Applied Science and Engineering Progress, Vol. 20, No. 2, 2027, 8283

Review Article

Global Research Trends in *Citrus aurantiifolia* (1987–2025): Insight into Bioactive Compounds, Biological Activities, and Food Applications from a Bibliometric Analysis

Einstivina Nuryandani
Faculty of Science and Technology, Universitas Terbuka, South Tangerang, Indonesia

Yusuf Andriana*
National Research and Innovation Agency, Research Center for Food Technology and Processing, Gunungkidul, Indonesia
Notokusumo College of Health Sciences, Pharmacy Study Program, Yogyakarta, Indonesia

Tia Erfianti
Post Doctoral Program, National Research and Innovation Agency, Gunungkidul, Indonesia

Muhammad Fatih Abdurrahman
Research Assistant Program, National Research and Innovation Agency, Gunungkidul, Indonesia

Jasmadi Jasmadi, Indyaswan Tegar Suryaningtyas, Erni Apriyati, Siti Dewi Indrasari, Rofiq Sunaryanto, Donowati Tjokrokusumo, Dedy Kurnianto, Jerry Wungkana, Suzanne Laura Liwu, and Christina Litaay
National Research and Innovation Agency, Research Center for Food Technology and Processing, Gunungkidul, Indonesia

* Corresponding author. E-mail: yusuf.andriana@brin.go.id DOI: 10.14416/j.asep.2026.08.008
Received: 26 April 2026; Revised: 15 June 2026; Accepted: 7 July 2026; Published online: 18 August 2026

Abstract
Over the period 1987–2025, research on *Citrus aurantiifolia* (key lime) has expanded substantially due to its rich phytochemical composition, diverse biological activities, and broad application potentials. However, a comprehensive assessment of research trends, collaborations, and thematic evolution of *C. aurantiifolia* remains limited. This bibliometric study addresses this gap by analyzing 454 Scopus-indexed publications published between 1987 and 2025, providing performance analysis and science mapping with a particular focus on bioactive compounds, biological activities, and food applications. The results revealed a considerable increase in publications since 2010, driven by growing scientific and industrial interest. Research productivity was led by Indonesia, Iran and India, while the highest citation impact was attributed to the United States, which also plays a central role in international collaborations. Keyword and thematic analyses revealed that antioxidant activity, antibacterial activity, essential oils, flavonoids, and phenolic compounds remain among the most prominent research themes. Science mapping showed a strong interconnected landscape among phytochemical characterization, bioactivity evaluation, and application-oriented research, while GC–MS and LC–MS emerged as widely used analytical tools. The thematic evolution analysis demonstrated progression from phytochemical characterization and analytical methodologies toward bioactivity assessment and more recent application-driven topics. Emerging themes such as green synthesis and nano-formulations further indicate increasing diversification toward sustainable and interdisciplinary research. This study provides a comprehensive synthesis of the intellectual structure of *C. aurantiifolia* research and identifies future directions, including standardized profiling, mechanistic investigations, clinical validations, and scalable nutraceutical applications.

Keywords: Bibliometric analysis, Bioactive compounds, Biological activities, *Citrus aurantiifolia*, Food applications

1 Introduction

Key lime (*Citrus aurantiifolia* Swingle), belonging to the Rutaceae family, is commonly cultivated in tropical and subtropical climates for food flavoring, beverages, traditional medicines, and fragrance production [1]. The distinctive scent, high acidity, and abundance of biologically active metabolites have attracted considerable scientific interest. A previous study reported that the peel and fruit of *C. aurantiifolia* exhibit high levels of flavonoids, limonoids, essential oils (e.g. limonene; β-pinene; citronellal) and phenolic compounds, which contribute to their diverse biological activities [2]. In addition to their biological functions, some volatile constituents of this plant play an important role in aroma and flavor development. Recent studies have emphasized the role of volatile flavor compounds in lime cultivars, reflecting growing interest in aroma-active metabolites and food applications [3].

Research on *C. aurantiifolia* has increased exponentially for nearly four decades (1987–2025), especially studies related to its chemical composition and biological activities. For example, *C. aurantiifolia* extracts have been reported to exhibit anticancer, antidiabetic and anti-insect activities [4–6]. Moreover, *C. aurantiifolia* has attracted considerable attention in the field of food science as an active ingredient in food development and preservation. Several bioactive compounds isolated from *C. aurantifolia* fruit, including essential oils, flavonoids, terpenoids, limonoids, and alkaloids, are under investigation for incorporation into food matrices as microencapsulated systems or as natural preservatives. Additionally, another study reported that the edible coatings enriched with functional additives, applied in both pre- and post-harvest studies, could increase shelf life while preserving phenolic and flavonoid contents of *C. aurantiifolia* fruit [7].

To capture the growing research interest in the field, bibliometric analysis serves as a powerful tool to explore publication trends, authorship and collaboration networks, thematic evolutions, and research gaps, thereby enabling a systematic mapping of the evolution of themes. For example, a bibliometric study has been conducted for the general genus of *Citrus,* showing comprehensive research trends over the last 22 years [8]. However, to the best of our knowledge, no dedicated bibliometric review has focused exclusively on *C. aurantiifolia*, particularly with respect to its bioactive compounds, biological activities, and food applications over the past four decades.

Therefore, this study conducted a bibliometric analysis of *C. aurantiifolia* research from 1987 to 2025, incorporating both performance analysis and a science mapping approach. Performance analysis was used to evaluate publication trends, author contributions, citation impact, and collaboration networks, whereas science mapping was employed to explore thematic evolution, intellectual structure, and emerging research trends related to bioactive compounds, biological activities, and food applications. Furthermore, this study identifies the research gaps and strategic directions for facilitating future research to support the translation of *C. aurantiifolia* bioactive compounds into functional and sustainable applications.

2 Materials and Methods

2.1 *Research framework and data collection*

To ensure reproducibility and analytical rigor, this study followed a structured methodological workflow aligned with established bibliometric standards and reporting protocols [9], [10]. The process comprised database selection, development of a predefined Boolean search strategy, application of document eligibility criteria, data cleaning and standardization, and subsequent bibliometric analyses to ensure transparency, consistency, and reproducibility throughout the study.

This study utilized the Scopus database as its primary data source, owing to its comprehensive indexing of multidisciplinary research and the structural integrity of its metadata for generating detailed bibliometric maps [11], [12]. In addition, Scopus was selected because it is one of the most widely used bibliographic databases for bibliometric studies and provides broad multidisciplinary coverage, standardized metadata, and strong compatibility with Biblioshiny and VOSviewer [13]. Previous studies have shown that Scopus indexes more active journals than Web of Science (WoS) [12] and provides relatively consistent metadata with fewer duplicate records [14]. Although integrating multiple databases may broaden publication coverage, merging Scopus and WoS datasets may introduce metadata inconsistencies, duplicate records, and bibliographic standardization challenges that can affect analytical consistency [15–17]. Therefore, Scopus was used as the sole database in this study.

Articles, reviews, and conference papers from 1987–2025 were retrieved using a strategy encompassing scientific and common names of *C. aurantiifolia*. The query targeted keywords involving phytochemical profiles, analytical techniques, biological activities, and food applications. Only English-abstracted documents were included to ensure linguistic and methodological uniformity. The Boolean search strategy was organized into several thematic categories related to *C. aurantiifolia*, bioactive compounds, biological activities, and food applications, as summarized in Table 1.

Table 1: Summary of Boolean search string components used for literature retrieval in the Scopus database related to *C. aurantiifolia*.

Search category	Boolean search terms
C. aurantiifolia keywords	"Citrus aurantiifolia" OR "Citrus aurantifolia" OR "Limonia aurantiifolia" OR "Key lime" OR "Mexican lime" OR "West Indian lime" OR "Omani lime" OR "Bartender's lime"
Bioactive compounds and analytical characterization	"bioactive compound*" OR "phytochemical*" OR "flavonoid*" OR "phenolic compound*" OR "terpenoid*" OR "alkaloid*" OR "essential oil*" OR "limonene" OR "citral" OR "naringenin" OR "hesperidin" OR "eriocitrin" OR "GC-MS" OR "HPLC" OR "LC-MS" OR "FTIR"
Biological activities and bioactivity evaluation	"bioactivit*" OR "antioxidant*" OR "antimicrobial*" OR "antibacterial*" OR "antifungal*" OR "antidiabetic*" OR "anti-inflammatory" OR "anticancer" OR "cytotoxic*" OR "α-amylase inhibition" OR "α-glucosidase inhibition" OR "DPPH" OR "ABTS" OR "ORAC" OR "FRAP" OR "*in vitro*" OR "*in vivo*"
Food, industrial, and traditional applications	"food application*" OR "functional food*" OR "natural preservative*" OR "nutraceutical*" OR "food product*" OR "edible coating*" OR "food additive*" OR "flavoring agent*" OR "shelf life extension" OR "clean label" OR "traditional medicine" OR "herbal extract*" OR "ethnobotany" OR "plant-based ingredient*" OR "value-added product*" OR "waste valorization"

The complete Boolean search query used for bibliographic retrieval in the Scopus database (1987–2025) was presented below:

("*Citrus aurantiifolia*" OR "*Citrus aurantifolia*" OR "*Limonia aurantiifolia*" OR "Key lime" OR "Mexican lime" OR "West Indian lime" OR "Omani lime" OR "Bartender's lime")

AND

("bioactive compound*" OR "phytochemical*" OR "flavonoid*" OR "phenolic compound*" OR "terpenoid*" OR "alkaloid*" OR "essential oil*" OR "limonene" OR "citral" OR "naringenin" OR "hesperidin" OR "eriocitrin" OR "bioactivit*" OR "antioxidant*" OR "antimicrobial*" OR "antibacterial*" OR "antifungal*" OR "antidiabetic*" OR "anti-inflammatory" OR "anticancer" OR "cytotoxic*" OR "α-amylase inhibition" OR "α-glucosidase inhibition" OR "food application*" OR "functional food*" OR "natural preservative*" OR "nutraceutical*" OR "food product*" OR "edible coating*" OR "food additive*" OR "flavoring agent*" OR "shelf life extension" OR "clean label" OR "traditional medicine" OR "herbal extract*" OR "ethnobotany" OR "plant-based ingredient*" OR "value-added product*" OR "waste valorization" OR "GC-MS" OR "HPLC" OR "LC-MS" OR "FTIR" OR "DPPH" OR "ABTS" OR "ORAC" OR "FRAP" OR "*in vitro*" OR "*in vivo*").

