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Mapping Research Landscape: Bibliometric Analysis of Microextraction Techniques in Drug Analysis Using Scopus Database

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Microextraction techniques have received significant recognition in the realm of analytical chemistry due to their recognized variety and efficacy in the process of sample preparation and the field of drug analysis, providing efficient and sensitive ways for extracting analytes from complicated matrices. This study has been carefully evaluated and utilizes an extensive bibliometric analysis to examine the patterns of publishing, authorship, citation networks, and clusters within the field of microextraction techniques and drug analysis, utilizing the Scopus database and VOSviewer software. The analysis encompasses the period from 2014 to 2023 and a total of 1321 articles sourced from 157 scholarly journals. The numerous citations that the Journal of Chromatography A's publications have received are proof of its significant contribution to the field of study, with a total publication count of 206 (29%). This highlights the journal's crucial role in the transmission of influential research in this particular domain. A comprehensive analysis of global scholarly contributions highlights China as a prominent participant, responsible for 23% of published publications, with Iran (19%) and Spain (11%) closely trailing behind. The findings of this bibliometric analysis indicate that the advancement of microextraction techniques necessitates collaborative efforts across multiple disciplines, including Chemistry, Biochemistry, and others. These subject areas contribute significantly to the establishment of drug analysis methodologies. This concise and comprehensive examination of research issues, thematic focus, and the discipline's future constitutes a significant intellectual contribution. This research helps academics, practitioners, and policymakers understand the importance of microextraction and drug analysis in analytical chemistry.

Keywords: VOSviewer, Clusters, Co-authorship, Co-occurrence, Citation

INTRODUCTION

Sample preparation is a critical and labor-intensive stage in the analysis process, serving a vital function in extracting desired analytes and eliminating unwanted substances from the sample. This is particularly significant when doing trace analysis on intricate matrices. An ideal sample preparation protocol of a mature and advanced nature should adhere to the subsequent criteria: for instance, it exhibits a high level of extraction efficiency for the target analytes, requiring only a limited number of stages, it is both cost-effective and time-efficient [1,2]. Additionally, it can be easily integrated with various analytical instruments, and it adheres to the principles of green chemistry by utilizing minimal solvent quantities, exhibiting low toxicity, and being environmentally benign. The advancement of bioanalytical sample preparation methods has presented increasing difficulties over several decades because of the ongoing requirement for achieving heightened levels of sensitivity, accuracy, and analysis speed within intricate biofluids such as serum, plasma, saliva, feces, and urine. Furthermore, due to the low concentration of analytes, it is often necessary to preconcentrate samples before doing analysis. Nevertheless, this frequently leads to an elevation in the concentrations of disruptive constituents, including diminutive molecules (for instance, pharmaceuticals, salts, and metabolites) or

