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Blossoming Insights: A Bibliometric Review of Botanical Gardens' Research Across Time (1960-2023)

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ABSTRACT

This bibliometric analysis presents an overview of the literature on botanical gardens. The study identifies research frontiers, themes, and interconnections within the field. It utilizes a dataset of 1340 publications and authors' keyword co-occurrence data, examining trends, patterns, and knowledge gaps from 1960 to 2023. The analysis shows a significant growth in literature, highlighting critical topics such as botanical gardens, conservation, taxonomy, biodiversity, ex-situ conservation, and diversity. Influential researchers such as Sanja Kovačić, Elaissi, and Chemli have directed research toward ex-situ conservation and essential oils, reflecting the field's interdisciplinary nature. Leading institutions dominating the discourse include the Chinese Academy of Sciences, the Royal Botanic Gardens UK, and the New York Botanical Garden US. Thematic analyses reveal core themes and emerging topics such as ecological restoration, essential oils, invasive species, and climate change, indicating an expanding scope. Consistent themes like 'botanical gardens' and 'conservation' underscore their enduring significance, while emerging topics like climate change and biodiversity signal shifting research priorities. The growing array of subjects, including 'invasive species' and 'genetic diversity,' reflects the increasing complexity of botanical garden research. This study outlines the developmental trajectory of botanical gardens, guiding future research directions and emphasizing the importance of interdisciplinary collaborations and a comprehensive approach to botanical garden studies.

1. INTRODUCTION

The conception of botanical gardens dates back to early human societies. However, they gained prominence only in the Renaissance as institutions dedicated to studying and displaying plant diversity [1]. Since their inception, botanical gardens have been associated with plant collections' exuberance and the advancement of botanical science and education [2]. In the contemporary context, botanical gardens function as dynamic repositories of botanical knowledge, serving multiple purposes—from conservation efforts to serving as living laboratories for scientific research [3, 4]. Their role has been continually redefined to meet ecological, educational, and research needs amid an increasing global emphasis on biodiversity conservation, sustainable living, tourism, and cultural services.

The significance of botanical gardens is further magnified when one considers the rapid environmental changes witnessed over the past few centuries. With accelerating biodiversity loss, climate change, and habitat destruction, botanical gardens stand at the forefront as defenders of common and rare plant species [3, 5]. They serve as gene banks and centers for research on plant propagation, horticulture, and environmental education. Despite their evident importance, the progression of scholarly research on botanical gardens has yet to be comprehensively charted.

Given their integral role in understanding and preserving plant species, there is a compelling need to explore how research output volume and content have evolved. Analyzing the global research activity surrounding botanical gardens will reveal shifts in scientific focus, changing priorities in plant conservation, and emerging themes such as public engagement, environmental education, and climate adaptability strategies. This analysis will offer crucial insights into how botanical gardens contribute to our collective understanding of plants and ecosystems within the broader scope of environmental and biological sciences.

Despite the substantial corpus of research on botanical gardens, the available literature lacks a comprehensive bibliometric analysis that systematically examines publishing trends over time and investigates thematic breadth across many fields. Previous studies were limited in time or focused

on small topic areas, creating a void in comprehending the overall landscape of botanical garden research, particularly in light of increasing global issues such as climate change and biodiversity conservation. This study fills that gap by providing a comprehensive bibliometric analysis of botanical garden research from 1960 to 2023. This study, which covers more than six decades of literature, provides a unique picture of the evolution of research issues and identifies major players in botanical garden science.

This study aims to meticulously analyze the extensive literature on botanical gardens from 1960 to 2023 using bibliometric methodologies to address this need. The goals are to trace publication trends, identify leading authors, institutions, and countries, uncover core themes and topics, elucidate collaboration patterns, and decode the evolution of keywords and themes. This investigation will answer the following research questions:

What are the publication trends in the botanical garden field, and how have they changed over time? Which key players—authors, institutions, and countries—are driving advancements in botanical gardens' research? What are the most highly cited documents in the botanical garden field, and what are the key themes and topics they address? What are the key themes and topics emerging from co-occurrence analyses of author keywords in the literature on botanical gardens?

By addressing these questions, this study will help us gain a deeper appreciation of botanical garden research and its pivotal role in contemporary scientific inquiry and societal welfare.

2. LITERATURE REVIEW

2.1 Evolution and impacts of botanical gardens

Botanical gardens have long been integral to human civilization, serving practical and aesthetic functions. Throughout history, these gardens have played a vital role in studying and preserving plant species, evolving from ancient medicinal gardens to modern institutions prioritizing education, research, conservation, and recreation. The origins of botanical gardens can be traced back to ancient Mesopotamia and Egypt, where medicinal gardens were cultivated to explore and utilize plants known for their medicinal properties [6]. The Hanging Garden of Babylon, commissioned by Nebuchadnezzar during the 7th and 8th centuries B.C., stands as a renowned example of an early botanical garden characterized by terraced layouts featuring various fruit-bearing trees, waterfalls, and irrigation systems [7].

The development of botanical gardens progressed during the Renaissance period of the 16th and 17th centuries when European botanical gardens became centers for scientific inquiry and exploration. Established by universities and affluent individuals, these gardens were gathering places to study and propagate plant species worldwide [8]. European university gardens in Pisa, Padua, Montpellier, and Oxford laid the groundwork for contemporary botanical gardens, initially focusing on the study of medicinal plants [9].

By the 19th century, botanical gardens had expanded their scope and purpose, facilitating global exchanges of seeds and plants. In the 20th century, they adapted to prioritize biodiversity and ecosystem preservation and conservation [10, 11]. These institutions strive to serve local and global communities by addressing contemporary challenges [12]. In addition to their traditional roles in researching and collecting plants, many botanical gardens now actively participate in ex-situ conservation efforts for endangered plant species [4, 13, 14]. These institutions also contribute to public awareness and education regarding the importance of plant conservation and sustainable environmental practices [15, 16]. Through initiatives such as seed banking, renowned botanical gardens like Kew and Sydney's Royal Botanic Gardens spearhead local and global conservation campaigns to preserve plant species for future generations [17-19]. Botanical gardens have transformed into research and innovation centers, collaborating with academic institutions and conservation organizations [20] to address urgent environmental challenges such as climate change [21], habitat destruction, food security, and invasive species [12, 20]. They have historically played a crucial role in plant taxonomy and horticulture but have shifted their focus towards preserving and conserving plant diversity and preventing species extinction [22, 23].

Moreover, these gardens play an important role in urban green infrastructure, supporting conservation research and environmental education [4] while also functioning as leisure spaces [24]. They are progressively combining with other urban green spaces [11, 25], giving ecological and mental health benefits to urban residents. Recent studies have highlighted their function in promoting ecotourism and sustainable tourism practices, emphasizing their significance in today's global setting [26, 27]. Botanical gardens today cater to a wide range of visitor motivations, including stress alleviation and social connection, with research indicating therapeutic benefits for visitors [28-31].

Botanical gardens have evolved from ancient medicinal collections to current sites for biodiversity conservation and environmental education, demonstrating their long-term relevance. Botanical gardens, which are crucial institutions for study, conservation, public engagement, and pleasure, have continually altered to meet society's and the environment's evolving requirements. However, there are still gaps in our understanding of their complete contributions, especially in light of recent global environmental issues like climate change and biodiversity loss.