2.2 *Data cleaning and standardization*

The dataset that exported from Scopus was cleaned with OpenRefine software (v3. 9. 3) to remove duplicates and standardize author names, institutional affiliations, country labels, and author keywords. Synonyms, spelling variations, and plural forms of terms (e.g., "flavonoids" vs. "flavonoid") were consolidated to ensure consistency. Manual validation was also conducted to minimize ambiguities and maintain the integrity of the bibliographic records following the previous method [10].

2.3 *Bibliometric analysis*

Data analysis was performed using Biblioshiny, the web interface of the bibliometrix package in RStudio (v4.5.0), and VOSviewer (v1.6.20), two widely used tools for bibliometric performance analysis and science mapping [9], [10]. Biblioshiny was used to generate descriptive bibliometric indicators such as annual publication trends, citation impact, author contribution, source productivity, country productivity, and thematic analysis based on established bibliometric laws. Network analyses were conducted in VOSviewer to visualize authorship structures and keyword co-occurrence patterns, while Biblioshiny was employed to construct thematic evolution maps and thematic structure maps that reveal the conceptual development of *C. aurantiifolia* research.

Applied Science and Engineering Progress, Vol. 20, No. 2, 2027, 8283

Descriptive analyses, including annual publication trends, leading journals, influential authors, most-cited documents, country productivity, corresponding-author countries, and country contributions, were presented using top-ranked items based on publication and citation frequencies. Additional visualizations generated in Biblioshiny included the three-field plot, which was constructed using the top 10 authors, top 15 author keywords, and top 15 countries.

For international co-authorship analysis, countries with a minimum threshold of three documents were included in the network visualization. Of the 70 countries identified in the dataset, 36 met this criterion and were included in the final map. Network visualizations were generated using the default settings of VOSviewer (v1.6.20), with association strength normalization applied for network mapping and visualization [18].

Keyword frequency analysis was performed using the top 50 author keywords. For keyword co-occurrence and overlay visualization analyses, author keywords with a minimum occurrence threshold of five were selected, resulting in 46 keywords being included from a total of 1,309 author keywords. These maps were used to identify thematic relationships, research hotspots, and emerging research clusters.

Temporal keyword evolution analysis was conducted in Biblioshiny using a minimum word frequency of five and three words per year. While for thematic map analysis, the top 150 keywords were analyzed using a minimum cluster frequency of five per thousand documents, three labels per cluster, and the Walktrap clustering algorithm.

The thematic evolution mapping analysis was conducted using 250 keywords, a minimum cluster frequency of five per thousand documents, an inclusion index weighted by word occurrences of 0.3, a minimum weight index of 0.1, three labels per cluster, the Walktrap clustering algorithm, and two cutting points. These parameter settings were selected to balance visualization clarity, analytical comprehensiveness, and reproducibility of the bibliometric workflow.

2.4 *Overview of methodological workflow*

This study follows a systematic workflow, as illustrated in Figure 1, consisting of data collection, preprocessing of bibliographic information, and bibliometric analysis, including performance analysis and science mapping with network-based visualization. This workflow was implemented to ensure transparency and reproducibility throughout the analysis of the bibliometric overview of 38 years (1987–2025) of research on *C. aurantiifolia*.

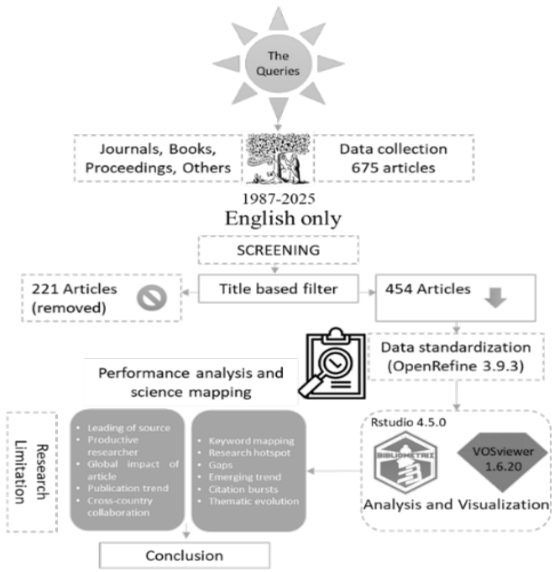

Figure 1: Visual representation of the study's approach.

3 Results and discussion

3.1 *Performance analysis*

3.1.1 *Descriptive characteristics of the dataset*

Table 2 illustrates the data set used in this study. Journal articles make up 86.8% of the research output. This indicates that peer-reviewed papers are the primary form of communication in this field. These findings align with the exploratory nature of the search query used in this study, which focuses on bioactive compounds, bioactivities, and food applications. Typically, this field requires extensive experimental validation, with journal publications prioritized for dissemination [10], [19].

Table 2: Summary of bibliometric characteristics of *C. aurantiifolia* research retrieved from the Scopus database (1987–2025).

Main information about data	
Timespan	1987:2025
Documents	454
Document Average Age	7.99
Average citations per doc	21.7
References	17191
Author's Keywords	1309
Authors	1922
Co-Authors per Doc	4.95
International co-authorships %	19.6
Document types	
Article	394
Review article	15
Book chapter	6
Conference paper	36
Others	3

Additionally, the dataset consists of 1,922 authors with a mean value of 4.95 co-authors per document. It shows a general collaborative and cross-disciplinary research [20], [21]. Furthermore, an average citation per document (21.7), alongside 17,191 references, demonstrates a highly interconnected and influential knowledge base. Moreover, the average document age of 7.99 years highlights its sustained relevance over time [22]. Finally, international collaboration accounted for 19.6% of total publications, reflecting a relatively modest level of global engagement and the need for stronger research partnerships between countries in the future [23].

3.1.2 Publication trends and growth dynamics

Figure 2 illustrates the publication trajectory of *C. aurantiifolia* research from 1987 to 2025, consisting of three main periods. The early phase (1987–2005) shows very low and irregular output, generally less than 8 publications per year. This is followed by a gradual increase between 2006 and 2014, with a moderate annual output of around 10–18 publications. A sharp and sustained rise occurs after 2015, with annual publications reaching 60 in recent years, demonstrating a strong acceleration of research activity over the last decade.

It seems *C. aurantiifolia* has changed its status from an underexplored species to a fast-developing research domain according to the trend observed.

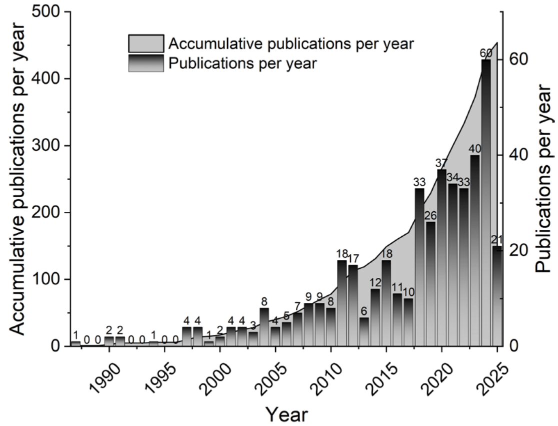

Figure 2: Annual and cumulative publication trends of *C. aurantiifolia* from 1987 to 2025.

The low publication output in earlier decades suggests that *C. aurantiifoli*a was relatively underexplored compared to other economically important citrus species like sweet orange (*Citrus sinensis*) and lemon (*Citrus limon*) [24]. The steep rise following 2010, particularly after 2015, could be associated not only with advances in analytical methodologies (e.g. GC–MS and LC–MS), but also with increasing global interest in natural bioactive compounds, clean-label products, plant-based functional foods, and sustainable utilization of citrus by-products [25–28]. In addition, advances in extraction technologies [29], improved database accessibility, expanding citrus research, increased funding opportunities, and stronger interdisciplinary collaborations may have further contributed to the substantial increase in publications [30].

3.1.3 Source and publisher analysis

Publications on *C. aurantiifolia* are spread across many journals. The *Journal of Essential Oil Research* is considered the leading source (14 articles), followed by *Acta Horticulturae* with 10 articles (Figure 3). Contributions from other leading journals such as *Food Chemistry* and *Journal of Agricultural and Food Chemistry* indicate that the research focus of *C. aurantiifolia* is primarily concentrated in the fields of phytochemistry, food science, and horticulture.

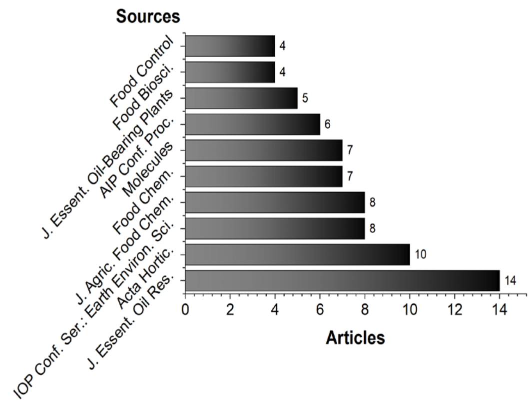

Figure 3: Leading publication sources for *C. aurantiifolia* research based on the number of articles indexed in Scopus (1987-2025).

The leading position of the *Journal of Essential Oil Research* suggests that research on *C. aurantiifolia* emphasizes essential oils and volatile compounds, aligning with industrial and nutraceutical significance [31], [32]. Publications in food and agricultural journals show growing interest in *C. aurantiifolia*, particularly in its nutritional, functional, and sustainable applications [33]-[35].