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substantial molecules (such as nucleic acids, proteins, and peptides) [3,4]. Therefore, it is imperative to implement precise and targeted measures for sample cleanup in order to ensure the reliability and specificity of bioanalytical data for regulatory compliance. Moreover, it is imperative to conduct comprehensive validation of bioanalytical sample preparation techniques before their implementation in practical sample analysis. Carbohydrates, proteins, lipids, salts, and various other endogenous components are typically found in significant quantities within biological samples. Matrix effects can impede the detection of desired trace analytes, necessitating the removal of these effects as the main objective of sample preparation before analysis [5]. In addressing these challenges, microextraction techniques offer a fundamental change in the methodologies used for sample preparation. Founded on the fundamental premise of employing small quantities of solvents. The sensitivity and accuracy of these techniques have significantly advanced in the extraction of analytes from complicated biological matrices. It has been found to possess characteristics that make it highly advantageous in various applications. These techniques are known for their robustness, versatility, lack of solvent usage, and cost-effectiveness. The implementation of automation in various microextraction techniques is suitable for routine laboratory analyses. The utilization of microextraction techniques has gained significant attention from analytical chemists due to their strong compatibility with the principles of green analytical chemistry and their capacity to meet the demands of environmental preservation and public safety. Microextraction techniques have indisputably transformed the practices of analytical chemistry across various fields, encompassing biological and therapeutic drug monitoring, environmental studies, the analysis of food samples, and applications in phytopharmaceutical research [6,7]. Bibliometrics is a statistical analysis of publications that utilizes various bibliometric tools, such as CiteSpace, VOSviewer, Bibliometrix R, Pajek, and Gephi. This approach enables the examination of the scientific knowledge network and its development within a specific discipline. Bibliometrics uses statistical analysis to provide quantitative insights into academic literature [8,9]. The utilization of bibliometric analysis allows for the examination of the growth of scholarly works and the dissemination of knowledge within a certain discipline within a certain period of time. This analysis involves the examination of many data points obtained from databases, including citations, authors, keywords, and the variety of journals consulted [10]. Bibliometrics encompasses different approaches, including citation analysis, co-citation analysis, reviews of top countries and institutions in research fields, and bibliographic coupling using citation [9]. Additionally, co-word analysis utilizing keywords has been employed [11]. The technique used additionally enables the identification of valuable citations and the visualization of hot topics and potential avenues for further research within a particular field. Several studies have employed bibliometric methodologies to investigate various facets of the microextraction procedures within the given context. Quiñones *et al.* (2018) conducted a bibliometric analysis to examine the microextraction processes in the specific context of research evolution on liquid-liquid extraction. The study focused on conducting a comprehensive bibliometric investigation on the issue of Research Evolution on Liquid-Liquid Extraction: A Bibliometric Study [12]. This study aimed to investigate the level of research output pertaining to liquid-liquid extraction during the period from 2007 to 2017. The analysis revealed valuable insights into the increasing importance of LLE, the prevalence of specific research groups, and the intricate relationships among various research fields within the realm of LLE. However, there is currently a lack of comprehensive bibliometric analysis that encompasses a variety of microextraction techniques and provides a detailed overview of the field. The objective of this work is to address the current research gap by conducting an extensive bibliometric analysis utilizing the Scopus database. The present analysis will concentrate especially on the scholarly literature concerning microextraction techniques and their application in drug analysis. The analysis will focus on the temporal distribution of trends in journal articles, the contributions of prolific authors, leading countries, and the most productive academic institutions. Additionally, the study aims to identify common terminology and research topics, identify the leading countries based on major applications, and provide insights into potential collaboration and future directions. This work will also provide valuable insights for academics, policymakers, and

individuals interested in understanding the current research trends in the analysis of drugs employing the microextraction technique. Furthermore, it seeks to identify the opportunities and potential that exist for future research in this field.

METHODS

Bibliometric analysis is a research methodology that employs statistical techniques to extract meaningful information from scholarly literature. The methodology employed in this study entails the examination of data obtained from databases, encompassing citations, authors, keywords, and article counts. The purpose is to investigate the progression of scholarly literature and the transmission of information within a particular discipline throughout a temporal framework [8,13]. The bibliometric data for this study was gathered by employing the Scopus database, a widely recognized and comprehensive resource that provides access to a vast array of scientific and academic information. This database includes abstracts and citations for peer-reviewed literature across various disciplines [14].

Data Source and Search Strategy

This bibliometric study involved a scholarly inquiry conducted in September 2023, utilizing the Scopus database. In order to acquire this information, a meticulous search was conducted on the database maintained by Scopus, with a particular emphasis on the microextraction process and its correlation with pharmaceutical substances. The objective was to conduct data mining and examine the worldwide trend. Carefully selected keywords were utilized to achieve this objective. A total of 1321 papers published throughout the time frame of 2014 to 2023 were initially identified. To maintain the significance and contemporaneity of the collected data, articles released before 2014 have been excluded in order to prevent the inclusion of obsolete information. The selection methodology utilized the query string "(TITLE-ABS (microextraction AND technique AND drug))". Through the implementation of this search method, a thorough examination of diverse bibliometric parameters linked to these data was undertaken. The investigation consisted of various facets, such as citation frequency, average citations per document, H-index, highly cited documents, global distribution of publications, leading countries in terms of productivity, prominent institutions and journals, international collaborations, prevalent terms in titles and abstracts, frequently utilized keywords, bibliographic coupling, and co-citations of journals. In order to depict the interrelationships among terms, keywords, and countries, as well as the bibliographic coupling and journal co-citation density, the researchers utilized VOSviewer software (version 1.6.18) developed by Van Eck and Waltman (2022) [15]. The software enabled the generation of graphic depictions that illustrate the interconnections among various components.