2.2 Previous studies on bibliometric analysis of botanical gardens

A study on botanical gardens by Bozdoğan et al. [32] used data from Web of Science, which may have reduced the depth of the study due to its narrow scope. The current study attempts to overcome this limitation by utilizing Scopus, which provides a wider selection of papers from various disciplines, resulting in a more comprehensive evaluation of botanical garden research. Furthermore, Bozdoğan et al. [32] focused mostly on instructional publications on botanical gardens, parks, and monuments, ignoring other important factors such as conservation activities, ecological services, and climate adaptability. Furthermore, the limited time period of 1975-2020 does not provide a complete picture of the evolution of botanical garden research, such as the biodiversity crisis and climate change. This study will expand the scope to the time period of 1960-2023 and integrate various keywords to provide a completer and more sustainable picture.

While the existing bibliometric literature provides fundamental insights, it is constrained by its focus on specific theme areas and insufficient temporal coverage. Furthermore,

there is a scarcity of research on new subjects in botanical garden research, such as climate change adaptation techniques, public participation in conservation efforts, and botanical gardens' role in supporting urban sustainability programs. This work aims to bridge these gaps by conducting a complete bibliometric examination of over six decades of research.

By addressing these limitations, this study aims for a more inclusive, globally inflected, and time-aware bibliometric analysis of botanical gardens. The authors have collected 1374 documents, honed to 1340 original articles post-screening, to ensure a comprehensive understanding of the research landscape. This study is set to explore the terrain of botanical garden research, tracking trends, key contributors, and primary research hubs while spotlighting seminal works and significant themes crucial to the sector's advancement. In pursuing these aims, we hope to respond to research questions and expand the scope of knowledge. This thorough exploration seeks to enhance the body of work, providing a meaningful addition to the existing literature for academics, professionals, and decision-makers alike.

3. METHOD

This study utilizes data from the Scopus database, accessed as of January 29, 2024. Scopus was chosen due to its extensive coverage and credibility in capturing a wide range of peer-reviewed academic material across essential disciplines, such as science, medicine, and the social sciences, all pertinent to our focus on botanical gardens. Known for its stringent quality checks and broad geographic scope, Scopus was the logical choice for the present bibliometric scrutiny. According to the study by Chadegani et al. [33], it provides valuable metadata attributes like citations and author affiliations, which are vital for this type of analysis. The collected data spanned source types, document types, subject fields, language distribution, publication patterns, authorship, institutional publishing contributions, global publication spread, and dominant authors' keywords, among other metrics.

3.1 Previous search strategy

The search was designed to pinpoint documents pertinent to botanical gardens, leveraging a suite of keywords—including but not limited to botanical gardens, arboreta, horticultural spaces, and living collections. To guarantee clarity and relevance, the search was restricted to article titles, with an emphasis on publications directly related to botanical gardens. By restricting the search region, we ensured that the results were closely related to our study objectives. The search query utilized for this purpose was structured as follows: TITLE ("botanical gardens" OR "botanic gardens" OR "arboretum" OR "horticultural gardens" OR "plant collections" OR "floral conservatories" OR "cultivated gardens" OR "living collections" OR "herbarium gardens") AND PUBYEAR > 1959 AND PUBYEAR < 2024 AND (LIMIT-TO (DOC-TYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")).

Our search yielded 2062 documents that broadly examined botanical gardens. We rigorously refined this data to ground our systematic review, ensuring a portrayal that captures the domain's nuanced state and identifies evolving patterns and difficulties. The refining process was meticulous: In the initial retrieval process, we obtained 2062 documents. After the removal of 674 documents due to irrelevance to our inclusion criteria, we retained 1388 research articles for our analysis. A further examination led us to discard 48 articles off-target with the central theme, sharpening the focus on pertinent and contemporary research. Thus, we compiled a dataset poised to deepen the insights into botanical garden research, spotlighting primary research that addresses the most pertinent developments. The delineation of this methodical curation is depicted in Figure 1.

3.2 Inclusion criteria and data filtering

Only peer-reviewed journal publications published between 1960 and 2023 in any language were considered, with a concentration on articles directly linked to botanical gardens as indicated by the titles. Conference papers, book chapters, and articles that were not relevant to the theme were excluded following a manual check to verify the analysis's relevance and consistency.

3.3 Data cleaning and harmonization

Ensuring data integrity is a cornerstone of bibliometric analysis. The OpenRefine [34] and biblioMagika [35] tools were employed for this study to refine and organize the data meticulously. These tools are specially designed to address data inconsistencies, like variances in author names, affiliations, and keywords, which are common in extensive datasets [35]. We began by importing the Scopus data into OpenRefine via a CSV file. Careful selection pinpointed the critical columns requiring cleansing, including keywords and author details. OpenRefine's clustering capabilities were instrumental in normalizing the data, while biblioMagika provided a suite of advanced bibliometric computations such as publication counts, citation metrics, and index calculations. In addition to automated refinement, biblioMagika highlighted gaps in the data that were then rectified manually to guarantee precision. A detailed review of the authors' keywords and other relevant entries was conducted post-cleaning to ensure their validity.

3.4 Tools

We used various tools to ensure our results were comprehensive and accurate. Microsoft Excel was used to organize and clean our data. To maintain consistency across the dataset, we then utilized biblioMagika [35] to refine various data points, including author details, affiliations, and geographical information. To synthesize the author's keyword data, we used OpenRefine, which allowed us to achieve a higher level of data coherence [35]. Once the data was prepared, we used Biblioshiny to generate further data visualization and science mapping [36]. These advanced tools and methodologies helped us comprehensively and transparently examine the scholarly landscape in botanical gardens research, giving us a holistic understanding of the research community.

3.5 Bibliometric indices

We analysed the articles' influence and output using three indices: h-index, g-index, and m-index. The h-index assesses both production and citation effect by counting the number of papers (h) that have been cited at least h times [37, 38]. g-index: Increases the weight of highly cited papers, outperforming the

h-index by ensuring that frequently cited works contribute more to the final score [39]. The m-index adjusts the h-index for career length, allowing for more equitable comparisons between early-career and experienced academics by representing the average annual rise in an author's h-index [40]. These indices, produced with biblioMagika, provided insights into scholarly influence by identifying major authors and trends in botanical garden research.