In addition, publisher analysis (Table 3) shows that only a few leading publishers are widely published on *C. aurantiifolia* research, specifically Taylor & Francis and Elsevier. Its wide-ranging medicinal, nutritional, and industrial relevance likely contributes to its strong presence in these platforms, which prioritize studies with high scientific and applied value [2], [5], [36].

Table 3: Leading publishers contributing to *C. aurantiifolia* research publications

Sources	Total Publication	Publisher
J. Essent. Oil Res.	14	Taylor & Francis
Acta Hortic.	10	International Society for Horticultural Science (ISHS)
IOP Conf. Ser.: Earth Environ. Sci.	8	IOP Publishing
J. Agric. Food Chem.	8	American Chemical Society (ACS)
Food Chem.	7	Elsevier
Molecules	7	MDPI (Multidisciplinary Digital Publishing Institute)
AIP Conf. Proc.	6	American Institute of Physics (AIP)
J. Essent. Oil Bear. Plants	5	Taylor & Francis
Food Biosci.	4	Elsevier
Food Control	4	Elsevier

3.1.4 Author productivity and influence

Based on the author productivity analysis of *C. aurantiifolia* research, as depicted in Figure 4, the field is largely driven by a small number of leading authors. Euis Julaeha ranks first with nine publications, followed by Paola Dugo and Luigi Mondello, each with eight articles. The other authors typically contribute between five and seven publications. This distribution suggests that research productivity and thematic influence are concentrated among several leading researchers with specialized expertise in phytochemical characterization, bioactivity evaluation, and food-related applications of *C. aurantiifolia*. The trend may reflect differences in research capacity, analytical access, collaborative networks, and research focus among authors [37], [38]. Moreover, the limited number of key contributors indicates that research on *C. aurantiifolia* is driven primarily by a relatively small group of specialized researchers, consistent with common scientometric patterns [39].

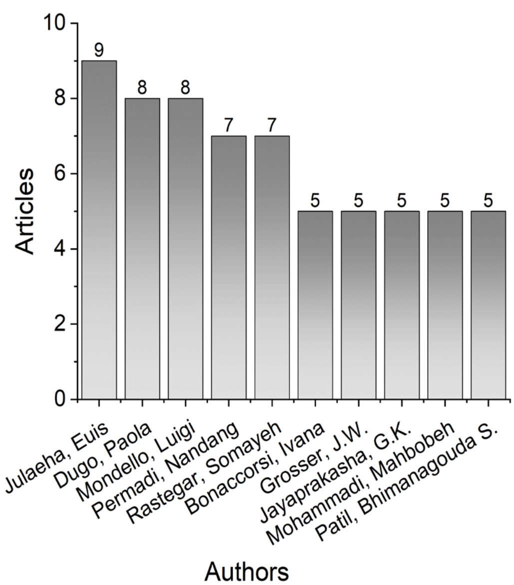

Figure 4: The most influential authors in bibliometric analysis according to Scopus data (1987-2025).

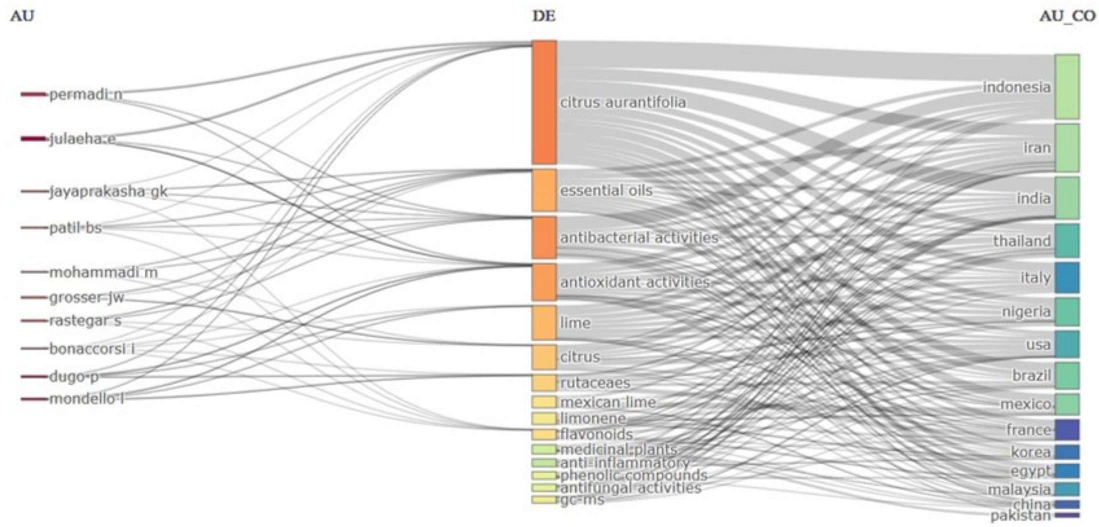

Figure 5: Three-field plot generated in Biblioshiny showing the relationship between Authors (AU), Keywords (DE), and Authors' Countries (AU_CO) based on Scopus data.

Figure 5 illustrates a three-field plot (authors–keywords–countries) demonstrating the correlation among leading authors, core research themes, and contributing countries. The most prominent themes include *Citrus aurantiifolia*, essential oils, antibacterial activities, and antioxidant activities, indicating their central role within the research landscape. Several prolific authors, including Euis Julaeha, Paola Dugo, Luigi Mondello, and others, are linked to multiple phytochemical and bioactivity-related topics, reflecting the diversity of research interests within the field. The figure also reveals thematic linkages between authors and major contributing countries, particularly Indonesia, India, and Iran, highlighting the geographical distribution of *C. aurantiifolia* research activities. Other authors exhibit fewer thematic connections within the three-field network.

This finding may demonstrate that author influence is determined by thematic specialization and collaboration networks. While some authors focus on specific bioactivity themes, others display broader thematic coverage. The dominance of phytochemical and bioactivity topics reflects current priorities and growing demand for natural bioactive compounds with antimicrobial and antioxidant potentials in food and health sectors [2], [40], [41].

3.1.5 Highly cited publications

Table 4 shows the most cited papers related to *C. aurantiifolia*. Bioactivity and phytochemical profiling represent two of the most prominent thematic areas in *C. aurantiifolia* research. Leading articles, such as the study conducted by Brito *et al.,* [42], emphasized the importance of phenolic compounds and antioxidant activity, whereas Dosoky and Setzer [43] highlighted the biological activities and applications of Citrus essential oils. Other reports explore anticancer potential [44], by-product

This finding may suggest that highly cited studies are often associated with broadly relevant research topics, including antioxidant, antimicrobial, and anticancer properties, which attract substantial scientific and industrial attention [47–49]. Methodologies, analytical techniques, and global health impacts in the field of food safety, public health, and sustainability aspects might also strengthen these contributions [50–52].

3.1.6 Country productivity and scientific impact

The global research output chart on C. aurantifolia is shown in Figure 6, demonstrating country productivity according to the number of publications. It shows that Indonesia, Iran, India and Thailand are the highest, followed by Nigeria, Brazil and Mexico. This shows global participation in C. aurantiifolia research with a higher concentration in Asia and tropical regions. This distribution implies that research on C. aurantiifolia may be strongly associated with regional relevance, driven by its widespread cultivation and its integration into daily dietary and traditional health practices as key lime. The availability of raw materials, high biodiversity, and strong local demand are likely to contribute to sustained research activity and continued interest in related research topics [58]-[60].

To further assess country productivity and scientific impact, Table 5 provides a detailed overview of publication output, citation impact measured by citation/document ratio and collaboration patterns. Notably, Italy recorded the highest citation/document value of 43.28, followed by the United States at 37.68 and Thailand at 31.45, indicating broader scientific recognition despite lower publication output. In contrast, Indonesia showed the highest number of publications but a lower citation/document ratio of 8.24. Furthermore, Iran and Nigeria demonstrated high total link strength values. A previous scientometric study has also demonstrated that international collaboration and co-authorship structures significantly influence citation performance and global research visibility [61]. Generally, this reflects a gap between productivity and impact, with international collaboration enhancing research visibility and impact [62]–[65].

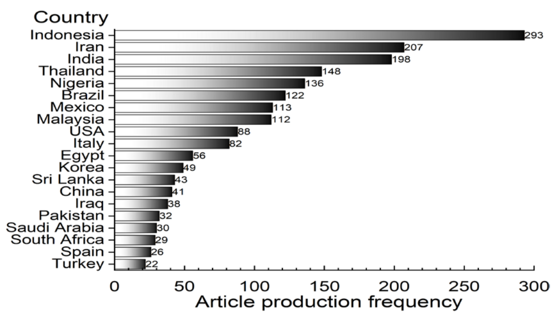

Figure 6: The 20 most productive countries in scientific publication from 1987 to 2025.

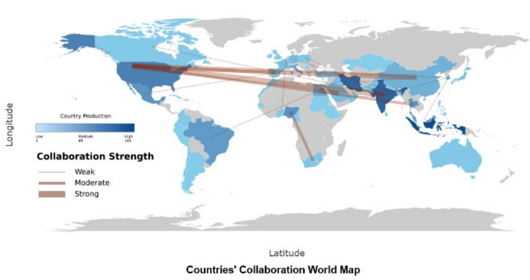

Figure 7: Country collaboration map generated using Biblioshiny. Note: Darker blue regions represent countries with higher collaboration frequency in this research area, as reflected by publication counts.

3.1.7 International collaboration network

Figure 7 presents a country collaboration map produced by Biblioshiny, demonstrating the strength of international scientific collaborations through co-authored publications. It demonstrates that research on *C. aurantiifolia* is supported by a global network, with key hubs in the USA, Iran, India and Nigeria. Moreover, increasing participation from Southeast Asia (especially Indonesia and Thailand) is also captured. In addition, corresponding author data for single-country publications (SCP) and multi-country publications (MCP) in Figure 8 show that Indonesia, Iran, and India lead in publication output, while countries such as Italy, Egypt, and Nigeria show stronger international collaboration. Furthermore, Figure 9 illustrates a co-authorship network by country displaying how countries are connected through shared publications, with central hubs (Iran, India, the United States, and Indonesia), as well as regional clusters and peripheral countries.

