European Food Research and Technology (2026) 252:8
https://doi.org/10.1007/s00217-025-04970-0

ORIGINAL PAPER

Antioxidant properties of propolis: the systematic and bibliometric analyses of research trends in the last decade (2015–2024)

Tuğba Nigar Bozkuş[1]

Received: 1 July 2025 / Revised: 19 August 2025 / Accepted: 11 October 2025 / Published online: 19 December 2025

Abstract
Propolis, a resinous substance produced by bees, has garnered significant scientific interest due to its diverse biological activities, particularly its antioxidant properties. This research addresses a notable gap in the literature by providing a comprehensive overview of research trends related to the antioxidant activity of propolis, analyzing 321 articles published in 142 journals between 2015 and 2024. The study reveals a substantial and growing body of research in this area, with a notable increase in publications over the past decade. While *Apis mellifera* propolis remains the most frequently studied type, there is a growing interest in propolis from stingless bees. The analysis highlights the predominance of studies focusing on Brazilian, Chinese, and Turkish propolis, reflecting regional research interests and propolis availability. A wide range of methodologies are employed, with spectroscopy, chromatography, and in vitro antioxidant assays being the most prevalent. Ethanol is the most used extraction solvent, although alternative methods are being explored. Keyword analysis and thematic mapping reveal a strong emphasis on chemical characterization, particularly the identification and quantification of phenolic compounds, and their relationship to antioxidant capacity. Research priorities have clearly evolved over the past decade. Studies are now moving beyond basic characterization to focus on optimizing extraction methods and exploring novel applications. The study identifies key research gaps, including the necessity of harmonization of methodologies, more comprehensive investigations of stingless bee propolis, and increased focus on in vivo and clinical studies to translate in vitro findings into practical applications. This analysis provides valuable data for researchers, highlighting key areas for future investigation and promoting a more focused and impactful approach to propolis research.

Keywords Propolis · Antioxidant · Bibliometric analysis · Content analysis · Apis mellifera

Introduction

Propolis, a resinous substance collected by bees, has a long history of use in traditional medicine, dating back to ancient civilizations. Today, it continues to garner significant attention for its potential therapeutic applications in a wide range of diseases, including cancer, neurodegenerative disorders, cardiovascular diseases, and gastrointestinal issues [1–5]. This scientific interest is mirrored by a burgeoning global market, where consumers increasingly seek out propolis in commercial products such as dietary supplements, tinctures, and functional cosmetics. For apiculturists, this demand translates into significant economic opportunity, establishing propolis as a valuable, value-added product that helps diversify their income beyond honey. Its pharmacological potential is attributed to its polyphenol-rich composition, particularly flavonoids and phenolic acids [6, 7]. Propolis is a complex mixture comprising over 300 compounds, including polyphenols, terpenoids, steroids, sugars, vitamins, and amino acids [8, 9]. Its composition varies significantly based on factors such as geographical location, plant source, and bee species [10].

Oxidative stress, an imbalance between the production of reactive oxygen species (ROS) and the body's ability to detoxify them, plays a crucial role in the pathogenesis of numerous diseases [11–13]. Antioxidants, compounds capable of scavenging ROS and mitigating their damaging effects, are therefore essential for maintaining cellular health [8, 12]. Propolis, with its diverse array of phenolic compounds, flavonoids, and phenolic acids, presents a promising natural

✉ Tuğba Nigar Bozkuş
tugbancakiroglu@artvin.edu.tr

[1] Laboratory Technology Program, Artvin Vocational School, Artvin Çoruh University, Artvin, Türkiye

source of these protective agents [8, 14–18]. Studies have shown that the antioxidant capacity of propolis extracts can be comparable to that of synthetic antioxidants or ascorbic acid [10, 19]. The antioxidant capacity of natural products is evaluated through a battery of established in vitro assays that function via different chemical mechanisms, primarily single electron transfer (SET) or hydrogen atom transfer (HAT). Commonly employed methods mentioned in the literature include the 2,2-di(4-tert-octylphenyl)-1-picrylhydrazyl (DPPH) radical scavenging assay, 2,2'-Azinobis-(3-ethylbenzothiazoline-6-sulfonic acid (ABTS) assay, and the Ferric Reducing of Antioxidant Power (FRAP) assay, all based on SET mechanisms. HAT-based methods, such as the Oxygen Radical Absorbance Capacity (ORAC) assay, are also widely used to provide a more complete assessment of antioxidant potential [8]. The use of multiple assays is often recommended to obtain a comprehensive antioxidant profile, as the results can be highly method-dependent.

While numerous reviews have broadly surveyed the biological properties of propolis, they often treat its antioxidant activity as just one of many effects, listed alongside its other bioactivities [20–22]. This approach, however, overlooks the pivotal role of antioxidant capacity as a fundamental mechanism that underpins many of propolis's other therapeutic potentials. The ability to mitigate oxidative stress—a key pathological factor in inflammation, neurodegenerative disorders, and cancer—is mechanistically linked to its widely reported anti-inflammatory, neuroprotective, and chemopreventive effects. Therefore, a comprehensive understanding of its antioxidant properties is not merely an academic exercise; it is essential for elucidating the foundation upon which many of its other health benefits are built. A dedicated and systematic examination of research focused exclusively on propolis as an antioxidant is currently lacking. This research fills this critical gap by providing a focused analysis of this cornerstone property, contributing to a more nuanced and comprehensive understanding that is vital for guiding future therapeutic research on this valuable natural product.

Despite numerous studies on propolis antioxidant activity, a global overview of research trends over the last decade is lacking. This study aims to address that gap through bibliometric and content analysis. This analysis, systematically reviews the scientific literature published between 2015 and 2024, focusing specifically on the antioxidant activity of propolis. The main objective of this study is to provide a comprehensive and up-to-date analysis of the research landscape surrounding the antioxidant activity of propolis, specifically aimed at guiding future research efforts. By systematically examining publication trends, methodologies, geographical origins, bee species, and key research themes, this study aims to identify areas of emphasis, knowledge gaps, and emerging trends in the field. In this way, it aims to provide a clear roadmap for future researchers, highlighting promising avenues for research, potential methodological improvements, and understudied areas that deserve further investigation. Ultimately, this analysis serves as a resource to inform and direct future research efforts, fostering more focused, efficient, and impactful investigations into the antioxidant potential of propolis and its applications.

Methods

A bibliometric analysis was conducted to evaluate the scientific literature on the antioxidant activity of propolis. A comprehensive search strategy, adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, was employed to identify relevant studies on the antioxidant activity of propolis. This methodology, which has gained significant momentum in recent years due to its ability to develop reliable literature review processes, ensured a comprehensive and rigorous approach to identifying relevant publications for this study [23–30].

The Web of Science (WOS) Core Collection, including the Science Citation Index Expanded (SCI-Expanded), served as the primary database for this search. WOS is a web-based tool that provides access to comprehensive bibliographic and citation information for leading academic journals, with a low rate of duplicate records and a wide range of ad hoc searches, and is well known in the academic community for its reputation, rigor and reliability [30–32]. Its comprehensive and well-structured bibliographic and citation information, combined with a low rate of duplicate records, provides a clean and robust dataset essential for accurate analysis. Furthermore, WOS is fully compatible with specialized analytical tools, including the Bibliometrix R package used in this study, facilitating a systematic and reproducible research process. While other databases like Scopus or PubMed also contain relevant literature, the use of WOS ensures a high degree of data integrity and allows for clear comparability with other major bibliometric analyses, which frequently rely on this same gold-standard source.

A combination of keywords and controlled vocabulary terms were utilized to capture a wide range of relevant articles. The search query incorporated terms such as "propolis", "bee glue", "antioxidant*", "oxidative stress", "free radical*", "ROS", and "reactive oxygen species". This strategy aimed to retrieve all English-language original research articles published in peer-reviewed journals between 01 January 2015 and 31 December 2024 that specifically investigated the antioxidant activity of propolis. The search results were refined using predefined inclusion criteria. Only original research articles indexed in the

Table 1 Inclusion and exclusion criteria for study selection

Category	Inclusion criteria	Exclusion criteria
Publication type	Original research articles.	Review articles, meta-analyses, book chapters, conference proceedings, editorials, letters to the editor, and abstracts.
Database & indexing	Indexed in the Web of Science (WOS) Core Collection (Science Citation Index Expanded).	Articles not indexed in the specified WOS collection.
Publication language	Article published in English.	Articles published in any language other than English.
Publication period	Published between January 1, 2015, and December 31, 2024.	Published outside the specified timeframe.
Primary research focus	Studies that directly investigate, measure, or report on the antioxidant activity of propolis as a primary or secondary objective.	Studies focused exclusively on other biological activities (e.g., antimicrobial, anti-inflammatory) with no measurement of antioxidant capacity.
Primary subject	Propolis is the primary substance under investigation.	Studies where propolis is only a minor component of a complex mixture or formulation (e.g., honey, herbal blends) and its specific contribution is not delineated. Studies on other bee products (e.g., bee pollen, royal jelly) without a focus on propolis.
Data availability	Full-text article is accessible for detailed screening.	Full-text article is unavailable.

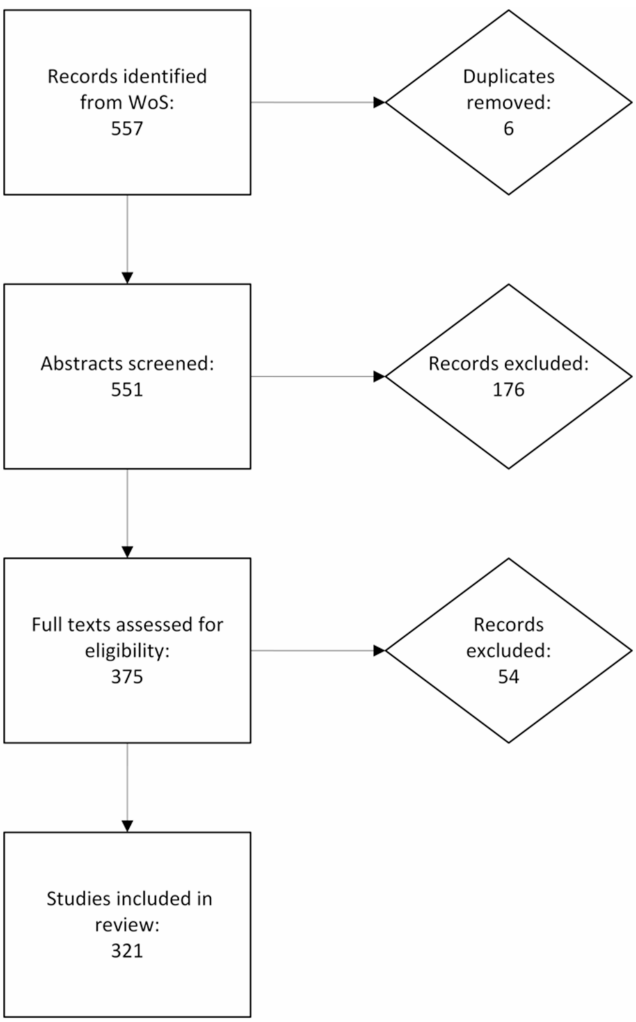

Fig. 1 Flow diagram of the search strategy

SCI-Expanded and published within the specified timeframe were considered. Furthermore, articles were carefully screened to ensure they directly addressed the antioxidant activity of propolis. Reviews, book chapters, conference proceedings, and studies focusing on other bee products without primary emphasis on antioxidant properties of propolis were excluded (Table 1).