Bibliometric Maps

The present study involved the careful processing and exportation of a comprehensive dataset comprising citation data, bibliographical references, and author keywords from a total of 1321 scholarly papers. The software tool VOSviewer, version 1.6.18, was utilized for this purpose. The power of VOSViewer to view bibliometric data by generating bibliometric maps is widely acknowledged. These maps will be discussed in the next sections of this research. Bibliometric maps will be utilized to illustrate co-authorship trends and correlations between author keywords. The maps encompass a range of components, according to the principles described in the VOSViewer documentation. The main emphasis of this study refers to the analysis of countries and author keywords as the principal subjects of interest. These objects have the potential to be joined or linked together. The strength of each link is represented by a positive numerical value, indicating the level of intensity in the relationship between the things being linked. A greater magnitude of strength value signifies a more robust relationship. In the analysis of co-authorship, the strength of the link between countries is indicative of the quantity of publications that have been collaboratively authored by those countries. Moreover, the aggregate link strength of a country signifies the collective strength of its co-authorship connections with other countries. Similarly, within the context of co-occurrence analysis, the strength of the association between author keywords serves as an indicator of the frequency with which those two keywords co-occur in scholarly publications [15].

Analysis of Co-authorship

The co-authorship analysis incorporated an extensive collection of 43 countries that were linked to 160 authors. Five main continents comprised these territories and countries: America, Africa, Asia, Europe, and Oceania.

Analysis of Co-occurrence

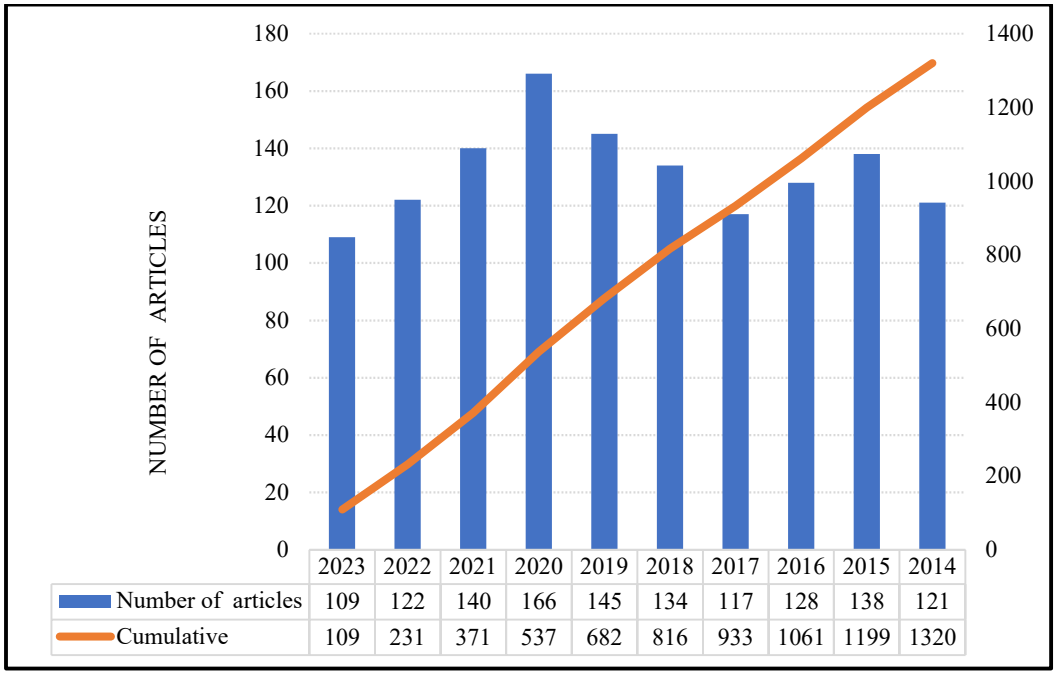
In this study, the VOSviewer was employed to analyze the co-occurrence patterns of author keywords. Initially, to categorize analogous terms, we generate a thesaurus document. Next, we proceed to examine all analogous concepts, categorize them, and substitute them with a singular term. The total number of keywords amounted to 3800, out of which 181 keywords were extracted and examined from a dataset of 1321 articles that satisfied the minimum occurrence requirement of five as required by VOSviewer.