Table 5: Country contributions, citation impact, and collaboration strength in *C. aurantiifolia* research (1987–2025)

Country	Documents	Citations	Citation/ Document	Total link strength
Indonesia	66	544	8.24	68
India	54	1151	21.31	67
Iran	53	893	16.85	84
United states	38	1432	37.68	29
Nigeria	30	693	23.10	82
Thailand	29	912	31.45	62
Mexico	28	811	28.96	49
Brazil	25	495	19.80	38
Malaysia	24	462	19.25	19
Italy	18	779	43.28	96

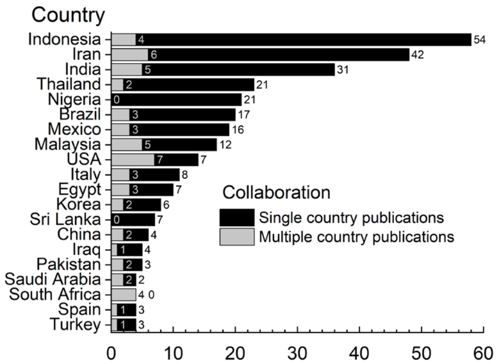

Figure 8: Top 20 countries ranked by the number of publications attributed to the corresponding author. SCP denotes publications from a single country; MCP involves authors from multiple countries.

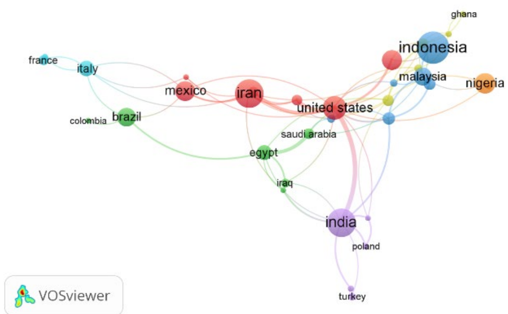

Figure 9: Bibliometric visualization of international co-authorship (1987–2025), generated with VOSviewer by the authors.

These findings imply that global collaborations are organized around a central hub and a few regional clusters, in which leading countries drive knowledge exchange between other countries and facilitate interdisciplinary integration [66]. In some countries, such as Indonesia, Iran and India, strong domestic research capacity coexists with collaboration-driven output. Furthermore, the United States plays a dual role as both a major contributor and a global connector. However, unequal connectivity across regions may reduce the visibility and citation impact of research [64]. In summary, international collaboration and research facilities at a country level promote scientific impact, but poor integration may reduce global reach [21], [23].

3.2 *Science mapping analysis*

3.2.1 Keyword co-occurrence and research hotspots

The 50 keywords with the maximum frequency in *C. aurantiifolia* research field can be visualized through a keyword co-occurrence word cloud as presented in Figure 10. The most frequent author keywords were *Citrus aurantiifolia*, antibacterial activities, antioxidant activities, and essential oils. Other commonly occurring terms included lime, citrus, flavonoids, phenolic compounds, limonene, and Rutaceae. The frequent occurrence of these keywords indicates that phytochemical characterization and bioactivity evaluation are among the most important research topics in *C. aurantiifolia* studies [2], [36], [67]. For example, the anti-plasmodial activity of phytochemicals isolated from *C. aurantiifolia* peels has also been investigated, indicating the broad range of bioactivities examined in this species [68]. In contrast, food-related terms appeared less frequently among the top keywords, suggesting comparatively lower representation of food application studies within the overall research landscape. These findings provide an overview of the principal topics that have attracted the greatest research attention in *C. aurantiifolia* studies.

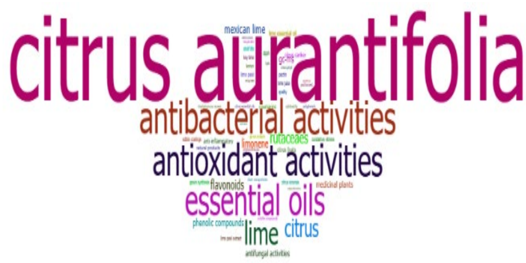

Figure 10: Visualization of the top 50 keywords that frequently appeared based on the Scopus collection from 1987 to 2025, generated using Biblioshiny.

3.2.2 Keyword network structure and emerging trends

Figure 11a illustrates the network of co-occurrence of keywords. The size of the nodes reflects the frequency of keywords, whereas the strength of the links reveals the connection between terms. The network visualization highlights the interconnections among phytochemical compounds, biological activities, and application-oriented research themes. Keywords associated with phytochemical characterization, including limonene, phenolic compounds, hesperidin, coumarins, and volatile compounds, were closely linked to antibacterial and antioxidant activities, demonstrating that investigations of biological properties were strongly supported by phytochemical characterization and compound identification.

Beyond the core phytochemical–bioactivity cluster, the network also reveals links to emerging application-oriented topics. Keywords such as pectin, postharvest, shelf life, and green synthesis are connected to the central bioactivity-related terms, suggesting increasing translation of phytochemical knowledge into food preservation, quality management, and sustainable technology applications. This network structure indicates the growing integration of fundamental phytochemical research with practical and interdisciplinary applications [69]-[73].

The overlay visualization (Figure 11b) complements the network analysis by identifying newer research directions within the literature. The appearance of terms such as cytotoxicity indicates increasing attention to biomedical applications, while their integration within the broader keyword network highlights the expanding scope and interdisciplinary nature of contemporary *C. aurantiifolia* research [74].

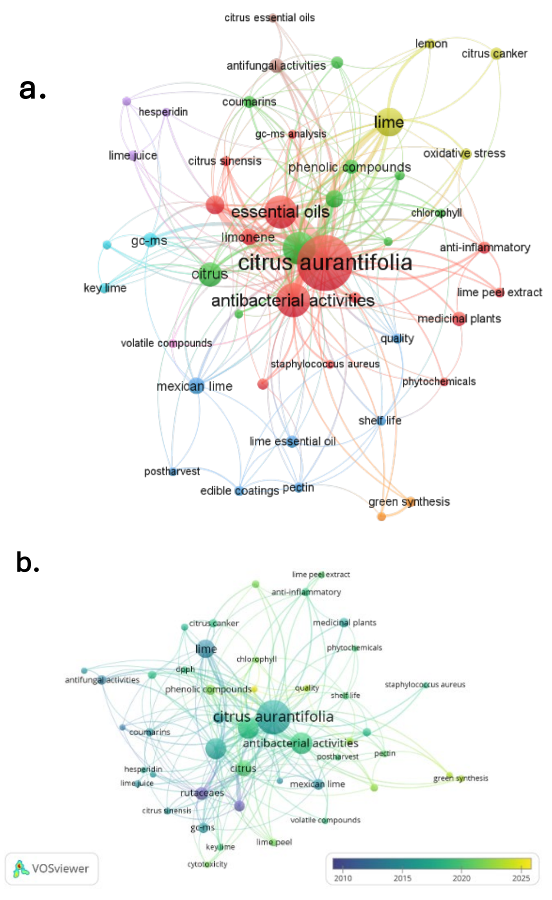

Figure 11: Bibliometric mapping of keyword co-occurrence (1987–2025) based on Scopus data, generated using VOSviewer: (a). Network visualization and (b). Overlay visualization.

3.2.3 Thematic evolution of research priorities

A detailed visualisation of keywords on *C. aurantiifolia* research across the years from 1987 to 2025 is illustrated in a thematic evolution map (Figure 12). Early studies were primarily characterized by taxonomic descriptors, phytochemical constituents, and analytical methodologies, as reflected by the prominence of keywords such as Rutaceae, limonene, coumarins, HPLC, and GC–MS analysis. Between 2014 and 2018, research expanded toward bioactive compounds and functional plant attributes, with increased attention to flavonoids, citrus fruits, lime essential oils, and medicinal plants. Subsequently, biological activity-related topics, including antioxidant and antibacterial activities, became more prominent, accompanied by application-oriented themes such as edible coatings and anti-inflammatory properties. In the most recent period, research themes have expanded further toward sustainability- and application-oriented areas, reflecting the continued diversification of *C. aurantiifolia* research.

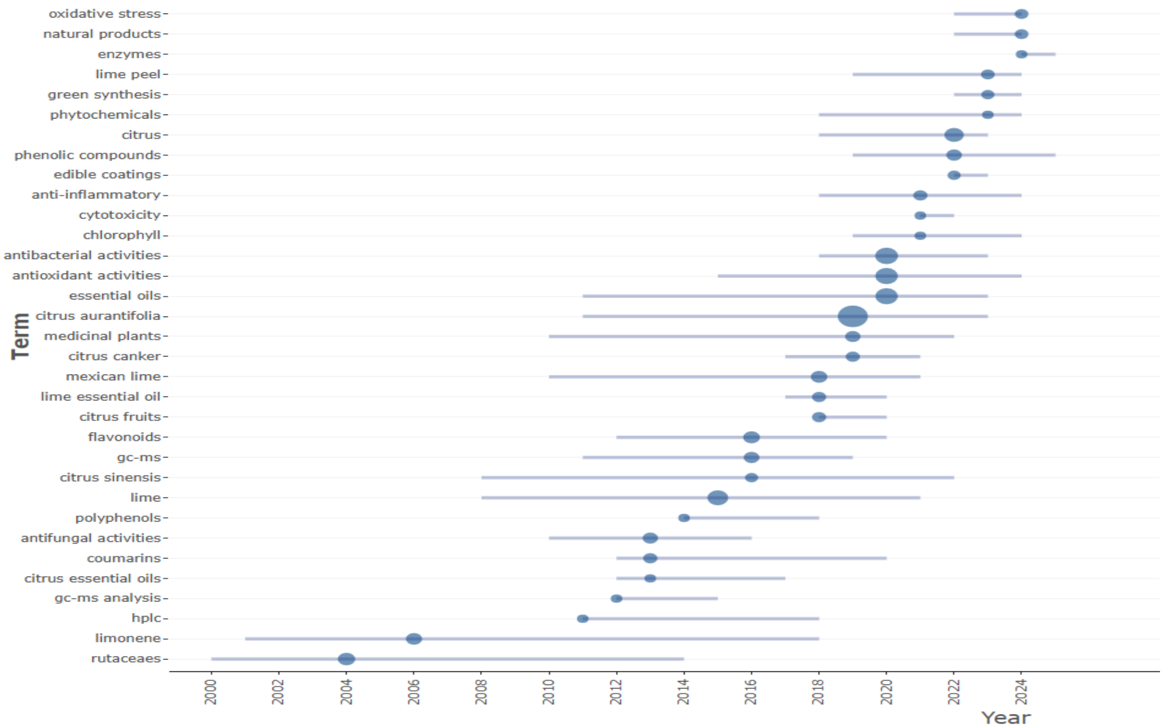

Figure 12: Temporal evolution of keywords in *C. aurantiifolia* research (1987–2025), illustrating shifts from phytochemical characterization to bioactivity and application-oriented topics.