To ensure the focus remained on propolis and its antioxidant properties, strict eligibility criteria were applied. Studies exclusively examining other bee products like honey or bee pollen, or those investigating other biological activities of propolis without a primary emphasis on antioxidant activity, were excluded. The database search was conducted in March 2025, and the resulting records were exported and deduplicated using reference management software. Subsequently, two independent reviewers meticulously screened the titles and abstracts of the retrieved records to assess their eligibility based on the predefined criteria. The full texts of potentially relevant articles were then obtained and independently reviewed by the same two reviewers to confirm their inclusion in the analysis. Any disagreements between reviewers during any stage of the study selection process were resolved through discussion and consensus, ensuring a rigorous and unbiased selection of studies. Figure 1 illustrates the PRISMA flow diagram to visually represent the study selection process, providing transparency and clarity regarding the identification and inclusion of eligible articles.

Data from the selected articles were extracted and analyzed using the Bibliometrix package in R. This package provided a comprehensive suite of tools for bibliometric analysis, enabling the assessment of various parameters, including publication trends, citation patterns, author collaborations, keyword frequencies, and research hotspots [33]. Descriptive statistics were used to summarize the data, and network visualizations were generated to illustrate the relationships between authors, keywords, and countries. The analysis aimed to provide a quantitative and qualitative overview of the research landscape related to the antioxidant activity of propolis, highlighting key contributors, influential publications, and emerging research themes.

A content analysis was conducted to systematically categorize and analyze the key themes, methodologies, and bee species prevalent in the scientific literature on propolis. Full texts of 321 research articles, retrieved from the Web of Science Core Collection database using a predefined search strategy and inclusion criteria, formed the basis of this analysis. To ensure consistency and capture relevant details, a standardized data extraction form was developed and employed by two independent reviewers. This form included categories designed to capture the multifaceted nature of propolis research. The ‘‘Purpose of Study’’ category documented the primary objective of each research article, ranging from assessing antioxidant activity and analyzing chemical composition to evaluating various biological activities and exploring formulation development. The ‘‘Primary Research Method’’ category recorded the principal experimental techniques employed, encompassing a wide spectrum of analytical methods from spectroscopy and chromatography to cell culture and animal studies.

Furthermore, the data extraction form included classifications for ‘‘Bee Species’’, differentiating between *Apis mellifera*, stingless bees, and unspecified/mixed species. Recognizing the impact of geographical origin on propolis composition, a ‘‘Geographical Origin of Propolis’’ category was also incorporated. Additionally, ‘‘Extraction Solvent Used’’ category was included to capture the influence of the solvents on the extracted compounds. Following independent data extraction, any discrepancies between the two reviewers were resolved through discussion and consensus, ensuring the accuracy and reliability of the data. Any disagreements between reviewers during any stage of the study selection process were resolved through discussion to reach a consensus. In the rare instance that a consensus could not be reached, a third senior researcher was designated to make the final determination, ensuring a rigorous and unbiased selection of studies. Descriptive statistics were then used to calculate the frequencies of each classification within each category. The results of this comprehensive content analysis were presented in tabular format and described narratively to provide a clear and structured overview of the research trends and prominent themes within the propolis literature.

Bibliometric analysis results

The bibliometric analysis, spanning the period from 2015 to 2024, identified a substantial body of research on the antioxidant activity of propolis. A total of 321 research articles were published across 142 journals, demonstrating a considerable interest in this topic. The field exhibited a healthy annual growth rate of 8.01%, indicating increasing research activity over the past decade. The average age of the documents was 5 years, suggesting relatively current research within the dataset. It is important to note that this average directly reflects the 10-year study window (2015–2024) and the sustained publication output throughout this period, rather than a concentration of research in a single year. The average number of citations per article was 25.06, highlighting the impact and influence of these publications within the scientific community.

The analysis also revealed a robust network of citations and collaborations. The included articles cited a total of 10,321 references, reflecting a broad and interconnected knowledge base. Furthermore, 798 keywords were extracted from the articles, providing data into the diverse research themes and specific aspects of antioxidant activity of propolis being investigated. A total of 1,844 authors contributed to the body of research, with a high degree of collaboration evident in the average of 6.58 co-authors per document. International collaboration was also prevalent, with 29.6% of the articles involving co-authors from different countries. Notably, only two single-authored documents were identified, emphasizing the collaborative nature of research in this area. These findings underscore the growing global interest and collaborative efforts driving research on the antioxidant properties of propolis.

Scientific production concerning the antioxidant activity of propolis showed fluctuations but an overall increasing trend between 2015 and 2024. Starting with 21 articles in 2015 and 19 in 2016, output increased to 33 articles in 2017. While publication numbers fluctuated slightly in the following years, a notable increase occurred in 2020 with 45 articles published. This upward trend continued, with 41 articles in 2022 and 42 in 2024, the highest number of publications within the analyzed timeframe. These data suggest a growing interest and sustained research activity in the field of propolis and its antioxidant properties.

The average citation count per article varied considerably over the period analyzed. Articles published in 2015 had the highest average citation count (54.29), likely due to their longer exposure time. Subsequent years saw a general decline in average citations per article, with publications from 2024 having an average of only 2 citations, reflecting their recent publication date. However, when considering the total number of citations accumulated per year, a more stable pattern emerges, peaking in 2017 (5.52) and generally decreasing toward the most recent years, again attributable to the citation accumulation process. It’s important to consider the number of citable years for each publication year when interpreting these results. For instance, 2015 publications had 11 years to accumulate citations, compared to only 2 years for 2024 publications. This ‘‘citation window’’ explains the observed trend and reinforces the need to consider publication year when evaluating citation impact.

The research on the antioxidant activity of propolis is published across a diverse range of journals, indicating a broad interest in the topic across different disciplines. The most prominent journal is Molecules, with 23 articles, followed by the Journal of Apicultural Research (19 articles) and Antioxidants (13 articles). Other journals with notable contributions include Evidence-Based Complementary and Alternative Medicine, Foods, and PLOS ONE, each with 9 articles. This distribution suggests that the research is disseminated through both specialized journals focused on natural products, food science, and apiculture, as well as broader, multidisciplinary journals. The remaining articles are spread across a long tail of journals, each with fewer publications on the topic. This wide distribution highlights the interdisciplinary nature of propolis research and its relevance to various scientific fields.

An analysis of the publication output of the most relevant journals over time reveals a clear trend of increasing research activity related to antioxidant activity of propolis (Fig. 2). Molecules demonstrate consistent growth in publications throughout the period, culminating in 23 articles in 2024. The Journal of Apicultural Research shows a similar trajectory, reaching 19 articles in 2024. Antioxidants, Evidence-Based Complementary and Alternative Medicine, Foods, and PLOS ONE also exhibit increasing publication numbers, albeit with some fluctuations. This consistent rise in publications across these key journals underscores the growing interest and sustained research effort dedicated to understanding the antioxidant properties of propolis. It also suggests that these journals serve as important platforms for disseminating research findings in this field.

The analysis identified several authors with significant contributions to the research on antioxidant activity of propolis. B. Lyoussi leads with 9 published articles, followed by S. Kolayli with 6 articles. Several authors have contributed 4 articles each, including V. Bankova, G. de Abreu Barreto, I. Diniz Basilio-Junior, J. Kenupp Bastos, C. Bensouici, S. Matias de Alencar, S. Keskin, and K. Wang. A larger group of researchers have published 3 articles each, indicating a broad base of active contributors to this field. These authors represent key figures driving research on propolis and its antioxidant properties.

Several institutions have emerged as prominent contributors to the research on antioxidant activity of propolis. The Egyptian Knowledge Bank leads with a significant number of publications (37 articles), likely reflecting a centralized repository of research output. The Universidade de Sao Paulo in Brazil also stands out with 30 articles, demonstrating a strong research focus on this topic within the institution. Other notable contributors include Firat University (20 articles), the Lithuanian University of Health Sciences (17 articles), and the Universidade Federal de Alagoas (17 articles). Several other universities across the globe also demonstrate significant research activity in this area, indicating a widespread interest in antioxidant properties of propolis and its potential applications. The strong representation of institutions from various countries underscores the global nature of this research field.