RESULTS AND DISCUSSION

Publication Output and Growth of Research Interest

As illustrated in Fig. 1, the graph portrays the trajectory of publishing from 2014 to 2023. It demonstrates a marginal rise in 2015, followed by declines in both 2016 and 2017. Subsequently, a discernible surge commenced in 2018 and culminated at its zenith in 2020. However, a further decline was observed from 2021 to 2023.

The study uncovers a range of topics related to the microextraction of drug analysis, with each article being published in the English language. The articles can be classified according to the quantity of publications within the respective fields. The field of Chemistry comprises a total of 1007 articles, while Biochemistry, Genetics, and Molecular Biology encompass 617 articles. Pharmacology, Toxicology, and Pharmaceutics have 228 articles, whereas Environmental Science has 194 articles. Chemical Engineering is represented by 187 articles, and Agricultural and Biological Sciences have 166 articles. The field of Medicine is covered by 111 articles, while Engineering has 37 articles. Health Professions and Physics and Astronomy have 33 and 28 articles, respectively. Table 1 displays the leading scholarly journals that have documented research pertaining to this particular topic. The results further indicated that the publications utilized in this study were published in four distinct languages. The language most



	2023	2022	2021	2020	2019	2018	2017	2016	2015	2014
Number of articles	109	122	140	166	145	134	117	128	138	121
Cumulative	109	231	371	537	682	816	933	1061	1199	1320

Fig. 1. Publication output and growth for microextraction of drug analysis from 2014 to 2023.

Table 1. The First Top 10 Journals that Published Microextraction Techniques and Drugs

	Journal	TP (%)	TC	CiteScore	The most cited article	Times cited	Article type	Publisher	Ref.
1	Journal Of Chromatography A	206(29%)	5385	6.9	Advances in covalent organic frameworks in separation science	197	Review	Elsevier	[16]
2	Trac Trends In Analytical Chemistry	100(14%)	5358	15.5	Application of magnetic nanoparticles for magnetic solid-phase extraction in preparing biological, environmental, and food samples	455	Review	Elsevier	[17]
3	Journal Of Separation Science	90(13%)	1642	5.5	Recent advances and trends in miniaturized sample preparation techniques	110	Review	Wiley-VCH	[18]
4	Analytica Chimica Acta	81(11%)	3443	10.7	QuEChERS-Fundamentals, relevant improvements, applications, and future trends	258	Review	Elsevier	[19]
5	Food Chemistry	51(7%)	1431	14.9	Comparative evaluation of the volatile profiles and taste properties of roasted coffee beans as affected by drying method and detected by electronic nose, electronic tongue, and HS-SPME-GC-MS	163	Article	Elsevier	[20]
6	Journal Of Chromatography B Analytical Technologies In The Biomedical And Life Sciences	48(7%)	1332	5.6	Bioanalytical method development and validation: Critical concepts and strategies	88	Article	Elsevier	[21]
7	Journal Of Pharmaceutical And Biomedical Analysis	33(5%)	553	5.9	Rapid and simple procedure for the determination of cathinones, amphetamine-like stimulants and other new psychoactive substances in blood and urine by GC–MS	81	Article	Elsevier	[22]
8	Bioanalysis	25(3%)	297	3.5	Mass spectrometric techniques for the analysis of volatile organic compounds emitted from bacteria	35	Review	Future Science	[23]
8	Talanta	25(3%)	730	9.4	Recent progress, challenges and trends in trace determination of drug analysis using molecularly imprinted solid-phase microextraction technology	119	Review	Elsevier	[24]
9	Electrophoresis	20(3%)	432	5.5	Beneficial mycorrhizal symbionts affecting the production of health-promoting phytochemicals	98	Review	Wiley	[25]
10	Analytical And Bioanalytical Chemistry	21(3%)	433	6.2	Determination of illicit drugs and metabolites in oral fluid by microextraction on packed sorbent coupled with lc-ms/ms	57	Article	Springer Science+Business Media	[26]
10	Microchemical Journal	20(3%)	224	8.6	Preparation and characterization of magnetic metal-organic framework nanocomposite as solid-phase microextraction fibers coupled with high-performance liquid chromatography for determination of non-steroidal anti-inflammatory drugs in biological fluids and tablet formulation samples	51	Article	Elsevier	[27]

TP (%): total publications; TC: total citations.

frequently utilized was English (1294; 98%), followed by Chinese (24; 2%), Persian (2; 0%), and Polish (1; 0%). For an article in a foreign language to be indexed in Scopus, the publisher must provide an English title and abstract.