The thematic evolution map demonstrates a sequential progression of research priorities within the *C. aurantiifolia* literature. Initial efforts focused on species characterization, phytochemical profiling, and analytical method development, which provided the foundation for subsequent investigations of bioactive compounds and biological functions [75]. As the field matured, research expanded from fundamental phytochemical studies toward bioactivity evaluation and, more recently, toward application-oriented and interdisciplinary research areas. This progression reflects the increasing translation of phytochemical knowledge into practical applications and the broader utilization of *C. aurantiifolia* in food, health, and sustainability-related contexts [76], [77].

3.2.4 Thematic structure and conceptual framework

Thematic map of *C. aurantiifolia* research, topologically distributed across thematic cluster which reflecting intellectual structure, is shown in Figure 13. In this map, basic themes represent fundamental and broadly connected research areas that form the conceptual foundation of the field, whereas motor themes indicate highly developed and strongly interconnected topics that actively drive research advancement. Prominent basic themes in the lower-right quadrant include *Citrus aurantiifolia*; antioxidant and antibacterial activities; phenolic compounds; flavonoids; and citrus, illustrating their core position. Research on these topics constitutes the fundamental biochemical and functional properties that account for the nutritional and therapeutic importance of *C. aurantiifolia*, with the foundations of studies on phenolic profiling and essential oil bioactivity forming the basis of current research [42], [43].

Motor themes such as lime juice, hesperidin, HPLC, *Aspergillus flavus*, and citrus essential oils characterize mature and well-established areas of research. Their focus demonstrates the maturity framework centered on identifying bioactive compounds through specific analytical methods, affording their application for antimicrobial use against *Aspergillus flavus* [78], [79]. In contrast, niche themes such as nano-emulsion, edible coatings, and specialized analytical techniques (capillary GC) are very narrow themes reflecting niche-related topics but with lower impact [80], [81]. Emerging themes, such as green synthesis and silver nanoparticles, though relatively few, show increasing interest in sustainable and/or nanotechnology-based applications, which points to future directions in functionalized eco-innovations [82], [83]. Furthermore, recent advances in microencapsulation technologies and optimized drying systems have demonstrated considerable potential for improving the stability, retention, and industrial applicability of plant bioactive compounds, suggesting additional opportunities for future research and commercialization of citrus-derived products [84].

Figure 14 illustrates the thematic evolution of *C. aurantifolia* research from 1987 to 2025. The Sankey diagram reveals a gradual transition from broad phytochemical and bioactivity-oriented investigations

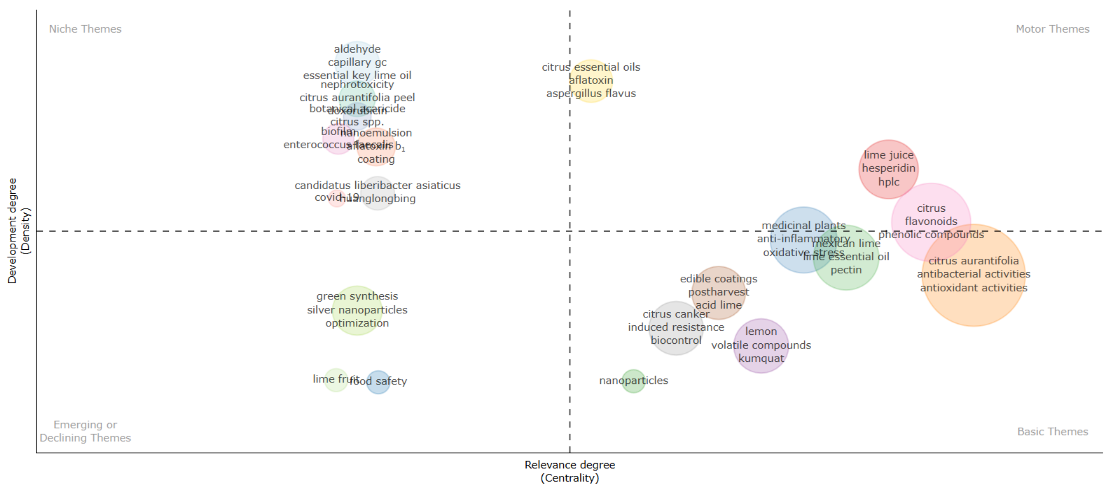

Figure 13: Thematic map of *C. aurantifolia* research (1987–2025), illustrating basic, motor, niche, and emerging themes based on author keywords.

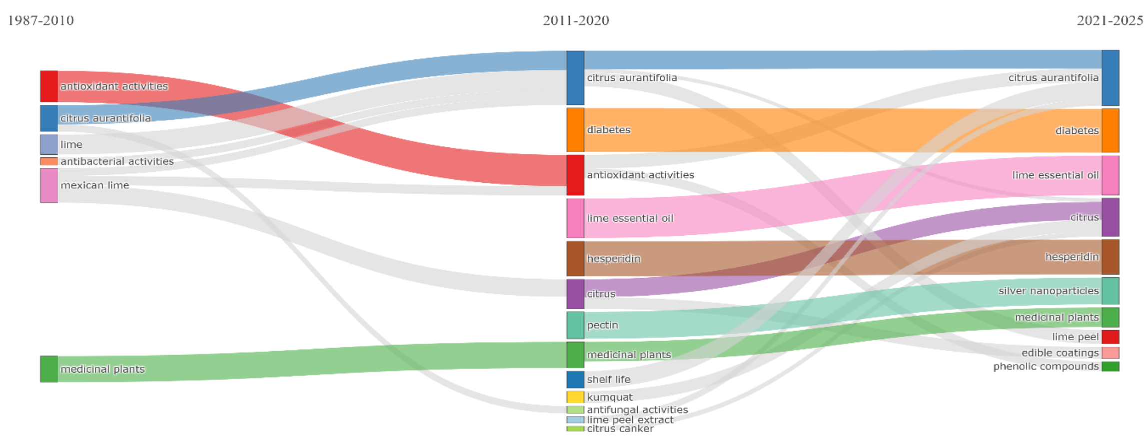

Figure 14: Thematic map illustrating key research themes from 1987 to 2025.

toward more specialized and application-focused research themes. During the early period (1987–2010), research was primarily centered on antioxidant and antibacterial activities, together with general topics related to *C. aurantiifolia*, lime, and medicinal plants. These themes formed the foundation for subsequent studies by establishing the biological potential of the species [2], [85].

Between 2011 and 2020, the research landscape became more diversified, with greater attention directed toward specific compounds, extracts, and health-related applications. For example, early studies on antioxidant activity evolved into investigations of specific bioactive compounds such as hesperidin, while broader research on *C. aurantiifolia* expanded toward diabetes-related applications and lime essential oil.

In the most recent period (2021–2025), the thematic structure expanded further, with the emergence of topics associated with nanotechnology, sustainable utilization of citrus by-products, and food-related applications. The appearance of themes such as silver nanoparticles, edible coatings, phenolic compounds, and lime peel indicates a broadening of research beyond phytochemical characterization toward value-added and interdisciplinary applications [82], [86]. Overall, the thematic evolution highlights a progressive shift from fundamental bioactivity studies to more targeted, technology-oriented, and application-driven research directions.

4 Limitations and future research directions

The present study provides a comprehensive bibliometric analysis of global scholarly output pertaining to *C. aurantiifolia* research, encompassing publications from 1987 to 2025. Data were retrieved from the Scopus database, selected based on its rigorous indexing standards and data consistency. Nevertheless, it is acknowledged that the reliance on a single bibliographic source constitutes an inherent limitation of the study, as database selection is well-documented to exert a measurable influence on bibliometric outcomes [19]. The integration of complementary databases in future investigations would, therefore, enhance the comprehensiveness and analytical robustness of future reviews.

Although terminological heterogeneity for the plant species (“*Citrus aurantiifolia*"; "*Citrus aurantifolia*"; "*Limonia aurantiifolia*"; "Key lime"; "Mexican lime"; "West Indian lime"; "Omani lime"; "Bartender's lime”) was systematically reconciled during the data preparation phase, further standardization is still needed. Enhanced consistency in search keywords and subject-indexing terminology in future studies will improve the precision and reproducibility of thematic and co-occurrence analyses.

The bibliometric approach used in this study offers solid information to research trends, co-authorship patterns, and thematic structures. Although visualization tools and clustering approaches have resulted in meaningful representations of scientific terrain, some complementary forms of analysis may further optimize unfrozen-node optimality and parameter resolution [87].

Building on these strengths, future research offers important avenues for progression. Focusing on data consistency and analytical depth by combining multiple databases and, particularly, deploying advanced text-mining or natural language processing methods can further strengthen the analysis. There are strong possibilities, at the scientific level, to move towards mechanism-of-action studies, omics-based approaches, and clinical validation to further elucidate and validate the biological activity of *C. aurantiifolia* bioactive compounds. Concurrently, focus on scalable applications, especially within functional foods, natural preservatives and bio-based materials with strong sustainability potential will encourage translation to product. Increasing scientific impact by deriving realistic inferences through interdisciplinary integration and translating the results into projected outcomes calls for renewed international collaboration.