The research output on antioxidant activity of propolis shows a global distribution (Fig. 3), with Brazil leading in

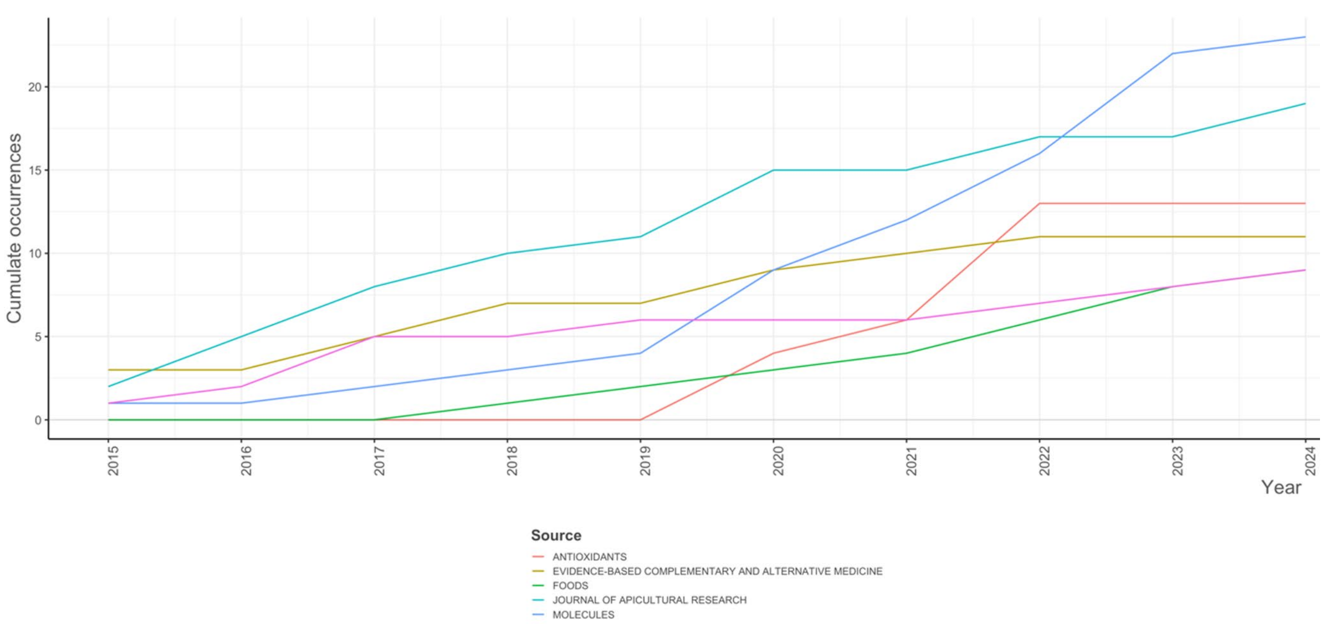

Fig. 2 Publication output of the most relevant journals over time

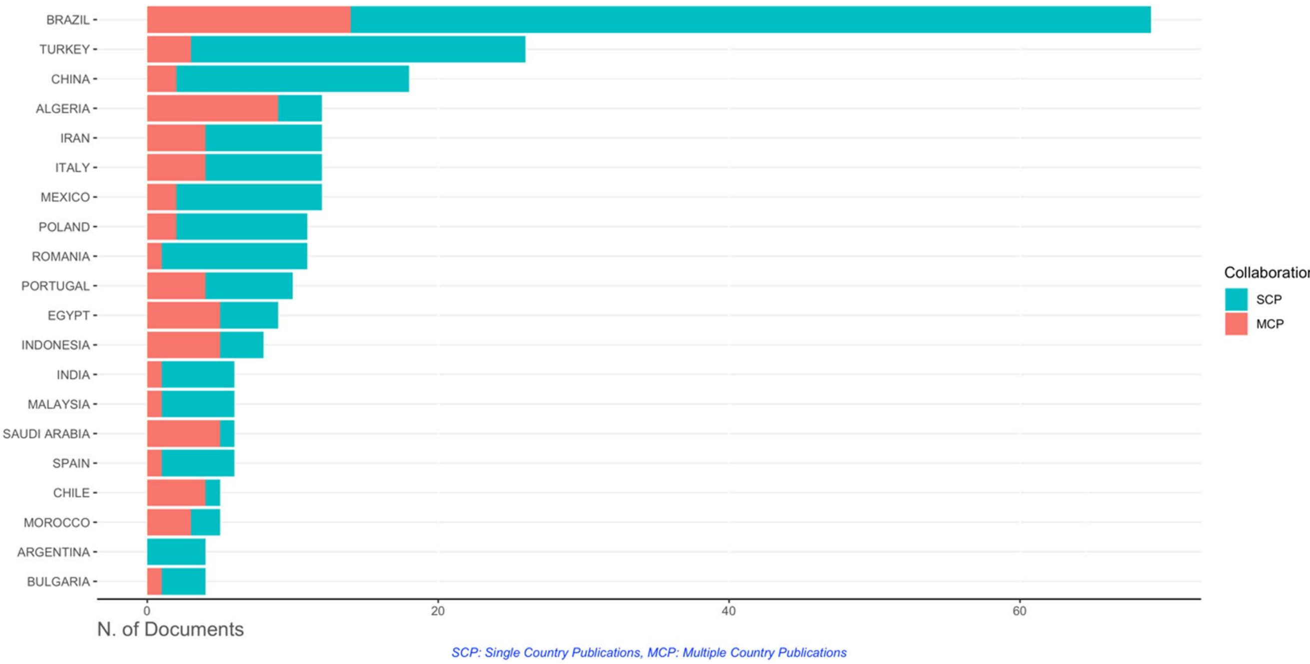

Fig. 3 Corresponding author's countries

the number of articles published by corresponding authors (69 articles). Turkey follows with a substantial contribution of 26 articles, and China with 18 articles. Several other countries, including Algeria, Iran, Italy, and Mexico, have also produced a notable body of research, each with 12 articles. This geographical distribution highlights the international interest in propolis research and suggests that regional factors, such as the availability of propolis and specific research priorities, may influence research activity. The involvement of numerous countries further emphasizes the global collaborative efforts to advance understanding of propolis and its beneficial properties.

The distribution of single and multiple country publications provides data into the collaborative nature of propolis research across different countries (Fig. 3). Brazil demonstrates a strong research presence, with the highest number of single-country publications (55) and a substantial number of multiple-country collaborations (14). This suggests that Brazil not only conducts significant independent research on propolis but also actively engages in international collaborations. Turkey, China, Mexico, and Romania also show a predominance of single-country publications, indicating strong domestic research programs. However, countries like Algeria, Iran, Italy, and Portugal exhibit a higher proportion of multiple-country publications, signifying a greater emphasis on collaborative research efforts. Interestingly, Canada, Bangladesh, Brunei, Cameroon, and Pakistan have only multiple-country publications, suggesting that their propolis research relies heavily on international partnerships. This analysis highlights the diverse approaches to propolis research globally, with some countries focusing primarily on domestic studies while others prioritize international collaborations. This variation may be influenced by factors such as research funding, access to resources, and the specific research expertise available within each country.

The analysis of annual scientific production by the most productive countries reveals distinct publication trends over the decade (Fig. 4). Brazil consistently leads in publication output, showing a steady increase from 16 articles in 2015 to a remarkable 246 articles in 2024. This substantial growth reflects Brazil's prominent role in propolis research. China also exhibits a consistent upward trend, albeit with a less steep incline, increasing from 5 articles in 2015 to 48 in 2024. Turkey's publication output shows some fluctuations, with a notable peak of 91 articles in 2021, followed by a slight decline and stabilization around 115 articles in the later years. Iran's publication record begins later in the analyzed period (2017), but demonstrates a rapid growth, reaching 49 articles by 2024. Indonesia's publication trend mirrors Iran's, starting with a slower pace and then accelerating significantly to 48 articles in 2024. These trends indicate sustained and increasing research interest in propolis across these countries, with Brazil maintaining a dominant position throughout the decade.

International collaboration network is a significant aspect of research on antioxidant activity of propolis. The data reveals a complex network of collaborations between researchers from different countries (Fig. 5). Strong collaborative ties exist between Algeria and Belgium (3 co-authored articles), as well as between several other countries,