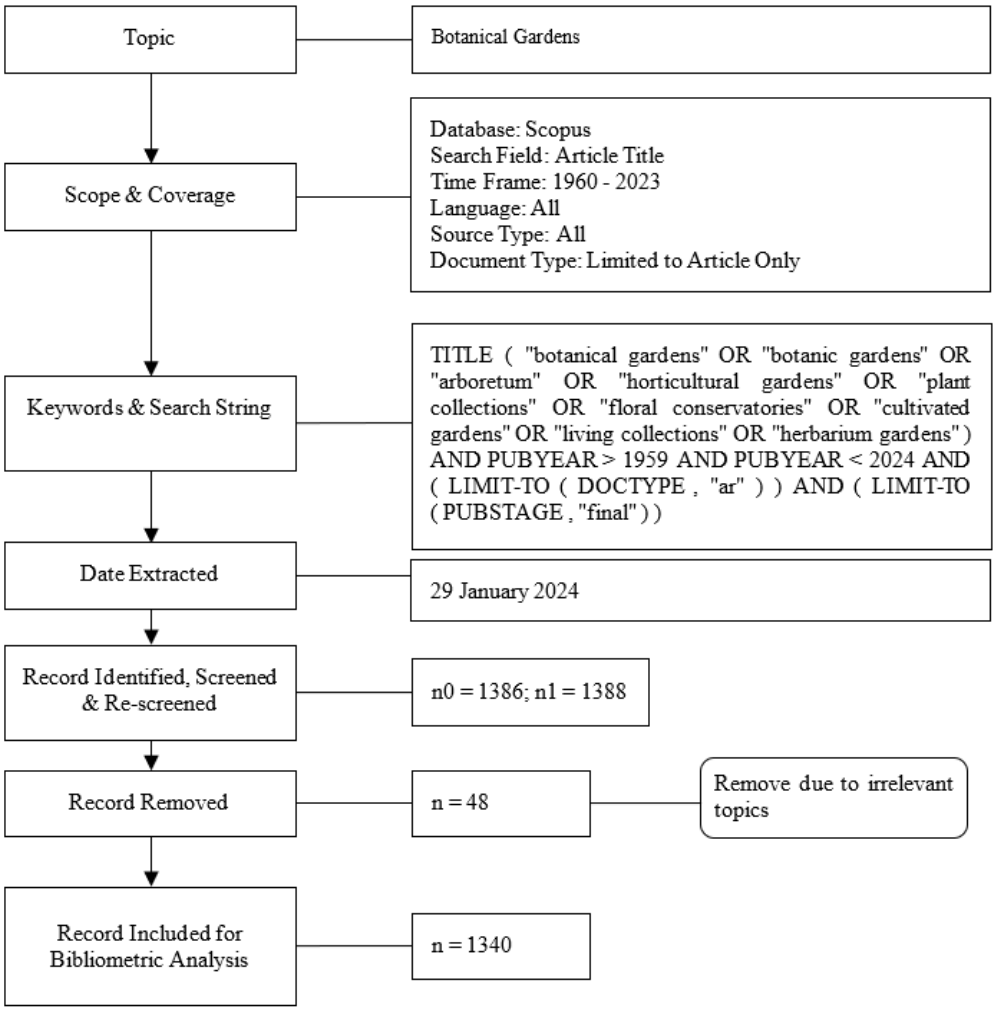

Figure 1. Flow diagram of the search strategy
Source: Adapted from studies [34, 35].

4. RESULTS

The forthcoming section will examine botanical garden research in depth. It will delve into the research questions presented earlier, aiming for a complete understanding of the area. This alignment ensures a detailed and nuanced review of the study field. The insights garnered from this analysis are poised to significantly benefit researchers, practitioners, and policymakers.

4.1 Publication and citation trends

To respond to the first research question, “What are the publication trends in the botanical garden field, and how have they changed over time?” we chart the growth trajectory of this burgeoning field (Figure 2). Over the past six decades, from 1960 to 2023, the academic study of botanical gardens has transformed significantly.

Figure 2 displays botanical gardens' research output and citation metrics from 1960 to 2023 over six decades. It shows a clear trend of increasing interest and impact in the scholarly community. The relationship between the volume of publications and citations is also positive, meaning that as botanical studies increase, their scholarly influence expands. However, from 2021 to 2023, the publication rate increased while the citation trend decreased, indicating the dynamics between the recency of research and citation practices. Table 1 provides valuable insights into botanical garden research's scholarly impact and relevance through the h-index and g-index values presented. The average citations per publication (C/P) and average citations per cited publication (C/CP) metrics also reveal the citation dynamics and research impact within this domain.

4.2 Publications by authors and their research’s key themes and topics (RKTT)

In addressing the second research question, "Which key players - authors, institutions, and countries - are driving the advancements in botanical gardens' research?”, we investigate the field’s most influential authors by examining their contributions, citation counts, research key themes and topics,

and overall impact on the botanical gardens' research landscape. After that, we apply the same investigation to the most productive institutions and countries. Table 1 provides a detailed analysis of the most accomplished authors in botanical garden research articles. It gives an overview of their affiliations, countries of origin, primary research themes, and specific areas of investigation. By examining their productivity and impact through metrics such as total publications, citations, and average citations per publication, valuable insights into the fundamental themes and topics that drive botanical garden research on a global scale are revealed.

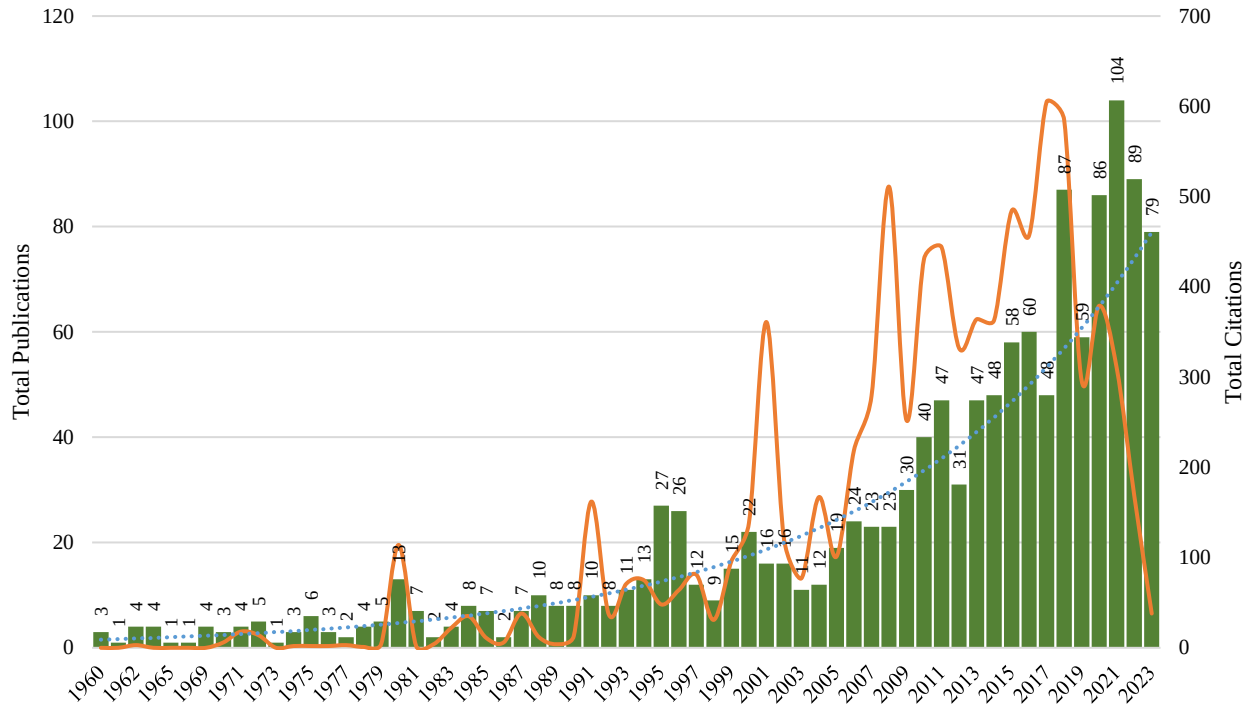

Figure 2. Total publications and citations by year
Source: Authors.