Preferred Journals

Table 1 displays a compilation of 10 scholarly publications, which have been ranked according to the number of research articles they have published and the citation counts they have received in the Scopus database. It is worth noting that all of these journals are associated with four distinct publishers, as stated in the table. Among these publishers, Elsevier is notable for having the highest representation, as it encompasses seven out of the 10 publications. Wiley-VCH is represented by two journals in the ranking, whereas Future Science and Springer Nature both have one journal included. Two publications, namely "Journal of Chromatography A" and "Trace Trends in Analytical Chemistry," both published by Elsevier, stand out in terms of citation counts, with 5385 and 5358 citations, respectively. It is noteworthy to mention that the article titled "Application of Magnetic Nanoparticles for Magnetic Solid-Phase Extraction in Preparing Biological, Environmental, and Food Samples," published in 2014 in the journal "Trace Trends in Analytical Chemistry," has received the highest number of citations among the articles in that journal, with a total of 455 citations. The "Journal of Chromatography A" has established itself as the foremost publication in terms of paper quantity, having produced 206 articles (constituting 29% of the overall total) focused on the analysis of drugs through the utilization of microextraction techniques. The subsequent publications are "Trace Trends in Analytical Chemistry" with a total of 100 articles, accounting for 14% of the total. Following that is the "Journal of Separation Science" with 90 articles, representing 13% of the total. Lastly, "Analytica Chimica Acta" contributes 81 articles, making up 11% of the total. According to the CiteScore study conducted in 2022, three journals demonstrated a score surpassing 10.0. These journals are "Trace Trends in Analytical Chemistry" with a score of 15.5, "Food Chemistry" with a score of 14.9, and "Analytica Chimica Acta" with a score of 10.7. Furthermore, it is worth noting that a total of eight scholarly journals achieved a commendable CiteScore exceeding 5.0. These journals include "Talanta" with a CiteScore of 9.4, "Microchemical Journal" with a CiteScore of 8.6, "Journal of Chromatography A" with a CiteScore of 6.9, "Analytical and Bioanalytical Chemistry" with a CiteScore of 6.2, "Journal of Pharmaceutical and Biomedical Analysis" with a CiteScore of 5.9, "Journal of Chromatography B" with a CiteScore of 5.6, "Journal of Separation Science" with a CiteScore of 5.5, and "Electrophoresis" also with a CiteScore of 5.5. The CiteScore of a journal is calculated by dividing the total number of citations received by the journal's published documents over a four-year period, by the total number of documents published by the journal during the same four-year timeframe. The utilization of data from Scopus in the computation of CiteScore renders it an essential metric for aspiring authors. It facilitates the decision-making process of researchers when choosing journals for their research papers.

Leading Countries, Top Institutions, and International Collaboration

This section focuses on analyzing the 15 countries that have published the greatest number of Scopus articles on the determination of drugs using microextraction techniques. According to the data presented in Table 2, China emerged as the leading country among the 15 major countries, exhibiting dominance with a total of 290 publications, which constituted almost 23% of the global publishing count (1258 articles). This underscores China's pivotal role as the primary global contributor to research in the realm of drug compound determination using microextraction techniques. China's publication count in this area was nearly equivalent to that of Iran, the second-ranked country, with a total of 242 publications. Spain, the United States, and Brazil have made significant contributions to the field, with 140, 103, and 81 publications, respectively.