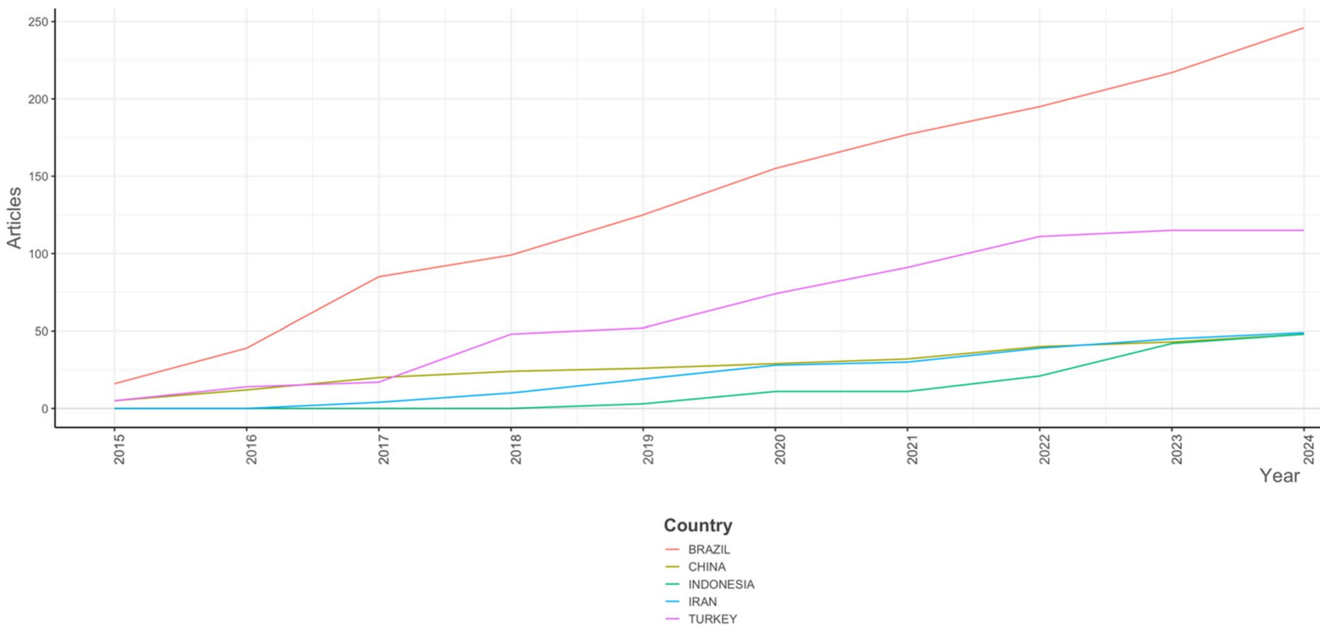

Fig. 4 Publication output of the most relevant countries over time

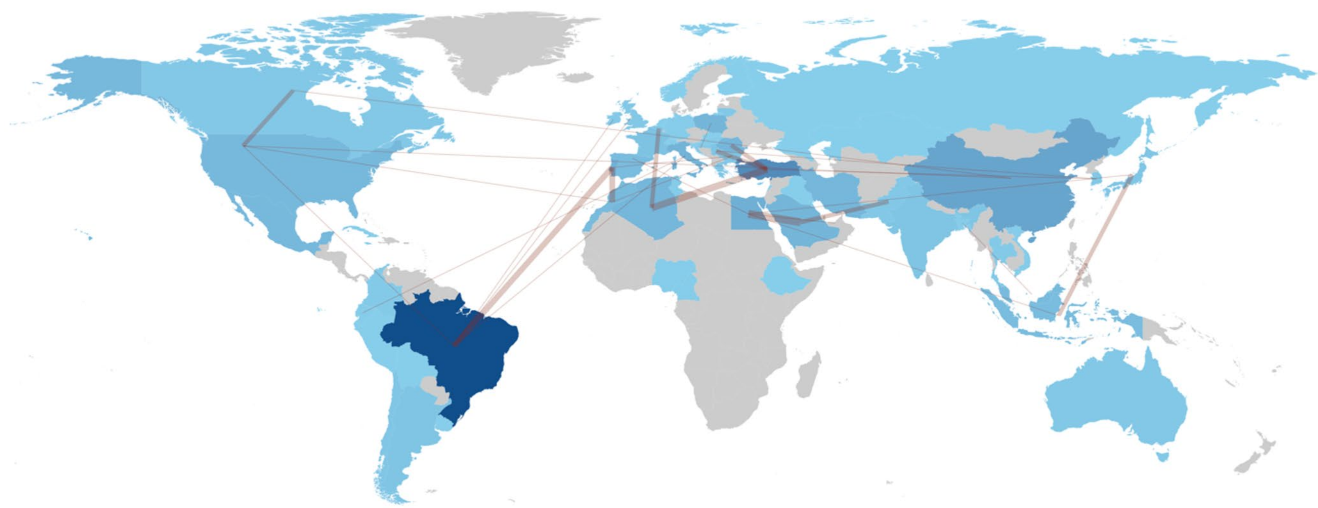

Fig. 5 Global distribution of research output and international collaboration

highlighting the global nature of this research field. Notably, Brazil collaborates with a wide range of countries, including Ireland, Italy, Portugal, the United Kingdom, and the USA. These collaborations likely facilitate the sharing of expertise, resources, and diverse propolis samples, enriching the research and promoting a more comprehensive understanding of properties of propolis. The data also shows collaborations involving countries with significant propolis production, such as Brazil and Turkey, with countries possessing advanced research infrastructure and expertise. This collaborative network strengthens the global research effort focused on propolis and its potential health benefits.

Analysis of the most cited countries reveals a similar pattern to publication output, but with some key differences. Brazil again leads with the highest total citation count (2454), followed by China (961) and Turkey (475). While Italy, Poland, and Mexico maintain strong citation numbers, Iran, Egypt, and Algeria show a slightly lower citation impact compared to their publication output. This suggests that while these countries contribute significantly to the research volume, the relative impact of their research, as measured by citations, may differ. Interestingly, Brunei, despite a lower publication output, receives a substantial number of citations (113), indicating a potentially higher impact within a more specialized research area. These variations highlight the complex interplay between research quantity and impact and underscore the importance of considering both factors when assessing a country's contribution to scientific literature. It's also worth noting that the citation counts can be influenced by factors such as the citation practices within different research communities and the accessibility of publications.

The keyword analysis provides valuable data into the core research themes within the field of propolis and its antioxidant properties. ''Propolis'' itself appears most frequently (159 occurrences), followed by ''antioxidant activity'' (82 occurrences) and ''antioxidant'' (45 occurrences), clearly establishing the central focus of the research. The prominence of keywords like ''flavonoids'', ''phenolic compounds'', ''polyphenols'', and ''phenolic acids'' highlights the importance of these chemical constituents in contributing to antioxidant capacity of propolis. Furthermore, the presence of keywords such as ''oxidative stress'', ''antimicrobial'', ''antibacterial activity'', and ''cytotoxicity'' suggests that the research explores the broader biological activities and potential therapeutic applications of propolis beyond its antioxidant properties. The inclusion of analytical techniques like ''HPLC'' and ''LC-MS'' indicates the methodologies employed for characterizing the chemical composition of propolis samples. Finally, keywords like ''green propolis'', ''red propolis'', and ''Algerian propolis'' point to research focusing on specific types of propolis and their unique properties. This keyword analysis provides a comprehensive overview of the dominant research themes and the specific aspects of bioactivity of propolis being investigated.

The analysis of the most frequent terms appearing in the articles reinforces the key themes identified in the keyword analysis (Fig. 6). ''Chemical composition'', ''extracts'', ''constituents'', and ''phenolic compounds'' are among the most prevalent terms, highlighting the significant focus on characterizing the chemical makeup of propolis and its extracts. The high frequency of ''in vitro'' indicates the widespread use of laboratory-based experiments in this research area. ''Flavonoids'', ''capacity'', ''oxidative stress'', and ''antimicrobial activity'' further emphasize the interest in antioxidant of propolis and other biological properties. ''Brazilian propolis'' and ''red propolis'' appear prominently, reflecting the substantial research conducted on these specific types of propolis. The terms "biological properties", "botanical origin", "toxicity", "apoptosis", "identification", "chemistry", "inhibition", and "biological activity" provide further data into the breadth of research topics covered, including studies on effects of propolis on various biological processes. These findings collectively underscore the dominant research trends within the field of propolis research, with a strong focus on its chemical characterization, antioxidant capacity, and potential therapeutic applications.

A thematic map was generated to visualize the research themes and their interrelationships within the propolis literature (Fig. 7). The map reveals distinct clusters of research activity, each centered around a specific theme. A prominent cluster focuses on oxidative stress, encompassing related terms like "cells", "damage", "inflammation", "proliferation", "rats", "metabolism", "activation", "assay", "insulin resistance", "quercetin", "DNA damage", "mechanisms", "Nrf2", and "stress". This cluster highlights extensive research on antioxidant properties of propolis and its potential role in mitigating oxidative stress-related conditions. Another cluster centers around chemical composition, represented by terms like "chemical composition", "extracts", "constituents", "phenolic compounds", "capacity", "Brazilian propolis", "antimicrobial activity", "honey", "antibacterial activity", "regions", "acid", and "biological properties". This cluster underscores the

Fig. 6 Tree map of the most frequent terms

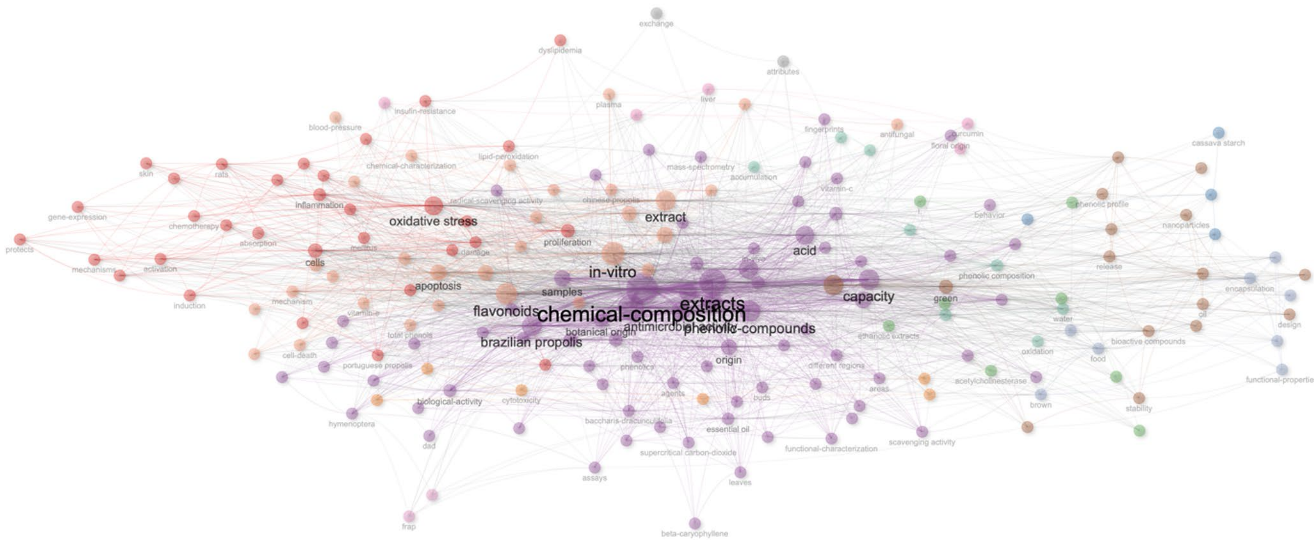

Fig. 7 Thematic map of the research themes

significant research effort dedicated to characterizing the chemical constituents of propolis and their contribution to its bioactivity. Additionally, there are smaller clusters focusing on red propolis, encompassing terms like ‘‘red propolis’’, ‘‘green’’, ‘‘bioactive compounds’’, ‘‘phenolic profile’’, ‘‘color’’, ‘‘physicochemical properties’’, and ‘‘stability’’. Another small cluster focuses on specific terms related to the liver, chitosan, and in vitro studies. The thematic map provides a valuable visual representation of the research landscape, illustrating the relationships between different research themes and their relative prominence within the propolis literature. It allows for a comprehensive understanding of the major areas of focus and the interconnections between various research topics.

The analysis of trend topics over time reveals the evolving research focus within the field of propolis. Early in the decade (2015–2017), research emphasized ‘‘growth’’, likely referring to plant growth and propolis production. Simultaneously, there was a focus on *Baccharis dracunculifolia*, the main botanical source of Brazilian green propolis. Around the mid-period (2017–2019), ‘‘Brazilian propolis’’, ‘‘oxidative stress’’, ‘‘constituents’’, and ‘‘flavonoids’’ emerged as prominent topics, reflecting an increasing interest in the chemical characterization and antioxidant properties of propolis. From 2018 onwards, there’s a shift towards more specific aspects, such as ‘‘chemical composition’’, ‘‘extracts’’, and ‘‘phenolic compounds’’. In the later years (2020–2024), topics related to applications and processing gain traction, including ‘‘honey’’, ‘‘red propolis’’, ‘‘damage’’, ‘‘acids’’, ‘‘bioactive compounds’’, ‘‘encapsulation’’, ‘‘scavenging activity’’, and ‘‘pollen’’. This chronological analysis illustrates how research initially focused on basic characterization and then progressed towards exploring potential applications of propolis and refining extraction and formulation techniques. The emergence of ‘‘pollen’’ as a trend topic in the most recent years suggests a growing interest in the combined use of propolis and pollen, potentially for synergistic health benefits.

