coupled with the increasing complexity of research topics, reflects a shift toward a more comprehensive understanding of the biochemical mechanisms governing fermentation and the formation of compounds responsible for sensory characteristics.

Despite this scientific progress, bibliometric evidence also reveals significant knowledge gaps. Current research remains predominantly focused on physicochemical characterization and conventional alcoholic fermentation, whereas studies integrating fermentable sugar composition, microbial interactions, metabolic pathways, and sensory perception remain comparatively limited. Furthermore, the relatively low level of international collaboration among various emerging research groups suggests that greater scientific integration is essential to accelerate methodological innovation, improve data reproducibility, and expand the global impact of research in this field.

Another relevant finding is that the intellectual foundation of this research area remains heavily rooted in studies concerning honey quality and composition, rather than investigations directly linking sugar metabolism to sensory attributes. This observation highlights the need for future research employing integrated approaches—combining advanced omics technologies, microbial ecology, metabolomics, and sensory science—to establish robust relationships between fermentable substrates, microbial metabolism, and the chemical compounds responsible for flavor and aroma.

Overall, this study provides a comprehensive overview of the field's scientific structure, evolution, and emerging trends, while identifying strategic opportunities for future investigation. By mapping key research networks, highly influential publications, and thematic developments, this bibliometric analysis not only consolidates the current state of knowledge but also establishes a strategic framework to guide future studies aimed at optimizing fermentation processes and developing honey-based fermented beverages with enhanced technological, functional, and sensory qualities.

ACKNOWLEDGMENTS

This study was supported by the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) – Funding Code 001.

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