5 Conclusion

This study provides a comprehensive bibliometric overview of global research on *C. aurantiifolia* from 1987 to 2025. The finding demonstrates a significant growth in publications, particularly after 2010, reflecting increasing academic and industrial interest in this species. The analysis identified the major contributing countries, influential authors, and collaboration patterns that have shaped the development of the field, with Indonesia, Iran, and India leading research productivity and the United States demonstrating the highest citation impact and strong international collaboration.

Science mapping analyses revealed a closely interconnected research landscape linking phytochemical characterization, bioactivity evaluation, and application-oriented studies. Furthermore, the thematic evolution analysis demonstrated progression from phytochemical characterization and analytical methodologies toward bioactivity assessment and broader application-driven research. Recent developments indicate increasing diversification into sustainable and interdisciplinary research areas. Emerging topics such as functional foods, green synthesis, and nano-formulations reflect the expanding scientific and practical relevance of *C. aurantiifolia* and highlight growing interest in value-added applications across food and health-related sectors.

Future studies should place greater emphasis on standardized phytochemical profiling, mechanistic validation of bioactivities, clinical investigations, and scalable food, nutraceutical, and health-related applications. Overall, this study provides a systematic understanding of the intellectual structure, thematic development, and global research landscape of *C. aurantiifolia*, serving as a useful reference for future bibliometric, phytochemical, and application-oriented research.

Acknowledgments

The authors thank the National Research and Innovation Agency (BRIN), particularly the Research Center for Food Technology and Processing, for technical support. We also thank Universitas Terbuka for supporting this study through the *Penelitian dan Pengabdian kepada Masyarakat Dana Internal* program with contract number B/232/UN31.LPPM/PT.01.03/2025. We gratefully acknowledge all researchers whose work over the past four decades forms the foundation of this review.

Funding

This study was fully funded by the *Penelitian dan Pengabdian Kepada Masyarakat Dana Internal*, *Universitas Terbuka* with contract number B/232/UN31.LPPM/PT.01.03/2025. No additional external funding was received.

Conflict of Interest Statement

The authors declare no competing financial or personal interests that could have influenced the outcomes of this work.

AI Assistance Statement

ChatGPT (OpenAI, San Francisco, USA) was used to assist with language editing and grammar refinement of the manuscript. All bibliometric analyses, data interpretation, and scientific conclusions were performed solely by the authors without AI involvement.

Author Contributions

E.N.: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. Y.A.: Conceptualization, Methodology, Validation, Writing – review & editing, Supervision. T.E.: Bibliometric analysis, Visualization, Writing – original draft. M.F.A.: Data curation, Investigation. J.J.: Methodology, Data curation, Validation, Writing – review & editing. I.T.S: Formal analysis and Writing – review & editing E.A.: Investigation, Resources. S.D.I.: Investigation, Resources. R.S.: Investigation, Resources. D.T.: Investigation, Resources. D.K.: Data curation, Bibliometric analysis, Visualization. J.W.: Data curation and Formal analysis, S.L.L: Data curation and Formal analysis. C.L.: Writing – review & editing.

References

[1] P. Weimer, J. G. Lisbôa Moura, V. Mossmann, M. L. Immig, J. de Castilhos, and R. C. Rossi, "*Citrus aurantiifolia* (Christm) Swingle: Biological potential and safety profile of essential oils from leaves and fruit peels," *Food Bioscience*, vol. 40, Art. no. 100905, 2021, doi: 10.1016/j.fbio.2021.100905.

[2] N. N. Indriyani, J. A. Anshori, N. Permadi, S. Nurjanah, and E. Julaeha, "Bioactive components and their activities from different parts of *Citrus aurantifolia* (Christm.) Swingle for Food Development," *Foods*, vol. 12, no. 10, Art. no. 2036, 2023. doi: 10.3390/foods 12102 036.

[3] J. Korkitpoonpol et al., "Flavor profile in fresh-squeezed juice of four Thai lime cultivars: Identification of compounds that influence fruit selection by master chefs," *Applied Science and Engineering Progress*, vol. 13, no. 2, pp. 146–157, 2020, doi: 10.14416/j.asep.2020.02.001

[4] N. Narang and W. Jiraungkoorskul, "Anticancer

activity of key lime, *Citrus aurantifolia*," *Pharmacognosy Reviews*, vol. 10, no. 20, pp. 118–122, 2016, doi: 10.4103/0973-7847.194043.
[5] L. Galovičová et al., "The potential use of *Citrus aurantifolia* L. essential oils for decay control, quality preservation of agricultural products, and anti-insect activity," *Agronomy*, vol. 12, no. 3, Art. no. 735, 2022, doi: 10.3390/agronomy1203 0735.
[6] Y. Desmiaty et al., "Molecular docking study of standardized lime (*Citrus aurantiifolia*) peel decoction as an antidiabetic herbal," *Tropical Journal of Natural Product Research*, vol. 9, no. 9, pp. 4621–4628, 2025, doi: 10.26538/tjnpr/ v9i9.65.
[7] M. Mohammadi, S. Rastegar, and A. Rohani, "Enhancing Mexican lime (*Citrus aurantifolia* cv.) shelf life with innovative edible coatings: xanthan gum edible coating enriched with *Spirulina platensis* and pomegranate seed oils," *BMC Plant Biology*, vol. 24, no. 1, Art. no. 906, 2024, doi: 10.1186/s12870-024-05606-3.
[8] V. Aksahin, I. Ortas, and M. Incesu, "Bibliometric analysis on citrus area publications on the last 22 years," in *Proceedings of the XIV International Citrus Congress, Acta Horticulturae*, vol. 1399. Leuven, Belgium: International Society for Horticultural Science, 2024, pp. 473–484, doi: 10.17660/ActaHortic. 2024.1399.59.
[9] M. Aria and C. Cuccurullo, "Bibliometrix: An R-tool for comprehensive science mapping analysis," *Journal of Informetrics*, vol. 11, no. 4, pp. 959–975, 2017, doi: 10.1016/j.joi.2017. 08.007.
[10] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: An overview and guidelines," *Journal of Business Research*, vol. 133, pp. 285–296, 2021, doi: 10.1016/j.jbusres.2021.04.070.
[11] M. E. Falagas, E. I. Pitsouni, G. A. Malietzis, and G. Pappas, "Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses," *The FASEB Journal*, vol. 22, no. 2, pp. 338–342, Feb. 2008, doi: 10.1096/fj.07-9492LSF.
[12] P. Mongeon and A. Paul-Hus, "The journal coverage of Web of Science and Scopus: a comparative analysis," *Scientometrics*, vol. 106, no. 1, pp. 213–228, 2016, doi: 10.1007/s11192-015-1765-5.
[13] R. Pranckutė, "Web of Science (WoS) and Scopus: The titans of bibliographic information in today's academic world," *Publications*, vol. 9, no. 1, Art. no. 12, 2021, doi: 10.3390/publi cations9010012.
[14] L. S. Adriaanse and C. Rensleigh, "Web of Science, Scopus and Google Scholar: A content comprehensiveness comparison," *The Electronic Library*, vol. 31, no. 6, pp. 727–744, Nov. 2013, doi: 10.1108/EL-12-2011-0174.
[15] A. Ferrara and S. Salini, "Ten challenges in modeling bibliographic data for bibliometric analysis," *Scientometrics*, vol. 93, no. 3, pp. 765–785, 2012, doi: 10.1007/s11192-012-0810-x.
[16] A. Caputo and M. Kargina, "A user-friendly method to merge Scopus and Web of Science data during bibliometric analysis," *Journal of Marketing Analytics*, vol. 10, no. 1, pp. 82–88, 2022, doi: 10.1057/s41270-021-00142-7.
[17] S. Echchakoui, "Why and how to merge Scopus and Web of Science during bibliometric analysis: the case of sales force literature from 1912 to 2019," *Journal of Marketing Analytics*, vol. 8, no. 3, pp. 165–184, 2020, doi: 10.1057/s41270-020-00081-9.
[18] N. J. van Eck and L. Waltman, "Software survey: VOSviewer, a computer program for bibliometric mapping," *Scientometrics*, vol. 84, no. 2, pp. 523–538, 2010, doi: 10.1007/s11192-009-0146-3.
[19] I. Zupic and T. Čater, "Bibliometric methods in management and organization," *Organizational Research Methods*, vol. 18, no. 3, pp. 429–472, Jul. 2015, doi: 10.1177/1094428114562629.
[20] D. W. Aksnes, L. Langfeldt, and P. Wouters, "Citations, citation indicators, and research quality: An overview of basic concepts and theories," *Sage Open*, vol. 9, no. 1, pp. 1-17, 2019, doi: 10.1177/2158244019829575.
[21] Q. Gui, C. Liu, and D. Du, "Globalization of science and international scientific collaboration: A network perspective," *Geoforum*, vol. 105, pp. 1–12, 2019, doi: 10.1016/j.geoforum.2019. 06.017.
[22] S. Milojević, "How are academic age,