Content analysis results

A content analysis of 321 research article full texts concerning propolis was performed, categorizing each study based on purpose, primary method, bee species, geographical origin of propolis and extraction solvent used. The content analysis revealed a diverse range of research purposes, with a strong focus on characterizing bioactive properties of propolis and chemical composition. The most common research purpose was the evaluation of antioxidant activity, encompassing studies that directly measured antioxidant capacity using standard assays (e.g., DPPH, ABTS, FRAP, ORAC), assessed cellular antioxidant activity, and investigated antioxidant effects in specific disease models (Table 2). A closely related and overlapping area of investigation was the analysis of chemical composition, with researchers identifying and quantifying phenolic compounds, characterizing volatile compounds, and performing other chemical analyses to understand the constituents contributing to bioactivity of propolis. A substantial portion of the research also focused on assessing various biological activities, primarily antibacterial, antifungal, and anti-inflammatory effects, as well as exploring potential of propolis in antiviral, anticancer, and wound healing applications.

Beyond characterizing the inherent properties of propolis, researchers also dedicated efforts to method development

Table 2 Purposes of studies

Purpose category	Specific focus	Frequency
Antioxidant activity evaluation	Direct measurement of antioxidant capacity (e.g., DPPH, ABTS, FRAP, ORAC)	125
	Cellular antioxidant activity (CAA)	42
	Antioxidant effects on specific disease models (e.g., diabetes, cancer)	38
Chemical composition analysis	Identification and quantification of phenolic compounds	115
	Characterization of volatile compounds	45
	Other chemical analyses (e.g., mineral content, waxes)	31
Biological activity assessment	Antibacterial activity	72
	Antifungal activity	42
	Antiviral activity	18
	Anti-inflammatory activity	51
	Anticancer activity	32
	Other biological activities (e.g., antiparasitic, wound healing, immunomodulatory)	21
Method development/optimization	Extraction methods	28
	Analytical methods	12
	Formulation methods	12
Formulation development	Nanoparticles	21
	Films/coatings	16
	Emulsions/gels	11
Bioavailability/bioaccessibility	In vitro studies	12
	In vivo studies	10
Clinical trials (human studies)	Antioxidant effects	10
	Other effects (e.g., anti-inflammatory, glycemic control)	8
Other	Toxicity assessment	9
	Safety evaluation	6

and optimization. This included refining extraction techniques to maximize the recovery of bioactive compounds, developing novel analytical methods for characterizing propolis components, and optimizing formulation strategies for enhancing propolis delivery and stability. A smaller but important area of research examined the bioavailability and bioaccessibility of propolis and its constituents, using both in vitro and in vivo models. Clinical trials conducted on human subjects further explored antioxidant effects of propolis and its potential role in managing specific health conditions. Finally, studies assessing the toxicity and safety of propolis provided valuable information regarding its potential use in various applications. This multifaceted approach to propolis research underscores the growing interest in understanding its diverse properties and potential applications in promoting human health.

The analysis of primary research methods employed in the 321 articles highlighted the diverse analytical techniques used to investigate this complex substance (Table 3). Spectroscopy, in its various forms (UV-Vis, IR, NMR), was widely employed for characterizing the chemical composition and identifying specific compounds within propolis extracts. Chromatographic techniques, including HPLC, GC, and TLC, played a similarly crucial role in separating and quantifying individual phenolic compounds and other constituents. A significant portion of the research utilized standard assays, such as the DPPH, ABTS, FRAP, and ORAC assays, to evaluate the antioxidant capacity of propolis extracts.

Cell culture studies, employing various cell lines, were frequently used to investigate the biological activity of propolis, including its cytotoxic effects, antioxidant activity within cells, and impacts on cellular processes like proliferation and migration. Animal studies provided valuable in vivo data, assessing antioxidant activity of propolis in living organisms, evaluating its toxicity and safety profiles, and exploring its therapeutic potential in various disease models. Electrochemical methods, such as cyclic voltammetry, offered data into the redox properties of propolis and its antioxidant mechanisms. Microscopy, employing both SEM and TEM, was used to visualize the microstructure of propolis samples and formulations, particularly in studies involving nanomaterials. Finally, other methods, including sensory analysis and physicochemical characterization, complemented the analytical techniques mentioned above, offering a more holistic understanding of properties of

Table 3 Primary research methods

Method category	Specific technique	Frequency
Spectroscopy	UV-Vis Spectroscopy	32
	Infrared (IR) Spectroscopy	41
	Nuclear Magnetic Resonance (NMR) Spectroscopy	29
Chromatography	High-Performance Liquid Chromatography (HPLC)	68
	Gas Chromatography (GC)	21
	Thin-Layer Chromatography (TLC)	9
Assays	DPPH assay	48
	ABTS assay	32
	FRAP assay	23
	ORAC assay	12
	Other antioxidant assays	10
Cell culture studies	Cytotoxicity assays	35
	Antioxidant activity in cell lines	22
	Other cell-based assays (e.g., proliferation, migration)	15
Animal studies	In vivo antioxidant activity	33
	Toxicity/safety assessment	15
	Other in vivo studies	13
Electrochemical methods	Cyclic Voltammetry	18
	Other electrochemical methods	10
Microscopy	Scanning Electron Microscopy (SEM)	9
	Transmission Electron Microscopy (TEM)	6
Other	Sensory analysis	7
	Physicochemical characterization	5

Table 4 Bee species

Bee species category	Specific genus/species	Frequency
**Apis mellifera*	*Apis mellifera* (general)	152
	Apis mellifera jemenitica	12
	Other *Apis mellifera* subspecies	20
Stingless bees	*Melipona* spp.	25
	Tetragonula spp.	19
	Scaptotrigona spp.	8
	Trigona spp.	5
	Other stingless bee genera (*Frieseomelitta*, *Tetragonisca*, *Plebeia*,* Austroplebeia*, *Lisotrigona*, *Homotrigona*)	5
Not specified/multiple species	Not specified	54
	Multiple species compared	21

propolis. The diverse methodologies employed reflect the multidisciplinary nature of propolis research and the need for a comprehensive approach to fully characterize its composition, bioactivity, and potential applications.

The examination of bee species in the propolis research revealed a predominant focus on propolis derived from *Apis mellifera*, the common honeybee (Table 4). The vast majority of studies utilized propolis collected by *Apis mellifera*, reflecting its widespread availability and established role in propolis production. While some studies investigated specific subspecies of *Apis mellifera*, such as *Apis mellifera jemenitica*, most research referred to the species generally, without specifying a particular subspecies.

Stingless bees, a diverse group encompassing various genera, also received considerable attention, although to a lesser extent than *Apis mellifera*. Within this group, *Melipona* and *Tetragonula* species were the most frequently studied, likely due to their significant propolis production and regional importance in certain parts of the world. Other stingless bee genera, including *Scaptotrigona*, *Trigona*, *Frieseomelitta*, *Tetragonisca*, *Plebeia*, *Austroplebeia*, *Lisotrigona*, and *Homotrigona*, were also represented, although less frequently. This research highlights the diversity of stingless bee propolis and its potential for unique chemical compositions and biological activities.

A notable portion of the articles either did not specify the bee species or compared propolis from multiple species, including both *Apis mellifera* and stingless bees. This suggests that while there's a significant focus on specific bee species, there's also interest in understanding the broader

Table 5 Geographical origin of propolis

Origin	Frequency
Brazil	112
China	48
Turkey	39
Europe (general)	28
Morocco	18
Algeria	15
Romania	14
Other / multiple origins	47

Table 6 Extraction solvent used

Solvent	Frequency
Ethanol	157
Methanol	52
Water	32
Ethanol/water mixtures	28
Other/multiple solvents	24
Not specified	28

characteristics of propolis and the variations across different bee sources. This approach may be valuable for identifying common bioactive compounds and properties across different propolis types, as well as for discovering unique constituents specific to certain bee species or geographical regions. Further research focusing on understudied bee species and their propolis could reveal novel chemical diversity and potentially valuable therapeutic applications.

The geographical origins of propolis samples used in the research displayed a clear concentration in certain regions, reflecting both the distribution of propolis-producing bees and regional research interests (Table 5). Brazil emerged as a major hub for propolis research, with a substantial number of studies utilizing Brazilian propolis, particularly green and red propolis from the northeastern and southeastern regions. This prominence aligns with Brazil's rich biodiversity and the extensive use of propolis in traditional medicine. China also represented a significant contributor, with numerous studies focusing on Chinese propolis, often characterized as poplar type.

Turkey, a country with a long history of propolis use, also featured prominently in the research, with studies examining propolis samples from various provinces across Anatolia. European propolis, often categorized as poplar type, was also frequently studied, with research encompassing samples from countries like Italy, Russia, Poland, and Romania. Morocco and Algeria, located in North Africa, represented other notable sources of propolis, with studies investigating the chemical composition and biological activities of propolis from these regions. While several other countries and regions were represented in the research, including Ecuador, Bolivia, Canada, India, and Thailand, their contributions were less frequent than those of the dominant regions mentioned above. This geographical distribution of propolis research highlights the global interest in this natural product and the potential for regional variations in propolis composition and bioactivity due to differences in climate, flora, and bee species. Further research exploring propolis from diverse and understudied regions could uncover novel chemical diversity and contribute to a more comprehensive understanding of this valuable bee product.

The choice of extraction solvents significantly influences the yield and composition of propolis extracts, and this was reflected in the diverse range of solvents employed across the analyzed studies (Table 6). Ethanol emerged as the most commonly used solvent, appearing in a large proportion of the articles. This prevalence likely stems from ethanol's effectiveness in extracting a broad spectrum of phenolic compounds from propolis, as well as its relative safety and ease of use. Methanol, another alcohol solvent, was also frequently utilized, though less so than ethanol. Water, while a more sustainable and biocompatible solvent, was used less frequently, possibly due to its lower extraction efficiency for certain lipophilic propolis constituents. However, mixtures of ethanol and water were employed in a substantial number of studies, potentially offering a balance between extraction efficiency and biocompatibility. Researchers also explored various other solvents, including acetone, chloroform, hexane, dichloromethane, and deep eutectic solvents (DES), often in studies seeking to target specific compounds or optimize extraction protocols. A smaller portion of the articles did not specify the extraction solvent used, making it challenging to fully assess the prevalence of different solvents across the entire body of literature. The choice of solvent is a crucial consideration in propolis research, as it directly impacts the chemical profile of the extract and can therefore influence the observed biological activities. The diverse range of solvents employed highlights the ongoing effort to optimize extraction methods and tailor them to specific research objectives.