Table 1. Most productive authors and respective key themes and topics of research

Author's Name	Affiliation	Country	RKTT[1]	TP[2]	NCP[3]	TC[4]	C/P[5]	C/CP[6]	*h*[7]	*g*[8]
Sanja Kovačić	University of Zagreb	Croatia	Botanical Gardens; Conservation Plants; Ex Situ Conservation	9	9	36	4.00	4.00	4	6
Mohamed Larbi Khouja	University of Carthage	Tunisia	3-Carene; Pinus Heldreichii; Essential Oil	8	8	32	4.00	4.00	4	5
Suzanne Sharrock	Botanic Gardens Conservation International	United Kingdom	Botanical Gardens; Conservation Plants; Ex Situ Conservation	7	5	143	20.43	28.60	5	7
Ameur Elaissi	Université de Monastir	Tunisia	3-Carene; Pinus Heldreichii; Essential Oil	7	7	63	9.00	9.00	7	7
Yuri V. Plugatar	Nikitsky Botanical Gardens	Ukraine	Plant Leaves; Stomatal Conductance; Photosynthesis	7	7	7	1.00	1.00	1	2
Rachid Chemli	Université de Monastir	Tunisia	Essential Oils; Thymus Plant; Antimicrobial Activity	7	7	133	19.00	19.00	7	7
Vernon Hilton Heywood	University of Reading	United Kingdom	Conservation Planning; Reserve Design; Environmental Protection	6	6	42	7.00	7.00	6	6
Féthia Harzallah-Skhiri	Institut Supérieur de Biotechnologie de Monastir	Tunisia	Wild Edible Mushrooms; Pleurotus Ostreatus; Antioxidant	6	6	36	6.00	6.00	6	6
Ewa Przyboś	Polish Academy of Sciences	Poland	Ciliate; Holospora; Rickettsiales	6	6	6	1.00	1.00	1	2
Nora Polláková	Slovak University of Agriculture	Slovakia	Biochar; Soil; Black Carbon	6	6	6	1.00	1.00	1	2

[1]Research's Key Themes and topics; [2]Total number of publications; [3]Number of cited publications; [4]Total citations; [5]Average citations per publication; [6]Average citations per cited publication; [7]h-index; [8]g-index.

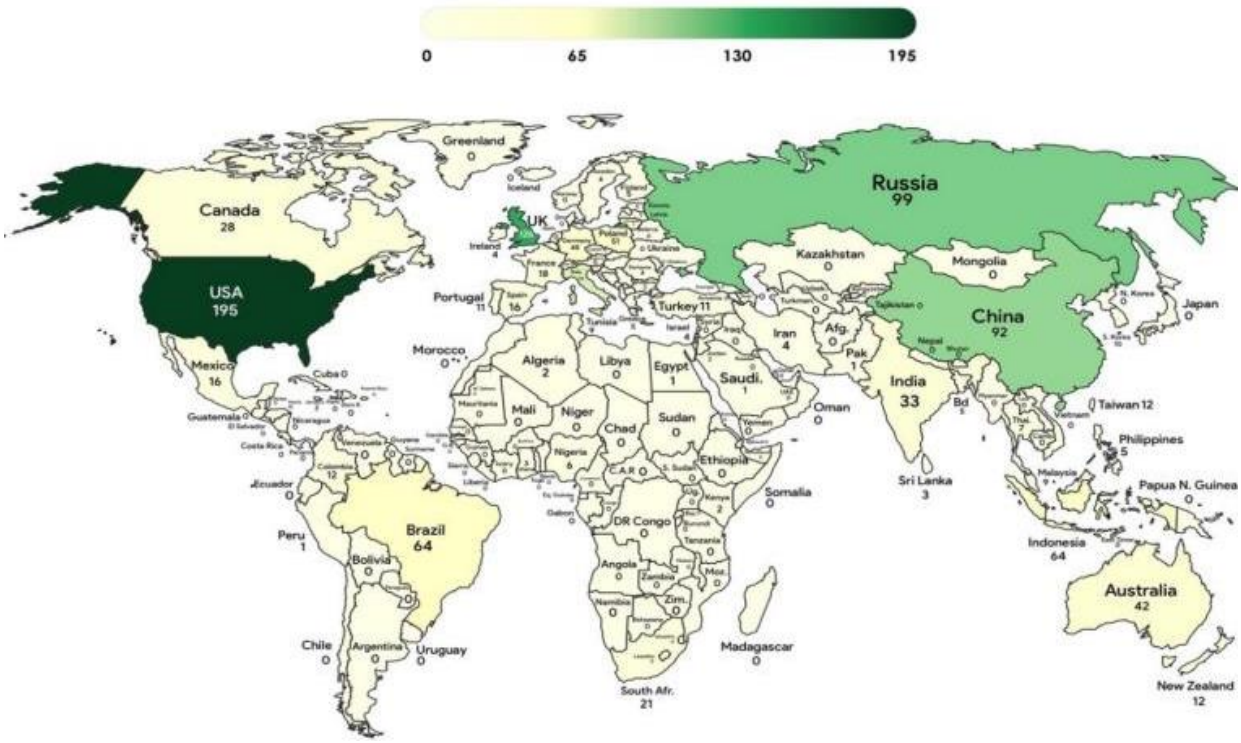

Figure 3. Global country-specific publications in botanical gardens from 1960 – 2023

Table 2. Most productive institutions in botanical gardens domain

Institution	TP[1]	TC[2]	NCP[8]	C/P[3]	C/CP[4]	*h*[5]	*g*[6]	*m*[7]
Chinese Academy of Sciences, China	63	240	29	3.81	8.28	9	15	0.167
Russian Academy of Sciences, Russian Federation	59	567	38	9.61	14.92	11	23	0.244
Indonesian Institute of Sciences, Indonesia	52	235	26	4.52	9.04	6	15	0.092
Royal Botanic Gardens, United Kingdom	42	295	30	7.02	9.83	11	17	0.239
New York Botanical Garden, United States	36	267	20	7.42	13.35	9	16	0.220
Nikitsky Botanical Gardens - National Scientific Center of the RAS, Russian Federation	34	128	23	3.76	5.57	5	11	0.106
Research Center for Plant Conservation, Indonesia	28	127	18	4.54	7.06	6	11	0.094
Polish Academy of Sciences, Poland	27	78	20	2.89	3.90	5	8	0.192
South China Botanical Garden, China	25	132	18	5.28	7.33	7	11	0.132
Taiwan Forestry Research Institute, Taiwan	22	93	15	4.23	6.20	5	9	0.132
BGI-Shenzhen, China	22	134	13	6.09	10.31	6	11	0.146
Montgomery Botanical Center, United States	22	172	19	7.82	9.05	7	13	0.233
University of Zagreb, Croatia	21	71	15	3.38	4.73	5	8	0.250
Universidade Federal Rural do Rio de Janeiro, Brazil	21	247	21	11.76	11.76	11	15	0.379
Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Brazil	20	125	17	6.25	7.35	7	11	0.159

[1]Total number of publications; [2]Total citations; [3]Average citations per publication; [4]Average citations per cited publication; [5]h-index; [6]g-index; [7]m-index; [8]Number of cited publications.