Remarkably, Brazil is the leader in terms of colleges contributing significantly to this field of research, even though it is placed fifth among prolific countries in terms of the Total Publications Index (TPI). Particularly, with 38 publications, the Universidade de São Paulo is Brazil's most productive university. According to the Total Publications Index (TPI), Sun Yat-Sen University is ranked fourteenth, the Chinese Academy of Sciences is ranked fourth, and the Ministry of Education of the People's Republic of China is

Table 2. The Top 15 most Productive Countries and Academic Institutions in Microextraction Technique and Drug

	Country	TPC	SCP (%)	Productive academic institutions	TPI	TLS
1	China	289	23%	Ministry of Education of the People's Republic of China	36	40
2	Iran	242	19%	Tarbiat Modares University	26	52
3	Spain	140	11%	Universitat de València	21	55
4	United States	103	8%	Florida International University	21	78
5	Brazil	81	6%	Universidade de São Paulo	38	18
6	Italy	68	5%	Sapienza Università di Roma	15	51
7	Poland	58	5%	Gdanski Uniwersytet Medyczny	17	15
8	India	50	4%	Florida International University	5	34
9	Turkey	43	3%	Yakın Doğu Üniversitesi	7	43
10	Canada	32	3%	University of Waterloo	22	26
11	Taiwan	32	3%	Kaohsiung Medical University	10	12
12	Saudi Arabia	31	2%	King Fahd University of Petroleum and Minerals	12	33
13	Germany	30	2%	Justus-Liebig-Universität Gießen	6	13
14	United Kingdom	28	2%	University of Glasgow	3	30
15	Greece	27	2%	Aristotle University of Thessaloniki	18	28

TPC: total publications of the country; SCP: single-country publications; TPI: total publications of the academic institutions; TLS: total link strength.

ranked second among Chinese academic institutions with 36, 23, and 16 publications, respectively. Notable is the noteworthy inclusion of four Iranian universities in this landscape: Islamic Azad University (20 publications), Shahid Beheshti University (18 publications), Tehran University of Medical Sciences (15 publications), and Tarbiat Modares University (26 publications). This joint effort demonstrates the significant dedication of these academic institutions' research to the estimation of medicinal chemicals by microextraction techniques. In relation to the twenty most productive universities worldwide, Spain ranks sixth and tenth. The Universidad de Santiago de Compostela provides 18 publications, while the Universitat de València produces 21 publications. In contrast, one university in each of the following countries Canada, the US, Greece, Norway, and Poland is included among the top 20 most prolific in the world. Table 3 provides a comprehensive list of the top countries and organizations, which can be used to enhance the data in Table 2. On the other hand, certain countries, such as Canada, the United States, Greece, Norway, and Poland, each own a single university that is prominently ranked among the top 20 most productive academic institutions. To further enrich the information presented in Table 2, a comprehensive compilation of the prominent countries and organizations may be observed in Table 3.

The process of co-authorship evaluation involved the utilization of VOSViewer software for data visualization, alongside the presentation of the data in Table 2. The visualization presented in this study demonstrates that each country is represented by a unique location on the map. Additionally, countries that commonly collaborate in authoring articles are organized into six distinct clusters, as illustrated in Fig. 2. The dimensions of the bubbles are indicative of the Total Link Strength (TLS), denoting that countries involved in a greater number of collaborations are represented by larger bubbles. Furthermore, the thickness of the lines that establish connections between two countries serves as an indicator of the frequency of their collaborative publications, as quantified by the Link Strength (LS) score. Figure 2 presents a graphical depiction wherein China, being the foremost contributor, is represented by the largest text

Table 3. The Top 20 most Productive Institutions in Microextraction Technique and Drug

Rank	Institution	Country	No. of Publications
1	Universidade de São Paulo	Brazil	38
2	Ministry of Education of the People's Republic of China	China	36
3	Tarbiat Modares University	Iran	26
4	Chinese Academy of Sciences	China	23
5	University of Waterloo	Canada	22
6	Universitat de València	Spain	21
7	Florida International University	United States	21
8	Islamic Azad University	Iran	20
9	Aristotle University of Thessaloniki	Greece	18
10	Universidad de Santiago de Compostela	Spain	18
11	Shahid Beheshti University	Iran	18
12	Universitetet i Oslo	Norway	17
13	Gdanski Uniwersytet Medyczny	Poland	17
14	Sun Yat-Sen University	China	16
15	Tehran University of Medical Sciences	Iran	15