The analysis of the 321 propolis research revealed a strong emphasis on specific compound classes and individual compounds within those classes (Table 7). Flavonoids and phenolic compounds, as broad categories, were ubiquitously studied, with the majority of articles mentioning their presence and often focusing on their total content. Among individual flavonoids, chrysin, pinocembrin, and galangin were frequently identified and quantified, appearing in a substantial proportion of the chemical composition analyses. Similarly, caffeic acid, p-coumaric acid, and ferulic acid were the most commonly studied phenolic acids, often investigated alongside their esters like CAPE.

A second tier of compounds, including pinobanksin, quercetin, naringenin, and artepillin C, were also frequently

Table 7 Frequencies of commonly studied compounds

Compound/compound class	Frequency	Notes
Flavonoids (general)		This broad category encompasses various subclasses.
Chrysin	74	Frequently mentioned, especially in poplar-type propolis.
Galangin	63	Often quantified alongside chrysin.
Pinocembrin	79	Frequently quantified, often a major constituent.
Pinobanksin	61	Often found along with pinocembrin.
Quercetin	86	A ubiquitous flavonoid, often used as a standard.
Kaempferol	53	Commonly quantified.
Apigenin	49	Less frequent than other flavones but still notable.
Naringenin	41	More commonly mentioned in certain propolis types (e.g., citrus).
Myricetin	27	Less frequently quantified than other flavonols.
Isorhamnetin	26	Sometimes reported, particularly in chemical profiling studies.
Rutin	25	Often mentioned as a marker compound.
Phenolic acids (general)		This includes various hydroxybenzoic and hydroxycinnamic acids.
Caffeic acid	82	A common phenolic acid, often quantified.
p-Coumaric acid	74	Frequently reported alongside caffeic acid.
Ferulic acid	61	Commonly quantified.
Gallic acid	43	More frequently mentioned in certain propolis types.
Caffeic acid phenethyl ester	37	Often studied for its biological activity.
Other phenolic compounds		
Artepillin C	41	Primarily found in Brazilian green propolis.
Vanillin	18	Occasionally quantified.
Resveratrol	7	Less frequently reported than other phenolics.

mentioned, though their occurrence was less consistent across the dataset. Artepillin C, specifically, was prominently featured in studies investigating Brazilian green propolis. While many other flavonoids and phenolic acids were identified, their individual frequencies were lower. Glycosides of flavonoids were frequently identified but not always individually quantified. Other phenolic compounds like vanillin and resveratrol were less prevalent, appearing mainly in studies investigating a wider range of phytochemicals. Finally, terpenes, steroids, and other non-phenolic constituents were noted in some chemical analyses, but the overall research focus remained predominantly on phenolic compounds. This targeted focus on specific compounds and compound classes reflects the ongoing effort to understand the key drivers of biological activity and therapeutic potential of propolis.

Discussion

This first-of-its-kind analysis reveals that research on the antioxidant activity of propolis is a substantial, globally collaborative, and rapidly evolving field. The consistent growth in publications over the last decade indicates sustained scientific interest. However, this trend must be interpreted within the broader context of scientific publishing; as Sousa et al. (2023) note, an increase in publications on a specific topic may partially reflect the general expansion of scientific literature rather than a disproportionate surge of interest [20]. Nonetheless, the high degree of co-authorship and the robust international collaboration networks observed are hallmarks of a dynamic and healthy research domain, a characteristic also seen in bibliometric analyses of other food science sectors, such as the wine industry [30, 34]. This collaborative structure, connecting researchers and institutions worldwide, is crucial for advancing knowledge in a field where product variability is a key factor.

The sustained growth in publication output observed in this analysis is not occurring in a vacuum; it is heavily influenced by powerful external market forces. The burgeoning global consumer demand for natural and ''clean-label'' products has transformed propolis from a traditional remedy into a lucrative ingredient for the nutraceutical and cosmetic industries. This commercial interest directly incentivizes research, as companies seek scientific validation to support marketing claims, fueling publication trends that prioritize studies aligned with marketable applications like antioxidant activity. Paradoxically, this same commercial ecosystem may contribute to the stagnation of research at the preclinical level. The lack of standardized international regulatory frameworks for apitherapy products creates significant ambiguity, and without a clear pathway for drug approval, pharmaceutical companies are hesitant to fund the high-cost, high-risk clinical trials required for pharmacological validation. Consequently, research remains largely confined to nutraceutical space, hindering the progression of propolis from a promising natural supplement to a clinically validated therapeutic agent.

The geographical distribution of research is heavily skewed, with Brazil leading significantly in both publication volume and citation impact. This dominance is consistent with findings from broader propolis reviews [20–22] and is intrinsically linked to the country's rich biodiversity, which provides a vast array of propolis types (e.g., green and red propolis) for investigation. The strong research output from Turkey and China also aligns with their long traditions of apitherapy and propolis use. While many countries contribute to the knowledge base, the prevalence of multiple-country publications from certain nations suggests that international partnerships are a vital mechanism for countries with developing research infrastructures to participate in the field, likely providing access to advanced analytical resources and diverse expertise [34].

A key finding of this analysis is the significant geographical skew in research, with regions like sub-Saharan Africa and Southeast Asia being notably underrepresented. This disparity appears to stem not from a lack of unique propolis resources, but from a confluence of socioeconomic and infrastructural barriers. Unlike in Brazil, where propolis is a high-value commodity driving research investment, apiculture in many of these underrepresented regions prioritizes honey production for local markets, leaving propolis as an undeveloped by-product. Consequently, limited national research funding is often allocated to more pressing public health and food security challenges, marginalizing natural product research. Furthermore, a significant infrastructure gap, particularly the lack of access to sophisticated analytical equipment like HPLC and mass spectrometry required for publication in high impact journals, creates a substantial technological hurdle. While valuable research may be occurring, it is often published in local, non-indexed journals, rendering it invisible to analyses confined to global databases like the Web of Science. This underrepresentation constitutes a significant missed opportunity, as these regions' unique flora and diverse bee species likely harbor novel propolis compositions with untapped bioactive potential, warranting targeted international collaboration and capacity-building efforts to explore.

The primary focus of the reviewed literature remains on characterizing the chemical composition of propolis and linking it to antioxidant activity. The predominance of studies on propolis from *Apis mellifera* is unsurprising given its global prevalence, a fact well-documented by Vit et al. (2024) [21]. However, the growing body of work on stingless bee propolis signals a promising shift towards exploring novel sources of bioactive compounds. This diversification is critical, as different bee species and geographical origins yield propolis with unique phytochemical profiles. The emphasis on specific phenolic compounds—such as chrysin, pinocembrin, caffeic acid, and artepillin C—highlights the scientific effort to identify the key molecules responsible for antioxidant effects of propolis.

The overwhelming predominance of research on propolis from the European honeybee, Apis mellifera, is a key finding of this analysis. This focus is pragmatic and largely unsurprising, as it logically stems from the species' global commercial ubiquity and its role as the primary source for the established international propolis market. However, this methodological conservatism, while convenient, casts a long shadow over the field's potential for novel discovery by effectively sidelining the vast and chemically diverse world of propolis from stingless bees (Meliponini). These bees inhabit different ecological niches and utilize a wider array of plant resins, meaning their propolis is a largely unexplored reservoir of unique phytochemicals. Consequently, the current body of literature may present a biased and incomplete picture of true therapeutic potential of propolis. By neglecting these alternative sources, the scientific community risks overlooking novel flavonoids, phenolic acids, and other bioactive compounds that could possess distinct or even superior antioxidant, antimicrobial, or anti-inflammatory properties. This represents a significant missed opportunity, underscoring a critical need for future research to diversify its focus and systematically investigate the untapped potential of stingless bee propolis.

Methodologically, the field relies heavily on in vitro assays (e.g., DPPH, ABTS) and chemical characterization techniques like HPLC, which is a common and necessary first step in natural product research [20]. The choice of extraction solvent, overwhelmingly ethanol, reflects a pragmatic approach prioritizing extraction efficiency for a broad range of polyphenols. This focus on optimizing extraction is not unique to propolis and is a central theme in research on other natural bee products, like bee bread, where the solvent system directly dictates the yield of bioactive components [35]. However, as noted by Sousa et al. (2023), there is a clear and pressing need to move beyond these initial characterizations [20]. The relative scarcity of in vivo studies and clinical trials represents the most significant gap in the current literature, hindering the translation of promising laboratory findings into credible therapeutic applications.

The thematic analysis of keywords reveals the conceptual structure of the field, which has evolved from basic characterization to more complex applications. As demonstrated in other bibliometric studies, keyword co-occurrence maps are effective tools for visualizing the intellectual core of a research area [30]. In this case, the analysis shows a progression from foundational topics like ''chemical composition'' and ''flavonoids'' toward more applied concepts such as ''oxidative stress'', ''inflammation'', and, more recently, ''encapsulation'' and ''synergistic activity'' (e.g., with pollen). This trajectory suggests the field is maturing, moving from discovery to application. Despite this, the research remains concentrated on certain biological activities. The preference for publishing studies on anti-inflammatory and neuroprotective effects in higher-impact journals, as observed by Sousa et al. (2023), may suggest that antioxidant research, while foundational, is often seen as a baseline property rather than a primary therapeutic endpoint in its own right [20].

A particularly telling finding from the analysis is the relative imbalance between studies focused on the beneficial bioactivities of propolis and those dedicated to assessing its safety profile. While the content analysis identified research on ''cytotoxicity assays'', ''toxicity assessment'', and ''safety evaluation'' (Tables 1 and 2), these studies are significantly outnumbered by those investigating antioxidant and antimicrobial effects. This observation is critical because the concept of cytotoxicity in propolis research is twofold and context-dependent. For its potential use in nutraceuticals or functional foods, a low cytotoxicity profile against healthy cells is essential to establish safety for widespread consumption. The current scarcity of comprehensive safety data presents a notable barrier to its evidence-based integration into mainstream wellness products.