productivity and collaboration related to citing behavior of researchers?," *PLoS ONE*, vol. 7, no. 11, Art. no. e49176, 2012, doi: 10.1371/journal.pone.0049176.
[23] J. A. Bol, A. Sheffel, N. Zia, and A. Meghani, "How to address the geographical bias in academic publishing," *BMJ Global Health*, vol. 8, no. 12, Art. no. e013111, 2023, doi: 10.1136/bmjgh-2023-013111.
[24] M. Agustí, C. Mesejo, C. Reig, and A. Martínez-Fuentes, "Citrus production," in *Horticulture: Plants for People and Places*, vol. 1, G. R. Dixon and D. E. Aldous, Eds., Dordrecht: Springer Netherlands, 2014, pp. 159–195. doi: 10.1007/978-94-017-8578-5_6.
[25] B. Bigliardi and F. Galati, "Innovation trends in the food industry: The case of functional foods," *Trends in Food Science & Technology*, vol. 31, no. 2, pp. 118–129, 2013, doi: 10.1016/j.tifs.2013.03.006.
[26] F. Bianchi, L. Ilag, V. Termopoli, and L. Mendez, "Advances in MS-based analytical methods: Innovations and future trends," *Journal of Analytical Methods in Chemistry*, vol. 2018, Art. no. 2084567, 2018, doi: 10.1155/2018/2084567.
[27] K. Shrinet, R. K. Singh, A. K. Chaurasia, A. Tripathi, and A. Kumar, "Bioactive compounds and their future therapeutic applications," in *Natural Bioactive Compounds Technological Advancements*, R. P. Sinha and D.-P. Häder, Eds., Cambridge, MA: Academic Press, 2021, pp. 337–362. doi: 10.1016/B978-0-12-820655-3.00017-3.
[28] N. E. Wedamulla, M. Fan, Y.-J. Choi, and E.-K. Kim, "Citrus peel as a renewable bioresource: Transforming waste to food additives," *Journal of Functional Foods*, vol. 95, Art. no. 105163, 2022, doi: 10.1016/j.jff.2022.105163.
[29] M. R. Goyal and A. Chauhan, "Extraction of bioactive compounds from citrus through novel innovative techniques" in *Valorization of Citrus Food Waste*, A. Chauhan, F. Islam, A. Imran, and J. Singh Aswal, Eds., Cham: Springer Nature Switzerland, 2025, pp. 61–73. doi: 10.1007/978-3-031-77999-2_5.
[30] M. P. Gonzatto and J. S. Santos, "Introductory chapter: World citrus production and research," in *Citrus Research : Horticultural and Human Health Aspects*, M. P. Gonzatto and J. Scherer Santos, Eds., London: IntechOpen, 2023. doi: 10.5772/intechopen.110519.
[31] L. Catani et al., "Essential oils and their applications in agriculture and agricultural products: A literature analysis through VOSviewer," *Biocatalysis and Agricultural Biotechnology*, vol. 45, Art. no. 102502, 2022, doi: 10.1016/j.bcab.2022.102502.
[32] A. Ben Hsouna et al., "The chemical variability, nutraceutical value, and food-Industry and cosmetic applications of citrus plants: A critical review.," *Antioxidants*, vol. 12, no. 2, Art. no. 481, 2023, doi: 10.3390/antiox12020481.
[33] N. A. N. Zainudin, M. H. I. Zalizan, N. N. A. N. Yusuf, S. Abdullah, A. H. A. Dabwan, and N. Abdullah, "Solvent extraction of pectin from key lime and calamansi lime," *AIP Conference Proceedings*, vol. 2370, no. 1, Art. no. 060013, 2021, doi: 10.1063/5.0062193.
[34] B. Basumatary, P. Das, P. K. Nayak, D. Saikia, and R. K. Kesavan, "A study on the physical, biochemical, thermal and textural Properties of key lime fruit," *Journal of Scientific & Industrial Research*, vol. 82, pp. 892–898, 2023, doi: 10.56042/jsir.v82i08.3182.
[35] D. Magalhães, A. A. Vilas-Boas, P. Teixeira, and M. Pintado, "Functional ingredients and additives from lemon by-products and their applications in food preservation: A review," *Foods*, vol. 12, no. 5, Art. no. 1095, 2023, doi: 10.3390/foods12051095.
[36] S. Jain, P. Arora, and H. Popli, "A comprehensive review on *Citrus aurantifolia* essential oil: its phytochemistry and pharmacological aspects," *Brazilian Journal of Natural Sciences*, vol. 3, no. 2, Art. no. 354, 2020, doi: 10.31415/bjns.v3i2.101.
[37] N. Wahid, N. F. Warraich, and M. Tahira, "Factors influencing scholarly publication productivity: a systematic review," *Information Discovery and Delivery*, vol. 50, no. 1, pp. 22–33, 2021, doi: 10.1108/IDD-04-2020-0036.
[38] W. C. Pascua, "Motivational factors influencing research productivity among higher education faculty," *Asian Research Journal of Arts &*

Social Sciences, vol. 25, no. 5, pp. 14–25, 2025, doi: 10.9734/arjass/2025/v23i5677.

[39] G. Yumnam, G. Yumnam, and W. Alam, "Quantifying the global research effort on bioactive compounds: A scientometric analysis (1989-2023)," *Journal of Scientific & Industrial Research*, vol. 83, no. 10, pp. 1125–1138, 2024, doi: 10.56042/jsir.v83i10.9135.

[40] R. Ciriminna et al., "Citrus flavonoids as antimicrobials," *Chemistry & Biodiversity*, vol. 22, no. 6, p. e202403210, 2025, doi: 10.1002/cbdv.202403210.

[41] A. Narayanankutty, A. C. Famurewa, and E. Oprea, "Natural bioactive compounds and human health," *Molecules*, vol. 29, no. 14, Art. no. 3372, 2024, doi: 10.3390/molecules29143372.

[42] A. Brito, J. E. Ramirez, C. Areche, B. Sepúlveda, and M. J. Simirgiotis, "HPLC-UV-MS profiles of phenolic compounds and antioxidant activity of fruits from three citrus species consumed in Northern Chile," *Molecules*, vol. 19, no. 11, pp. 17400–17421, 2014, doi: 10.3390/molecules191 117400.

[43] N. S. Dosoky and W. N. Setzer, "Biological activities and safety of *Citrus spp*. essential oils," *International Journal of Molecular Sciences*, vol. 19, no. 7, p. 1966, 2018, doi: 10.3390/ijms1907 1966.

[44] E. Meiyanto, A. Hermawan, and A. Anindyajati, "Natural products for cancer-targeted therapy: citrus flavonoids as potent chemopreventive agents," *Asian Pacific Organization for Cancer Prevention*, vol. 13, no. 2, pp. 427–436, 2012, doi: 10.7314/APJCP.2012.13.2.427.

[45] P. Rodsamran and R. Sothornvit, "Extraction of phenolic compounds from lime peel waste using ultrasonic-assisted and microwave-assisted extractions," *Food Bioscience*, vol. 28, pp. 66–73, 2019, doi: 10.1016/j.fbio.2019.01.017.

[46] M. Razzaghi-Abyaneh et al., "Chemical composition and antiaflatoxigenic activity of *Carum carvi* L., *Thymus vulgaris* and *Citrus aurantifolia* essential oils," *Food Control*, vol. 20, no. 11, pp. 1018–1024, 2009, doi: 10.1016/j.foodcont.2008.12.007.

[47] P. Xie, "Study of international anticancer research trends via co-word and document co-citation visualization analysis," *Scientometrics*, vol. 105, no. 1, pp. 611–622, 2015, doi: 10.1007/s11192-015-1689-0.

[48] N. Ghosh, S. Chatterjee, and P. C. Sil, "Evolution of antioxidants over times (including current global market and trend)," in *Antioxidants Effects in Health : The Bright and the Dark Side*, S. M. Nabavi and A. S. Silva, Eds., Cambridge, MA: Elsevier, 2022, pp. 3–32. doi: 10.1016/B978-0-12-819096-8.00011-2.

[49] J. Hou et al., "Global trend of antimicrobial resistance in common bacterial pathogens in response to antibiotic consumption," *Journal of Hazardous Materials*, vol. 442, Art. no. 130042, 2023, doi: 10.1016/j.jhazmat.2022.130042.

[50] J. A. Custodio-Mendoza, P. Pokorski, H. Aktaş, A. Napiórkowska, and M. A. Kurek, "Advances in chromatographic analysis of phenolic phytochemicals in foods: Bridging gaps and exploring new horizons," *Foods*, vol. 13, no. 14, Art. no. 2268, 2024, doi: 10.3390/foods13142 268.

[51] R. E. Mutha, M. Kalaskar, and Z. G. Khan, "Modern analytical techniques for quality control and chemical identification of phytochemicals," in *Pharmacognosy and Phytochemistry: Principles, Techniques, and Clinical Applications,*, U. E. Odoh, S. S. Gurav, and M. O. Chukwuma, Eds. Hoboken, NJ: John Wiley & Sons, Inc., 2025, pp. 167–188. doi: 10.1002/9781 394203680.ch09.

[52] F. Ahmed, S. Maqsood, M. F. Ahmad, and A. Zahir, "Optimizing health and sustainability: innovations in harnessing phytochemicals for functional foods," *Food Science & Nutrition*, vol. 13, no. 9, Art. no. e71002, 2025, doi: 10.1002/fsn3.71002.

[53] J. R. Patil, K. N. Chidambara Murthy, G. K. Jayaprakasha, M. B. Chetti, and B. S. Patil, "Bioactive compounds from Mexican lime (*Citrus aurantifolia*) juice induce apoptosis in human pancreatic cells.," *Journal of Agricultural and Food Chemistry*, vol. 57, no. 22, pp. 10933–10942, 2009, doi: 10.1021/jf901718u.

[54] E. I. Oikeh, E. S. Omoregie, F. E. Oviasogie, and K. Oriakhi, "Phytochemical, antimicrobial, and antioxidant activities of different citrus juice concentrates.," *Food Science & Nutrition*, vol. 4, no. 1, pp. 103–109, 2016, doi: 10.1002/fsn3.268.