Table 1 provides a comprehensive overview of the most productive authors in botanical gardens research and their key themes and topics. The identification of top influencers was based on the number of publications and citations explicitly related to botanical gardens, arboretums, horticultural gardens, plant collections, floral conservatories, cultivated gardens, living collections, and herbarium gardens. It includes authors such as Sanja Kovačić from the University of Zagreb, Croatia; Mohamed Larbi Khouja from the University of Carthage, Tunisia; Sharrock Suzanne from the Botanic Gardens Conservation International, United Kingdom; and A. Elaissi from Université de Monastir, Tunisia. Their key themes and topics cover many areas, including botanical conservation, essential oils, environmental restoration, climate change, plant species, and their properties.

Table 2 presents research productivity at the institutional

level by focusing on institutions that produce at least 20 research articles on botanical gardens. The Chinese Academy of Sciences is at the top of the chart with a total productivity (TP) of 63, indicating its strong position in this field of research. However, when looking at the substantial impact and quality of research output, measured by total citations (TC) and h-index, the Russian Academy of Sciences (567 & 11), Royal Botanic Gardens (295 & 11), New York Botanical Garden (267 & 9), and Universidade Federal Rural do Rio de Janeiro (247 & 11) outperform the Chinese institution (240 & 9). Overall, this analysis provides a foundation for understanding the quality, depth, and influence of botanical gardens' research from different institutions. This nuanced portrayal contributes to a comprehensive understanding of the diverse landscape of the research and lays the groundwork for further exploration and tailored analysis.

Furthermore, Figure 3 shows research productivity and impacts at the country level, with a minimum of 20 research articles. Figure 3 was created using iipmaps.com, offers a geographic representation of country-specific contributions to research in botanical gardens. This visualization effectively highlights the global distribution and intensity of research activity. The United States (US) is a leading player in botanical gardens research, showcasing a remarkable total of 195 publications and an impressive total citation count of 1,990. Additionally, the US exhibits a substantial Number of Cited Publications (NCP) and achieves a noteworthy h-index of 26. The g-index of 44 further underscores the country's research productivity and the concentration of highly impactful studies. Following closely, the United Kingdom demonstrates a commendable presence in botanical gardens research with 126 publications and a total citation count of 1,685.

4.3 Highly cited documents

Responding to the third research question, "What are the most highly cited documents in the botanical garden field, and what are the key themes and topics they address?" Top 10 highly cited articles have significantly influenced the discourse of botanical gardens. Ten of the 1340 research articles on botanical gardens being assessed received more citations. Encompassing a broad spectrum of botanical inquiry, these articles explore pivotal aspects such as plant diversity conservation, visitor engagement, plant growth patterns, chemical analysis, and more, highlighting the diverse and impactful contributions that have shaped the trajectory of botanical research from 1960 to 2023. These highly cited papers show botanical gardens' extensive effect in interdisciplinary research, benefiting both conservation and education.

4.4 Co-occurrence network analysis

The last research question is, "What are the key themes and topics emerging from co-occurrence analyses of author keywords in the literature on botanical gardens?". Responding to the question, a thematic analysis was conducted to identify the core research themes in botanical gardens, mapping their interrelationships and examining how they have evolved to shape the field's development.

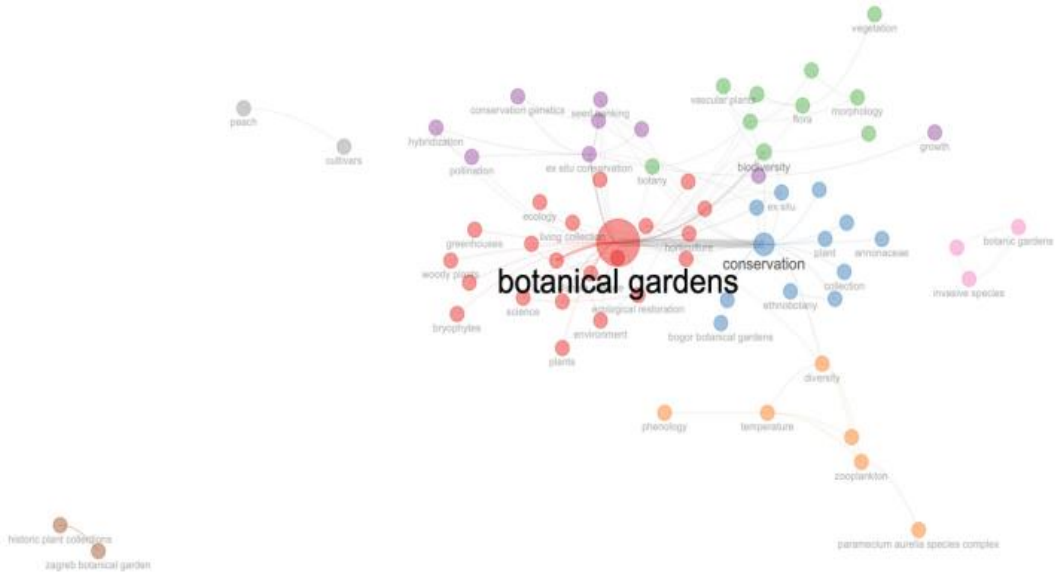

Figure 4. Co-occurrence network of the author's keywords in botanical garden research

The co-occurrence network illustrated in Figure 4 presents the relationships between frequently used keywords in botanical garden research. Each node in the network represents a keyword, and the edges between the nodes indicate the co-occurrence of these keywords in the context of research articles or publications on botanical gardens. Moreover, the size of each node corresponds to the frequency of a keyword's co-occurrence with other keywords. Larger nodes signify keywords that co-occur more frequently, indicating their significance and prevalence in botanical garden studies. By analyzing the connections between nodes, researchers can recognize patterns and trends in keyword associations, providing valuable insights into the interrelated concepts and topics within the field [41]. Furthermore, the properties of nodes, such as cluster, betweenness, closeness, and PageRank, contribute to identifying significant concepts within the co-occurrence network. Co-occurrence analysis is a method used to identify how frequently two or more keywords appear together in a given dataset. This type of analysis helps reveal the relationship between concepts by identifying the frequency

of keywords or terms co-occurring within documents. According to Zhang et al. [41], the number of occurrences of an author keyword is defined as the frequency of a keyword, whereas co-occurrence frequency is defined as the frequency of a pair of keywords occurring simultaneously.

Cluster analysis in the co-occurrence network for botanical gardens' research identifies related concepts based on their co-occurrence patterns. The assigned cluster values represent the thematic groups to which the nodes belong. Nodes sharing the same cluster value exhibit more substantial relatedness to each other within their respective thematic contexts. By dividing the network into eight clusters, nodes within each cluster are grouped based on thematic relevance, revealing shared attributes and common themes among keywords. For instance, the keywords in Cluster 1 include "botanical gardens," "climate change," "ecology," "horticulture," "plants," "ecological restoration," "environment," "living collection," "bryophytes," "greenhouses," and "woody plants."