Conversely, in therapeutic areas such as oncology—a field where ''anticancer activity'' and ''apoptosis'' were identified as key research themes—selective cytotoxicity against malignant cells is the primary therapeutic goal. Here, the challenge is not simply to avoid toxicity, but to harness it in a targeted manner. This highlights a crucial gap: literature often demonstrates efficacy (e.g., propolis kills cancer cells in vitro) without adequately defining the therapeutic window—the dose range that is effective against the target pathology without causing unacceptable harm to the host. This gap has profound implications for the translational potential of propolis. The path from a promising laboratory finding to a clinically approved therapeutic is paved with rigorous safety and toxicology data. Without more dedicated in vivo toxicity studies to establish safe dosage limits and assess potential adverse effects, the translation of decades of promising in vitro research into credible clinical applications will remain significantly hindered. Therefore, future research must place a greater emphasis on systematically evaluating the safety of propolis in parallel with its efficacy to bridge this critical translational gap.

Beyond mapping the research landscape, this analysis reveals important insights into the collective methodological quality of the field, which carries significant implications for potential bias in the literature. The overwhelming reliance on in vitro antioxidant assays—such as DPPH, ABTS, and FRAP—and chemical characterization via HPLC, as shown in the content analysis (Table 2), highlights a field that excels at preliminary screening but often stops there. While essential for initial discovery, the heavy dependence on these methods without sufficient in vivo validation introduces a significant positive bias, where promising laboratory results may not translate into tangible biological effects. Furthermore, this analysis underscores a critical lack of methodological standardization across studies. The wide variation in propolis sourcing, extraction solvents and protocols, and the specific antioxidant assays employed makes it exceedingly difficult to compare findings directly or conduct robust meta-analyses. This methodological heterogeneity can lead to conflicting results and creates a bias where outcomes may be more reflective of the chosen experimental conditions than the intrinsic properties of the propolis itself. The most pronounced methodological gap, however, is the stark scarcity of rigorous clinical trials compared to the abundance of laboratory-based research. This imbalance in the evidence hierarchy means the field is heavily weighted towards discovery and preclinical exploration, creating a high risk that the therapeutic potential of propolis is currently overstated, as it remains largely unconfirmed in human subjects. Addressing this systemic bias by promoting standardized protocols and prioritizing clinical validation is essential for the maturation of the field.

The analysis also highlights a pragmatic, yet potentially limiting, approach to extraction and compound analysis. The overwhelming preference for ethanol as an extraction solvent is practical, as it is effective for a broad range of polyphenols. However, this methodological conservatism means that compounds that are less soluble in ethanol may be consistently overlooked. The practical implication for researchers is that exploring greenery, alternative, and more selective extraction techniques could unlock new chemical diversity within propolis. Furthermore, while the field has become adept at identifying specific marker compounds like chrysin, pinocembrin, and artepillin C, the focus on individual molecules often overshadows the study of the synergistic effects of the whole extract. This points to another underexplored area: understanding how the complex interplay of compounds contributes to the overall antioxidant effect.

A critical finding with direct translational implications is the imbalance between efficacy and safety studies. This analysis identified research on cytotoxicity and toxicity, but these are vastly outnumbered by studies on beneficial properties. For propolis to be used safely in nutraceuticals or therapeutics, its safety profile is as important as its efficacy. The current literature lacks sufficient data to define the therapeutic window for propolis—the dose that is effective without causing harm. This gap severely limits its translational potential. Without robust in vivo toxicology data, moving from promising laboratory findings to credible clinical applications is impossible. Future research must, therefore, treat safety assessment not as an afterthought but as a core component of the investigation, conducted in parallel with efficacy studies.

A particularly telling finding from this analysis is the critical imbalance between the vast body of literature dedicated to the beneficial bioactivities of propolis and the relative scarcity of studies assessing its safety profile. While the content analysis identified research on cytotoxicity and safety, these investigations are significantly outnumbered by those focused on antioxidant and antimicrobial effects. This gap has profound implications for the translational potential of propolis. The path from a promising laboratory finding to a clinically credible therapeutic is paved with rigorous toxicology data, yet the literature largely fails to define the therapeutic window—the crucial dose range that is effective against a pathology without causing unacceptable harm to the host. This lack of comprehensive safety data is a major barrier to clinical translation, and it is compounded by the field's wider methodological heterogeneity. The lack of standardization in propolis sourcing, extraction, and analytical protocols not only makes robust meta-analyses nearly impossible but also significantly hinders efforts toward regulatory acceptance. Therefore, to bridge this stark lab-to-clinic gap, future research must fundamentally shift its priorities. It is imperative to move beyond simple efficacy screening and dedicate resources to systematic in vivo studies on pharmacokinetics, bioavailability, metabolism, and toxicology. Only through such rigorous investigation can the promising in vitro findings of the last decade be translated into safe and effective real-world applications.

The findings of this analysis present several clear directions for future research. While *Apis mellifera* propolis is well-studied, significant potential lies in exploring propolis from under-researched stingless bee species and diverse geographical locations. Such studies must include meticulous documentation of bee species, botanical origins, and collection parameters to build a robust, comparable dataset. Research should move towards greener and more selective extraction techniques, such as supercritical fluid extraction [20]. More importantly, the field requires greater methodological standardization across studies—from extraction to analytical protocols—to ensure data are comparable and can be used in future meta-analyses. The most critical need is to validate the health benefits of propolis through rigorous in vivo and clinical trials. Future work must prioritize studies on bioavailability, metabolism, and mechanisms of action of propolis antioxidants in biological systems to establish effective dosages and confirm therapeutic efficacy. Investigating the synergistic effects of propolis with other natural products (e.g., pollen) or conventional drugs is a promising avenue. Furthermore, developing novel formulations, such as nanoparticles and functional food coatings, can enhance the stability and delivery of propolis antioxidants, expanding their practical applications.

This research offers a robust and multifaceted analysis of the literature on antioxidant activity of propolis, grounded in a systematic methodology and a substantial dataset from the Web of Science. By employing established bibliometric tools and contextualizing findings with comprehensive reviews, this study provides a clear overview of the research landscape, identifies key trends, and offers concrete recommendations for future work.

Limitations of the study

While this systematic and bibliometric analysis provides a comprehensive overview of the research landscape, it is important to acknowledge its inherent limitations to ensure a balanced interpretation of the findings.

First, the analysis was confined exclusively to the WOS Core Collection. While this database was strategically chosen for its high-quality data, rigorous indexing standards, and suitability for bibliometric analysis, this single-source approach inevitably means that relevant articles indexed solely in other significant databases, such as Scopus, PubMed, or various regional indexes, were not included. Consequently, although the findings provide a robust overview of the research landscape published in leading international journals, they may not capture the absolute entirety of global scientific output on this topic, potentially underrepresenting publications from journals not covered by WOS.

Second, the scope of this research was intentionally focused on the "antioxidant activity" of propolis. This narrow focus allowed for a deep and detailed analysis of a foundational research area, but it means that the conclusions drawn regarding publication trends, key contributors, and thematic evolution are specific to this subfield. These trends may not be generalizable to the broader field of propolis research, which includes extensive work on other biological properties like antimicrobial, anticancer, and immunomodulatory activities that were not the primary subject of this research.

Finally, while bibliometric indicators such as publication counts and citation rates are valuable for mapping the structure and impact of a research field, they are not definitive measures of research quality or scientific importance. Citation patterns can be influenced by various factors, including journal visibility, author reputation, and the time elapsed since publication, independent of a study's methodological rigor. Furthermore, as a bibliometric research, this study did not include a formal risk-of-bias assessment for each of the 321 included articles. Therefore, the conclusions reflect the quantity, focus, and collaborative structures of the existing literature rather than a systematic evaluation of its internal validity.

Conclusion

This systematic and bibliometric analysis of 321 research articles published between 2015 and 2024 provides a comprehensive overview of the scientific landscape surrounding the antioxidant activity of propolis. The study confirms that this is a vibrant and globally collaborative field, characterized by a steady growth in publications. Research is geographically concentrated, with Brazil, Turkey, and China emerging as key contributors, a trend largely driven by regional biodiversity and long-standing traditions of apitherapy. This research reveals a predominant focus on propolis sourced from *Apis mellifera* and extracted with ethanol. Thematic analysis shows that research is heavily centered on the chemical characterization of phenolic compounds, particularly flavonoids and phenolic acids, and the quantification of their antioxidant capacity through in vitro assays.

Collectively, these findings indicate that the field has established a robust foundation, successfully demonstrating the potent antioxidant potential of propolis in a laboratory setting. However, the most critical conclusion drawn from this analysis is the significant translational gap that exists between in vitro discovery and clinical validation. While the chemical basis of antioxidant activity of propolis is increasingly well-understood, there remains a stark scarcity of rigorous in vivo and clinical studies needed to substantiate these findings in humans. Furthermore, the lack of methodological standardization across studies (in terms of propolis sourcing, extraction, and analytical protocols) remains a major obstacle, limiting the comparability of results and hindering the ability to perform robust meta-analyses.

In conclusion, the research on propolis as an antioxidant has reached a pivotal point of maturity. The foundational work of the past decade provides a solid launching pad for a new era of research focused on application and validation. Future efforts must prioritize the exploration of novel propolis sources, adopt standardized methodologies, and, most crucially, shift focus towards well-designed in vivo and clinical investigations. By systematically addressing these gaps, the scientific community can bridge the divide between laboratory potential and clinical reality, ultimately unlocking the full therapeutic value of propolis and establishing it as an evidence-based tool for combating oxidative stress and promoting human health.

Acknowledgements The author gratefully acknowledges the assistance of Assoc. Prof. Dr. Kıvanç Bozkuş during the bibliometric analysis phase of this research.

Author contributions Tuğba Nigar Bozkuş: Conceptualization; formal analysis; investigation; methodology; supervision; writing – original draft; writing – review and editing.

Funding The author received no specific funding for this research.