[55] M. R. Loizzo et al., "Evaluation of *Citrus aurantifolia* peel and leaves extracts for their chemical composition, antioxidant and anti-cholinesterase activities.," *Journal of the Science of Food and Agriculture*, vol. 92, no. 15, pp. 2960–2967, 2012, doi: 10.1002/jsfa.5708.
[56] R. Tundis et al., "Comparative study on the antioxidant capacity and cholinesterase inhibitory activity of *Citrus aurantifolia* Swingle, *C. aurantium* L., and *C. bergamia* Risso and Poit. peel essential oils.," *Journal of Food Science*, vol. 77, no. 1, pp. H40-H46, 2012, doi: 10.1111/j.1750-3841.2011.02511.x.
[57] R. A. Onyeagba, O. C. Ugbogu, C. U. Okeke, and O. Iroakasi, "Studies on the antimicrobial effects of garlic (*Allium sativum* Linn), ginger (*Zingiber officinale* Roscoe) and lime (*Citrus aurantifolia* Linn)," *African Journal of Biotechnology*, vol. 3, no. 10, pp. 552–554, 2004, doi: 10.5897/AJB2004.000-2108.
[58] A. Kaur et al., "Lemon and lime" in *Recent Advances in Citrus Fruits*, S. S. Purewal, S. P. Bangar, and P. Kaur, Eds., Cham: Springer International Publishing, 2023, pp. 1–24. doi: 10.1007/978-3-031-37534-7_1.
[59] H. Hardiyanto, N. F. Devy, K. Budiarto, C. Martasari, and Z. Hanif, "Current status and prospect of citrus production, research, and development of Indonesia," in *Asian Citrus Industry: Growth and Sustainability*, D. K. Ghosh, K. J. Song, S. Bhattacharyya, S. S. Roy, and C. Ramadugu, Eds., Boca Raton, FL, USA: CRC Press, 2025, pp. 307–335, doi: 10.1201/9781003584599-14.
[60] D. Naphrom, C. Tiyayon, and P. Hemrattrakun, "Citrus industry of Thailand," in *Asian Citrus Industry: Growth and Sustainability*, D. K. Ghosh, K. J. Song, S. Bhattacharyya, S. S. Roy, and C. Ramadugu, Eds., 2025, 99-126. doi: 10.1201/9781003584599-5.
[61] H. Pohl, "Using citation-based indicators to compare bilateral research collaborations," *Scientometrics*, vol. 129, no. 8, pp. 4751–4770, 2024, doi: 10.1007/s11192-024-05087-z.
[62] C. J. Gomez, A. C. Herman, and P. Parigi, "Leading countries in global science increasingly receive more citations than other countries doing similar research," *Nature Human Behaviour*, vol. 6, no. 7, pp. 919–929, 2022, doi: 10.1038/s41562-022-01351-5.
[63] J. Wang, R. Frietsch, P. Neuhäusler, and R. Hooi, "International collaboration leading to high citations: Global impact or home country effect?," *Journal of Informetrics*, vol. 18, no. 4, Art. no. 101565, 2024, doi: 10.1016/j.joi.2024.101565.
[64] S. Majhi, L. Sahu, and K. Behera, "Practices for enhancing research visibility, citations and impact: review of literature," *Aslib Journal of Information Management*, vol. 75, no. 6, pp. 1280–1305, 2023, doi: 10.1108/AJIM-11-2023-532.
[65] M. A. Atwell, S. De Caires, and M. N. Wuddivira, "Advancing ecosystem services and sustainability research in the Global South: A bibliometric review," *Discover Environment*, vol. 4, no. 1, p. 60, 2026, doi: 10.1007/s44274-026-00565-y.
[66] L. Zhang, J. Gong, Y. Yang, and J. Li, "Cities in global and sustainable scientific collaboration network: unveiling cooperation centers," *Humanities and Social Sciences Communications*, vol. 12, no. 1, p. 1406, 2025, doi: 10.1057/s41599-025-05667-1.
[67] A. Banerjee Mukherjee and P. Singh, "An overview of nutraceutical, antimicrobial, antioxidant properties of citrus fruits and their role in food preservation," *Applied Fruit Science*, vol. 67, no. 6, p. 444, 2025, doi: 10.1007/s10341-025-01679-y.
[68] A. H. Elmaidomy et al., "Antiplasmodial potential of phytochemicals from *Citrus aurantifolia* peels: A comprehensive in vitro and in silico study," *BMC chemistry*, vol. 18, Art. no. 60, 2024, doi: 10.1186/s13065-024-01162-x.
[69] Q. Zhang et al., "Advances in analytical techniques for bioactive compound quantification in medicinal plants: Innovations, challenges, and pharmaceutical applications," *Microchemical Journal*, vol. 214, Art. no. 114119, 2025, doi: 10.1016/j.microc.2025.114119.
[70] A. A. Vilas-Boas et al., "Innovative processing technologies to develop a new segment of functional citrus-based beverages: Current and future trends," *Foods*, vol. 11, no. 23, Art. no. 3859, 2022, doi: 10.3390/foods11233859.

[71] S. Samanta, J. Banerjee, R. Ahmed, and S. K. Dash, "Potential benefits of bioactive functional components of citrus fruits for health promotion and disease prevention" in *Recent Advances in Citrus Fruits*, S. Singh Purewal, S. Punia Bangar, and P. Kaur, Eds., Cham: Springer International Publishing, 2023, pp. 451–499. doi: 10.1007/978-3-031-37534-7_15.

[72] C. Nunes, M. Silva, D. Farinha, H. Sales, R. Pontes, and J. Nunes, "Edible coatings and future trends in active food packaging–fruits' and traditional sausages' shelf life increasing," *Foods*, vol. 12, no. 17, Art. no. 3308, 2023, doi: 10.3390/foods12173308.

[73] X. Wang et al., "Emerging strategies for food preservation: recent advances and challenges in nanotechnology for edible coatings," *Agricultural Products Processing and Storage*, vol. 1, no. 1, Art. no. 13, 2025, doi: 10.1007/s44462-025-00015-7.

[74] M. M. Alkhulaifi et al., "Green synthesis of silver nanoparticles using *Citrus limon* peels and evaluation of their antibacterial and cytotoxic properties," *Saudi Journal of Biological Sciences*, vol. 27, no. 12, pp. 3434–3441, 2020, doi: 10.1016/j.sjbs.2020.09.031.

[75] V. L. Sanches et al., "Insights on the extraction and analysis of phenolic compounds from citrus fruits: Green perspectives and current status," *Critical Reviews in Analytical Chemistry*, vol. 54, no. 5, pp. 1173–1199, 2024, doi: 10.1080/10408347.2022.2107871.

[76] S. Šafranko, D. Šubarić, I. Jerković, and S. Jokić, "Citrus by-products as a valuable source of biologically active compounds with promising pharmaceutical, biological and biomedical potential," *Pharmaceuticals*, vol. 16, no. 8, Art. no. 1081, 2023, doi: 10.3390/ph16081081.

[77] S. AlZahabi and W. Mamdouh, "Valorization of citrus processing waste into high-performance bionanomaterials: green synthesis, biomedicine, and environmental remediation," *RSC Advances*, vol. 15, no. 43, pp. 36534–36595, 2025, doi: 10.1039/D5RA04307G.

[78] K. Rammanee and T. Hongpattarakere, "Effects of tropical citrus essential oils on growth, aflatoxin production, and ultrastructure alterations of *Aspergillus flavus* and *Aspergillus parasiticus*," *Food and Bioprocess Technology*, vol. 4, no. 6, pp. 1050–1059, 2011, doi: 10.1007/s11947-010-0507-1.

[79] C. Restuccia, G. Oliveri Conti, P. Zuccarello, L. Parafati, A. Cristaldi, and M. Ferrante, "Efficacy of different citrus essential oils to inhibit the growth and B1 aflatoxin biosynthesis of *Aspergillus flavus*," *Environmental Science and Pollution Research*, vol. 26, no. 30, pp. 31263–31272, 2019, doi: 10.1007/s11356-019-06169-9.

[80] C. Wu, L. Wang, Y. Hu, S. Chen, D. Liu, and X. Ye, "Edible coating from citrus essential oil-loaded nanoemulsions: physicochemical characterization and preservation performance," *RSC Advances*, vol. 6, no. 25, pp. 20892–20900, 2016, doi: 10.1039/C6RA00757K.

[81] L. T. C. Maswanganye, S. K. Pillai, and D. Sivakumar, "Chitosan coating loaded with spearmint essential oil nanoemulsion for antifungal protection in soft citrus (*Citrus reticulata*) fruits," *Coatings*, vol. 15, no. 1, p. 105, 2025, doi: 10.3390/coatings15010105.

[82] M. V Sujitha and S. Kannan, "Green synthesis of gold nanoparticles using citrus fruits (*Citrus limon*, *Citrus reticulata* and *Citrus sinensis*) aqueous extract and its characterization," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, vol. 102, pp. 15–23, 2013, doi: 10.1016/j.saa.2012.09.042.

[83] P. A. Luque et al., "Green synthesis of zinc oxide nanoparticles using *Citrus sinensis* extract," *Journal of Materials Science: Materials in Electronics*, vol. 29, no. 12, pp. 9764–9770, 2018, doi: 10.1007/s10854-018-9015-2.

[84] C. Nabbala and W. Krasaekoopt, "Microencapsulation of *Thunbergia laurifolia* crude extract and its antioxidant properties," *Applied Science and Engineering Progress*, vol. 15, no. 1, 2021, doi: 10.14416/j.asep.2020.11.002.

[85] F. Ni, Z. Li, and J. Huang, "Worldwide productivity and research trend on fruit quality: a bibliometric study.," *Frontiers in Plant Science*, vol. 14, pp. 1294989, 2023, doi: 10.3389/fpls.2023.1294989.

[86] J. D. Padilla de la Rosa, P. Ruiz-Palomino, E. Arriola-Guevara, J. García-Fajardo, G. Sandoval, and G. M. Guatemala-Morales, "A green process for the extraction and purification

of hesperidin from Mexican lime peel (*Citrus aurantifolia* Swingle) that is extendible to the citrus genus," *Processes*, vol. 6, no. 12, Art. no. 266, 2018. doi: 10.3390/pr6120266.
[87] N. Cucari, I. Tutore, R. Montera, and S. Profita, "A bibliometric performance analysis of publication productivity in the corporate social responsibility field: Outcomes of SciVal analytics," *Corporate Social Responsibility and Environmental Management*, vol. 30, no. 1, pp. 1–16, 2023, doi: 10.1002/csr.2346.