Centrality measures such as betweenness, closeness, and PageRank emphasize the significance and influence of keywords within the network. Nodes with higher betweenness values connect different parts of the network, facilitating the flow of information. Similarly, higher closeness values indicate that a keyword has closer connections to others, reflecting its importance. Elevated PageRank values suggest the centrality and prominence of a keyword, indicating its influence and associations with other keywords. In the current study, keywords within specific clusters (e.g., botanical gardens, conservation, biodiversity, taxonomy, ex-situ conservation, diversity) demonstrate higher betweenness, closeness, and PageRank scores.

A keyword co-occurrence analysis (Figure 5) demonstrates how botanical garden study issues are interrelated. The terms "botanical gardens," "climate change," "biodiversity," and "ecological restoration" emerge as essential, highlighting the field's emphasis on conservation and environmental issues. The network demonstrates how these subjects evolve in relation to one another, emphasising the significance of tackling climate change and plant variety in research.

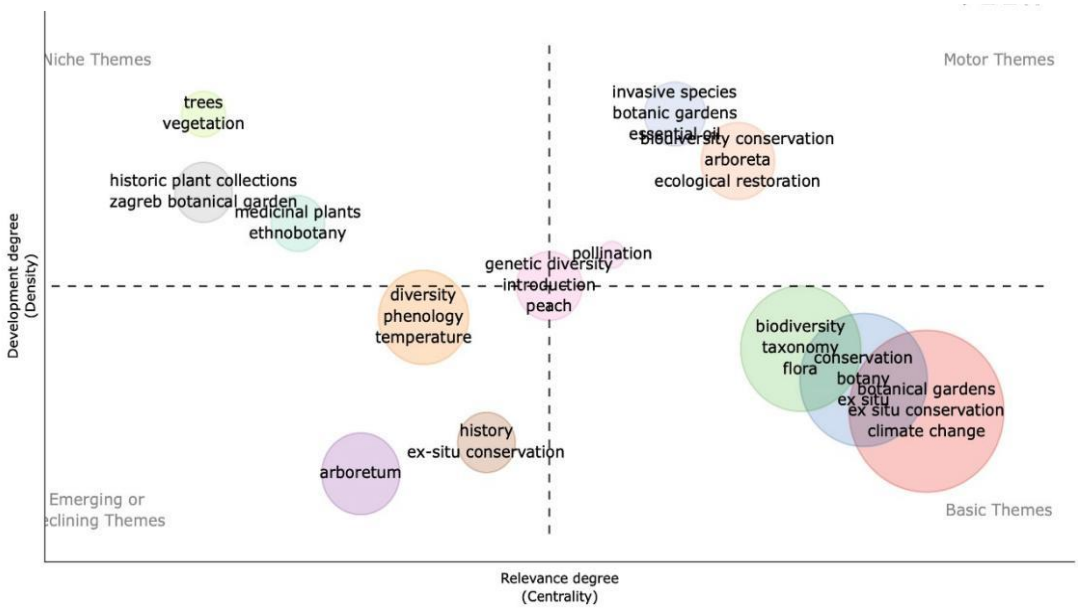

Figure 5. Thematic map of authors' keywords

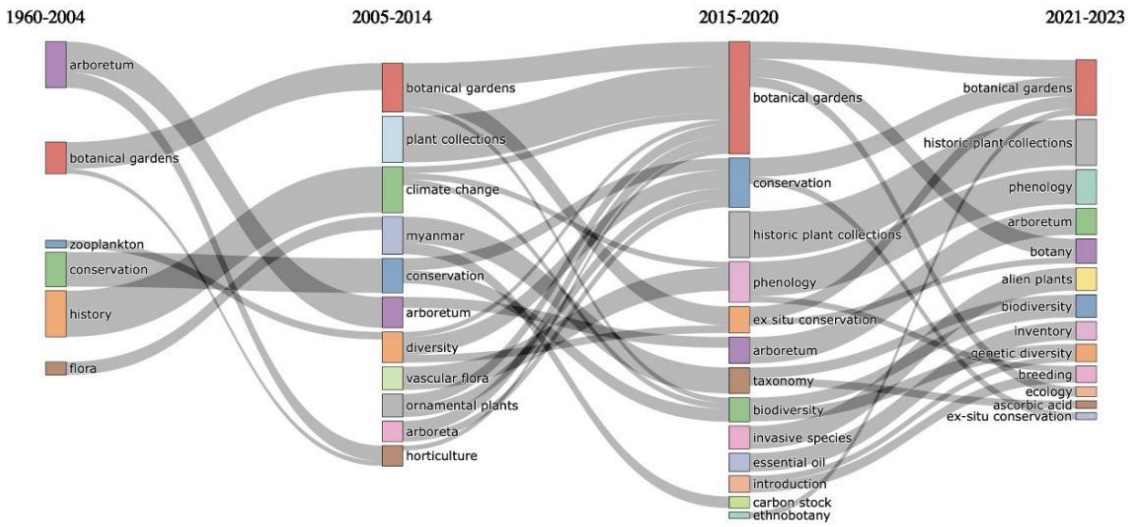

Figure 6. Thematic evolution in botanical gardens' research (1960 - 2023)

4.5 Thematic map and evolution

We studied botanical gardens using Biblioshiny, a small application of the Bibliometric R package created by Aria and Cuccurullo [36]. Figure 6 displays the thematic map generated by the Bibliometrix R package, which provides insights into the relationships and importance of various topics in botanical gardens. The map visually represents the centrality (relevance degree) and density (development degree) of various research themes within the botanical gardens field. We utilize such maps to determine which areas of botanical gardens' studies are saturating, which are nascent and growing and warrant further investigation due to their foundational nature across the field. This understanding is critical for identifying research gaps, future trends, and potential areas of interdisciplinary study. The research field of botanical gardens can be divided into four main themes, categorized based on their centrality and density. Motor Themes are highly central and dense in the top right quadrant. These themes, such as "essential oils," "invasive species," and "ecological restoration," play a critical role and have a well-established presence in botanical garden studies. Niche themes are in the top left quadrant and have high density but low centrality. These specialized themes, such as "trees" and "vegetation," have limited interconnectedness with broader disciplines despite being well-studied within their specific domains, indicating potential for greater integration into the broader spectrum of research.

Basic and transversal themes are located in the bottom right quadrant. Although fundamental to varying domains, they exhibit a lower density and could benefit from more scholarly focus. Themes such as "biodiversity" and "climate change" resonate across different fields yet require more profound exploration to enrich their contribution to botanical garden research. Emerging or Declining Themes are placed in the bottom left quadrant. These themes have relative underdevelopment and low centrality, signaling either nascent fields poised for growth or diminishing areas of interest. For instance, "arboretum" resides within this quadrant, but its definitive categorization as either emerging or declining is contingent upon the clarity and further interpretation of the thematic map. Overall, this thematic map provides a strategic overview of the research landscape within botanical gardens, revealing the multifaceted nature of the field and highlighting areas where development and collaboration can enhance the depth and reach of these vital research themes.