Data availability The data are available at https://doi.org/10.17632/6cf3s3m47p.1.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

References

1. Mendonça ICG, Moraes Porto ICC, Nascimento TG, Souza NS, Santos Oliveira JM, Santos Arruda RE, Mousinho KC, Santos AF, Basílio-Junior ID, Parolia A, Barreto FS (2015) Brazilian red propolis: phytochemical screening, antioxidant activity and effect against cancer cells. BMC Complement Altern Med 15(1):357. https://doi.org/10.1186/s12906-015-0888-9
2. Ahmed R, Tanvir EM, Hossen S, Afroz R, Ahmmed I, Rumpa NEN, Paul S, Gan SH, Sulaiman SA, Khalil I (2017) Antioxidant properties and cardioprotective mechanism of Malaysian propolis in rats. Evid-Based Complement Altern Med 2017:5370545. https://doi.org/10.1155/2017/5370545
3. Bazmandegan G, Boroushaki MT, Shamsizadeh A, Ayoobi F, Hakimzadeh E, Allahtavakoli M (2017) Brown propolis attenuates cerebral ischemia-induced oxidative damage via affecting antioxidant enzyme system in mice. Biomed Pharmacother 85:503–510. https://doi.org/10.1016/j.biopha.2016.11.057
4. Nanaware S, Shelar M, Sinnathambi A, Mahadik KR, Lohidasan S (2017) Neuroprotective effect of Indian propolis in β-amyloid induced memory deficit: impact on behavioral and biochemical parameters in rats. Biomed Pharmacother 93:543–553. https://doi.org/10.1016/j.biopha.2017.06.072
5. Silva FRG, Matias TMS, Souza LIO, Matos-Rocha TJ, Fonseca SA, Mousinho KC, Santos AF (2017) Phytochemical screening and *in vitro* antibacterial, antifungal, antioxidant and antitumor activities of the red propolis Alagoas. Brazilian J Biology 79(3):452–459. https://doi.org/10.1590/1519-6984.182959
6. Calegari MA, Prasniewski A, Silva C, Sado RY, Maia FMC, Tonial LMS, Oldoni TLC (2017) Propolis from Southwest of Parana produced by selected bees: influence of seasonality and food supplementation on antioxidant activity and phenolic profile. Anais Da Acad Brasileira De Ciencias 89(1):45–55. https://doi.org/10.1590/0001-3765201620160499
7. Boufadi MY, Soubhye J, Van Antwerpen P (2021) Anti-inflammatory, antioxidant effects, and bioaccessibility of Tigzirt propolis. J Food Biochem 45(4):e13663. https://doi.org/10.1111/jfbc.13663
8. Sun C, Wu Z, Wang Z, Zhang H (2015) Effect of ethanol/water solvents on phenolic profiles and antioxidant properties of

Beijing propolis extracts. Evid-Based Complement Altern Med 2015:595393. https://doi.org/10.1155/2015/595393
9. Zhao L, Pu L, Wei J, Li J, Wu J, Xin Z, Gao W, Guo C (2016) Brazilian green propolis improves antioxidant function in patients with type 2 diabetes mellitus. Int J Environ Res Public Health 13(5):498. https://doi.org/10.3390/ijerph13050498
10. Bonamigo T, Campos JF, Alfredo TM, Perrella Balestieri JB, Lima Cardoso CA, Paredes-Gamero EJ, Picoli Souza K, Santos EL (2017) Antioxidant, cytotoxic, and toxic activities of propolis from two native bees in brazil: scaptotrigona depilis and Melipona quadrifasciata anthidioides. Oxidative Med Cell Longev 2017(1038153). https://doi.org/10.1155/2017/1038153
11. Mişe Yonar S, Köprücü K, Yonar ME, Silici S (2017) Effects of dietary propolis on the number and size of pleopadal egg, oxidative stress and antioxidant status of freshwater crayfish (*Astacus leptodactylus Eschscholtz*). Anim Reprod Sci 184:149–159. https://doi.org/10.1016/j.anireprosci.2017.07.010
12. Ni J, Wu Z, Meng J, Zhu A, Zhong X, Wu S, Nakanishi H (2017) The neuroprotective effects of Brazilian green propolis on neurodegenerative damage in human neural SH-SY5Y cells. Oxid Med Cell Longev 2017:7984327. https://doi.org/10.1155/2017/7984327
13. Sun L, Wang K, Xu X, Ge M, Chen Y, Hu F (2017) Potential protective effects of bioactive constituents from Chinese propolis against acute oxidative stress induced by hydrogen peroxide in cardiac H9c2 cells. Evid-Based Complement Altern Med 2017:7074147. https://doi.org/10.1155/2017/7074147
14. Narimane S, Demircan E, Salah A, Özçelik B, Salah R (2017) Correlation between antioxidant activity and phenolic acids profile and content of Algerian propolis: influence of solvent. Pak J Pharm Sci 30(4):1417–1423
15. Oliveira LFAM, Silva LVAT, Nascimento TG, Almeida LM, Calumby RJN, Nunes AM, Magalhaes Oliverira LMT, Silva Fonseca EJ (2020) Antioxidant and antimicrobial activity of red propolis embedded mesoporous silica nanoparticles. Drug Dev Ind Pharm 46(7):1199–1208. https://doi.org/10.1080/03639045.2020.1782423
16. El-Awady MS, El-Agamy DS, Suddek GM, Nader MA (2014) Propolis protects against high glucose-induced vascular endothelial dysfunction in isolated rat aorta. J Physiol Biochem 70(1):247–254. https://doi.org/10.1007/s13105-013-0299-7
17. Zhang J, Shen X, Wang K, Cao X, Zhang C, Zheng H, Hu F (2016) Antioxidant activities and molecular mechanisms of the ethanol extracts of *Baccharis* propolis and *Eucalyptus* propolis in RAW264.7 cells. Pharm Biol 54(10):2220–2235. https://doi.org/10.3109/13880209.2016.1151444
18. Gomes KO, Silva LCFM, Santos RD, Prado BA, Silva Montes P, Rodrigues LFS, Araujo MO, Bilac CA, Freire DO, Gris EF, Silva ICR, Sa Barreto LCL, Orsi DC (2024) Chemical characterization and antibacterial activities of Brazilian propolis extracts from *Apis mellifera* bees and stingless bees (Meliponini). PLoS ONE 19(7):e0307289. https://doi.org/10.1371/journal.pone.0307289
19. Kumari S, Naik P, Vishma BL, Salian SR, Devkar RA, Khan S, Mutalik S, Kalthur G, Adiga SK (2016) Mitigating effect of Indian propolis against mitomycin C induced bone marrow toxicity. Cytotechnology 68:1789–1800. https://doi.org/10.1007/s10616-015-9931-4
20. Sousa ARS, Santana E, Guedes TJFL, Araujo ED (2023) Bee glue scientometrics and therapeutics: phytochemical screening, methodological trends and prospects. J Apic Res 62(1):148–161. https://doi.org/10.1080/00218839.2022.2054537
21. Vit P, Wang Z, Zakaria R (2024) Stingless bees (1955–2021) and other bees (1945–2021) in propolis Research. A bibliometric review of scholarly articles. In: Vit P, Bankova V, Popova M, Roubik DW (eds) Stingless bee nest cerumen and propolis, vol 1. Springer, Cham, pp 117–135. https://doi.org/10.1007/978-3-031-43274-3_6
22. Bozkuş TN (2025) The evolution of propolis research: A bibliometric analysis. Eur J Integr Med 78:102518. https://doi.org/10.1016/j.eujim.2025.102518
23. Moher D, Liberati A, Tetzlaff J, Altman DG, Prisma Group (2009) Reprint-preferred reporting items for systematic reviews and meta–analyses: the PRISMA statement. Phys Therapy 89(9):873–880. https://doi.org/10.1093/ptj/89.9.873
24. Grosseck G, Ţiru LG, Bran RA (2019) Education for sustainable development: evolution and perspectives: a bibliometric review of research, 1992–2018. Sustainability 11(21):6136. https://doi.org/10.3390/su11216136
25. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Int J Surg 88:105906. https://doi.org/10.31222/osf.io/jb4dx
26. Pham HH, Dong TKT, Vuong QH, Luong DH, Nguyen TT, Dinh VH, Ho MT (2021) A bibliometric review of research on international student mobilities in Asia with scopus dataset between 1984 and 2019. Scientometrics 126(6):5201–5224. https://doi.org/10.1007/s11192-021-03965-4
27. Thukral S, Jain A (2021) Unveiling contemporary dimensions in the internationalisation of family firms through bibliometric analysis and thematic analysis. Rev Int Bus Strategy 31(4):507–539. https://doi.org/10.1108/ribs-09-2020-0121
28. Kim H, So KKF (2022) Two decades of customer experience research in hospitality and tourism: a bibliometric analysis and thematic content analysis. Int J Hosp Manag 100:103082. https://doi.org/10.1016/j.ijhm.2021.103082
29. Fauzi MA (2023) Knowledge hiding behavior in higher education institutions: a scientometric analysis and systematic literature review approach. J Knowl Manag 27(2):302–327. https://doi.org/10.1108/jkm-07-2021-0527
30. Sanchez–Garcia E, Martinez–Falco J, Marco–Lajara B, Georgantzis N (2024) Value creation in the wine industry—a bibliometric analysis. Eur Food Res Technol 250:1135–1148. https://doi.org/10.1007/s00217-023-04451-2
31. Dima A, Bugheanu AM, Boghian R, Madsen DO (2022) Mapping knowledge area analysis in e–learning systems based on cloud computing. Electronics 12(1):62. https://doi.org/10.3390/electronics12010062
32. Popescu DV, Dima A, Radu E, Dobrotă EM, Dumitrache VM (2022) Bibliometric analysis of the green deal policies in the food chain. Amfiteatru Econ 24(60):410–428. https://doi.org/10.24818/ea/2022/60/410
33. Büyükkıdık S (2022) A bibliometric analysis: A tutorial for the bibliometrix package in R using IRT literature. J Meas Evaluation Educ Psychol 13(3):164–193. https://doi.org/10.21031/epod.1069307
34. Martínez-Falco J, Sanchez-Garcia E, Marco-Lajara B, Millan-Tudela LA (2024) Analysis of the scientific knowledge structure on automation in the wine industry: a bibliometric and systematic review. Eur Food Res Technol 250:2273–2289. https://doi.org/10.1007/s00217-024-04553-5
35. Gülbaz G, Akbaba GB, Öztürkkan FE (2025) Assessment of chemical composition and *in vitro* and *in Silico* anticarcinogenic activity of bee bread samples from Eastern Anatolia (Kars). Eur Food Res Technol 251:899–914. https://doi.org/10.1007/s00217-025-04679-0