Aside from studying the thematic map, we also conduct a thematic evolution analysis. Thematic evolution occurred when themes evolved across different subperiods [42]. It is beneficial to evaluate the evolution of themes through time by dividing the period into distinct time slices and comparing the conceptual structures [36]. The shifting focus and frequency of various topics over different periods within the context of botanical gardens. It encompasses four distinct periods: 1960-2004, 2005-2014, 2015-2020, and 2021-2023. Each period is associated with labeled rectangles representing different topics relevant to botanical gardens. The connections between these rectangles, depicted as bands, signify transitions, persistence, or changes in the relevance of the topics. The width of the bands denotes the volume or degree of connection between the topics across different periods. This analysis shows how research priorities have changed throughout time. Thematic evolution study follows the history of research themes over four time periods (1960-2023), illustrating how conservation and climate change have gained prominence, reflecting their growing importance in global ecological and conservation contexts.

5. DISCUSSION

The bibliometric review conducted on botanical garden research from 1960 to 2023 has provided important insights into the evolution and impact of this field. One of the notable findings from the analysis is the exponential increase in publications and citations over the past six decades, signaling an expanding interest and recognition of the importance of botanical gardens in academic and conservation contexts. This growth is most notable in the sharp rise of publications toward the latter part of the review period. This trend reflects an increasing focus on botanical research, signifying the expanding interest in this field and its relevance in scientific inquiry and environmental conservation efforts. The observed publication trends could be attributed to the increasing global emphasis on biodiversity conservation and environmental sustainability, areas where botanical gardens hold distinct advantages and responsibilities. According to Primack et al. [21], botanical gardens are significant in climate change research utilizing their living collections and historical specimens. Additionally, botanical gardens are crucial in biosecurity efforts, emphasizing education, research, and ecological restoration [12]. Additionally, their role in promoting environmental awareness, preserving natural resources, conserving ecosystems [43], and increasing popularity of garden visiting, the rising interest in environmental issues, and the growing number of people participating in gardening as a leisure pursuit [44] have further fueled this trend.

Although the number of publications from botanical gardens has consistently increased, their citations have recently decreased. This is concerning because it challenges the recognition and impact of botanical garden research. We have investigated why the citation rates have decreased, and it is clear that a better understanding of the challenges and dynamics affecting the recognition and utilization of botanical garden research in academic and conservation spheres is required. While the decrease in citation rates of publications can be attributed to self-citation rates [45], the decline in uncited articles [46], title characteristics [43], and the quality and subject category of articles [47, 48], we argue if in the present study, the age of publication can be the most factor decreasing the citation rates of recent publication of botanical gardens. This means that the age of a publication of botanical gardens may influence its visibility and scholarly assimilation. This aligns with Aksnes et al. [49], stating that research recency and citation practices are linked, suggesting that newer research may be less cited initially. In summary, the recent increase in publications, juxtaposed with a slight decrease in citation rates, might indicate a proliferation of new research areas or methodologies that have not yet achieved widespread recognition or integration into existing research frameworks.

The review has also identified key contributors, individuals, and institutions, significantly shaping the research landscape. Prolific authors such as Sanja Kovačić, Mohamed Larbi Khouja, and Sharrock Suzanne and leading institutions like the Chinese Academy of Sciences and the Royal Botanic Gardens have contributed substantial work and possess high citation metrics, underscoring their influential roles in the domain. The

recent study on the prominent contributors in botanical gardens and their influential roles demonstrates similarities with insights from past literature. The high citation metrics of the prominent authors underscore their influential roles in advancing research and understanding of botanical gardens, contributing significantly to topics ranging from ex-situ conservation, plant conservation, and essential oils. This echoes findings from past literature regarding the relationship between research quality and citation metrics [50]. Past studies have also emphasized that assessing an author's impact should involve a comprehensive evaluation of various citation metrics beyond just raw citation count [51], which aligns with the approach taken in the recent study. Furthermore, Hu and Wu [48] claim that the context in which an author's work is situated can also influence his citation metrics. This contextual aspect may be relevant in understanding the influential roles of the critical contributors highlighted in the recent study.

Meanwhile, a few reasons may contribute to the important roles played by the Chinese Academy of Sciences and the Royal Botanic Gardens in botanical garden research and impacts. The centrality of institutions in specific countries, particularly those with rich biodiversity and significant environmental challenges, underscores botanical garden research's geographic and strategic importance. For example, the botanical gardens of the Chinese Academy of Sciences have collected about 20,000 vascular plant species for conservation purposes, which accounts for a significant portion of all plant species maintained by Chinese botanical gardens [2]. Moreover, the Chinese Academy of Sciences has conducted ethnobotanical studies on wild edible plants and surveys on spider species, which have enhanced their research output [52, 53]. Interestingly, although the Chinese Academy of Sciences plays a more critical role in the botanical garden domain compared to other institutions, at the country level, China has to acknowledge the significant role of the United States, both in terms of productivity and highly impactful studies.

The productivity and success of botanical research in the United States can be attributed to its robust academic and research infrastructure and its commitment to public engagement and environmental conservation. The country has numerous universities and research centers with solid botanical research programs. Additionally, it has a diverse range of botanical gardens, arboreta, and resources that support plant-focused research in ways that may be limited in other countries, particularly those with lower incomes [54, 55]. This diverse academic and research landscape provides a solid foundation for conducting high-quality botanical studies and promoting innovation. Furthermore, the United States Botanic Garden and other botanical institutions in the country actively engage in initiatives aimed at positively influencing visitors' environmental attitudes, promoting pollinator conservation, and contributing to fungal diversity research [56, 57]. These efforts not only enhance public awareness and education but also highlight the varied contributions of botanical gardens to biodiversity conservation and scientific research.

The dominance of conservation and biodiversity themes in the research of botanical gardens aligns with their historical role as custodians of plant diversity. This is evident in the growing trend among botanical gardens worldwide to prioritize conservation efforts, particularly in preserving rare and endangered plant species and conserving biodiversity [12, 55]. International agendas, such as the International Agenda for Botanic Gardens in Conservation and the Global Strategy for Plant Conservation, have played a significant role in shaping the conservation-oriented approach of botanical gardens [58, 59], underscoring the importance of plant conservation, restoration, and reintroduction programs.

However, the emergence of themes related to climate change and invasive species reflects a broader shift in the botanical gardens community toward addressing more immediate and pressing environmental issues. This evolution in research focus is likely driven by the escalating impacts of climate change and invasive species, necessitating innovative approaches to conservation and sustainable management [60]. Botanical gardens now play a crucial role in mitigating and adapting to global warming, as highlighted by initiatives like the Xishuangbanna Declaration on Botanical Gardens and Climate Change. Additionally, botanical gardens contribute to identifying and preventing the introduction and cultivation of invasive plant species while also acknowledging their past involvement in the early spread of specific invasive taxa [61, 62].

5.1 Recommendation for future research

After conducting a thorough review of botanical garden research and future predictions, five key recommendations have emerged as crucial for future studies. Firstly, there is a need to emphasize the importance of continued evolution and global participation in botanical garden research. The growing scholarly activity and productivity highlight the increasing role of botanical gardens in scientific and conservation domains. We should advocate for ongoing evolution and broader global participation to enrich botanical garden studies. Secondly, assessing and responding to thematic and evolutionary trends uncovered in botanical garden research is essential. Understanding the persistence of topics across different periods and the emergence of specific areas of interest is crucial for aligning future research with the evolving landscape of botanical garden studies. Fourthly, there is potential for greater integration of niche themes. The thematic map highlights "trees" and "vegetation" within the niche themes quadrant, marked by high density but low centrality. This suggests that while a significant cluster of research focuses on these topics within botanical garden studies, they need to be integrated into the broader research landscape. Fifthly, there should be a focus on amplifying the scholarly impact of botanical garden research through crucial research areas such as environmental restoration, climate change, plant genetics, medicinal plants, and ethnobotany. Continuing and expanding impactful studies in these critical research areas and increasing global participation can enhance the scholarly impact of botanical garden research.

Furthermore, diverse research areas within botanical garden studies, including biodiversity, essential oils, taxonomy, ex-situ conservation, and antimicrobial activity, offer extensive avenues for exploration. Future research endeavors should explore these impactful themes to gain a comprehensive understanding of botanical ecosystems and their conservation. Lastly, nurturing interdisciplinary collaborations and multidisciplinary projects is essential. Integrating expertise from plant science, environmental science, ecology, horticulture, and conservation biology can enrich the scholarly landscape of botanical garden studies. These recommendations, informed by current trends and thematic relevance, provide a robust framework for advancing impactful contributions to botanical garden research.

5.2 Implication of the study

The current study presents significant implications across multiple dimensions, including theoretical, methodological, practical, and societal. These implications provide valuable insights into the comprehensive impact of our bibliometric analysis on botanical gardens' research.

Theoretical Implication: The study's bibliometric analysis shows that botanical garden research has grown significantly. This indicates its increasing importance in scientific and conservation domains. The rising number of publications and citation frequency reflect botanical gardens' expanding role and influence across various scientific disciplines. This underscores the need for continuous evolution and global participation to enrich the landscape of botanical garden studies. The interpretation of the h-index and g-index shows that botanical garden research is becoming more relevant and influential. This highlights the scholarly impact and productivity patterns within the field, with evolving citation behaviors emphasizing the need for nuanced evaluation of how botanical garden research is perceived and utilized within the academic community. These theoretical implications provide insights into the changing scholarly landscape and the evolving significance of botanical gardens in scientific endeavors.

Methodological Implications: The study's bibliometric analysis, indices interpretation, and co-authorship analysis offer valuable insights for evaluating research perception, utilization, and collaboration patterns. Analyzing multiple indices, such as the h-index, g-index, and co-authorship patterns, provides a methodological foundation for future research trajectories within the expansive domain of botanical garden studies. Thematic mapping guides future research pathways, influencing project planning and interdisciplinary engagements.

Practical Implications: The study's practical implications underline botanical gardens' societal, environmental, and scientific significance. It emphasizes the prominence of botanical gardens in addressing pressing societal and environmental challenges, reflecting greater scientific and environmental changes. The study's focus on essential oils and common research areas further highlights the potential to develop new medicinal products and drive societal awareness towards plant diversity conservation and sustainable environmental practices. Moreover, identifying highly productive authors, institutions, and countries provides practical insights into collaboration patterns, scholarly output, and the quality of publications within botanical garden research. These implications guide the way for continued evolution, global participation, and in-depth exploration of key themes and research trends, equipping researchers with valuable insights for impactful contributions to the botanical gardens research domain.

Societal Implications: As botanical gardens contribute mitigate climate change and biodiversity loss, their research can influence regulations and promote public awareness, supporting sustainable behaviors and greater environmental stewardship.

5.3 Limitations and future directions

Our study provides a comprehensive overview of botanical gardens' research. However, it is essential to acknowledge its limitations. We only used the Scopus database, which ensured uniformity in data collection and analysis, but we may have overlooked insights from other databases. Future research should explore multi-database approaches for complementary insights. Moreover, our study has some methodological limitations. Our keyword search strategy may have missed relevant articles that used different terminologies. Future research should consider a broader range of keywords and consult experts in the field for a more comprehensive coverage of the literature. Another limitation of our study is excluding non-research documents such as conference papers, book chapters, and review articles. While these documents provide valuable insights and context, our focus was on original research articles to ensure the relevance and precision of our findings. Future studies could consider including these documents to provide a more holistic view of the research landscape. Also, differences in interpretation may exist among researchers in our classification into clusters or themes. Lastly, while our bibliometric analysis provides a quantitative overview of the literature, it may need to capture the full richness of research in botanical gardens. Future studies could complement our findings with content reviews or meta-analyses to provide a more nuanced understanding. Despite these limitations, our study offers valuable insights into the progression, key contributors, and prospective avenues in botanical gardens research, contributing to the understanding and promoting sustainable practices. Our bibliometric analysis reveals historical progression, geographical distribution, dominant themes, and influential contributors. This study significantly promotes sustainable practices in botanical gardens by identifying key trends and future research directions.

6. CONCLUSIONS

This bibliometric review has systematically examined the expansive body of research related to botanical gardens from 1960 to 2023, revealing profound insights into the growth, trends, and thematic evolution of this vital field. Our analysis underscores the significant role that botanical gardens have played and continue to play in advancing botanical research, conservation efforts, and education. Through the decades, an evident increase in research output demonstrates the escalating scientific interest and the critical importance placed on botanical gardens worldwide.

The results of this study have highlighted several key trends: (1) Rapid Growth in Research Output: The research related to botanical gardens has seen a substantial increase in publication volume, reflecting the growing recognition of their importance in addressing environmental and ecological challenges; (2) Influential Authors and Institutions: Certain authors and institutions have emerged as leaders in the field, contributing significantly to developing research themes and disseminating knowledge within the botanical gardens' community; (3) Evolution of Research Themes: Traditional themes such as plant conservation and biodiversity have been consistently popular, while emerging themes like climate change and invasive species point to a responsive shift in the research focus, aligning with global environmental priorities; and (4) Geographic and Strategic Importance: The geographical distribution of influential research underscores the strategic importance of botanical gardens in biodiversity-rich regions and significant environmental challenges, highlighting the role of local contexts in shaping research agendas.

The implications of these findings are significant. Firstly, they call for increased collaboration and communication among botanical gardens, researchers, and policymakers to ensure that the research is informed by and contributes to solving real-world conservation and environmental issues. Secondly, aligning research themes with global challenges such as climate change and habitat loss suggests botanical gardens must continually adapt and innovate in their research focus and conservation strategies.

Looking ahead, the future of botanical garden research should embrace a more integrated approach that combines botanical science with technological advancements and cross-disciplinary collaborations. This will enhance the capacity of botanical gardens to serve as modern-day arks of biodiversity and centers of education and innovation. As the world faces unprecedented environmental challenges, the role of botanical gardens is more crucial than ever—not only as sanctuaries for plant conservation but also as active participants in the global dialogue on sustainability and environmental stewardship. In conclusion, this bibliometric review not only maps the historical landscape of botanical garden research but also sets the stage for future inquiries and initiatives. It is hoped that the insights provided herein will catalyze further research, fostering a deeper understanding of the complex roles that botanical gardens occupy at the intersection of science, conservation, and society. To maximize impact, academics, institutions, and policymakers must work together. Future study should concentrate on new areas, include technology and interdisciplinary approaches, and expand the role of botanical gardens in conservation and sustainability.

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