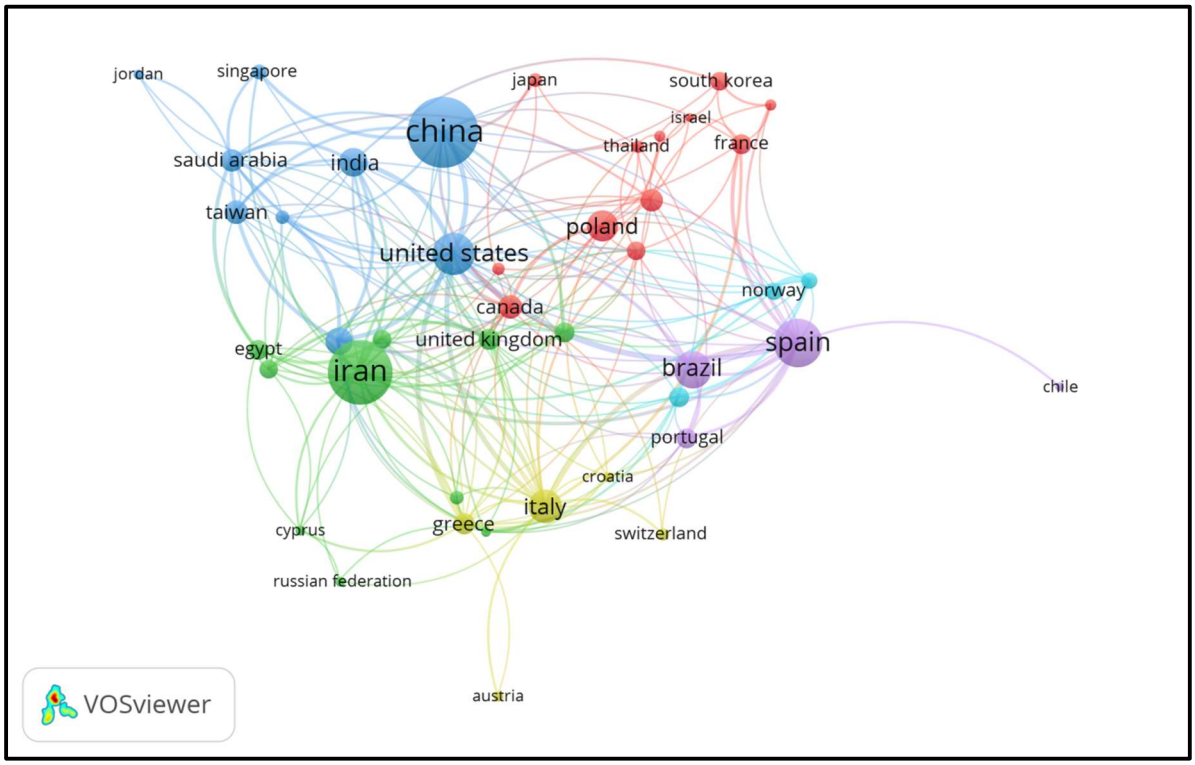


Fig. 2. Bubble map of co-authorship by the country for the selected search terms. Only countries with > 5 published articles were presented (43 countries in 6 clusters).

size on the map, followed closely by Iran and other countries. Table 2 highlights the significant role of China, as demonstrated by a Total Link Strength (TLS) of 40 and a total of 289 publications. Iran follows closely with (52 links and 242 publications), while Spain ranks third with (55 links and 140 publications). The United States, Brazil, and other countries also make notable contributions, with the former having (78 links and 103 publications), and the latter having (18 links and 81 publications). The collaborative effort highlighted in this context emphasizes the crucial significance of international cooperation in facilitating the exchange of information across national boundaries. Governments play a crucial role in facilitating these collaborations, ensuring sufficient allocation of research money, advocating for diversity in institutions, and cultivating conditions that are conducive to research, all of which contribute to the advancement of the global research landscape and the flow of information.

Leading Authors

The data regarding the most productive authors in the fields of microextraction techniques and drug research were obtained from the Scopus database, encompassing the top 15 authors. Table 4 presents an extensive overview of the authors, encompassing a wide array of countries. The list was led by Iranian researchers, who had three authors, followed by the United States and Poland, each with two authors. Furthermore, the other countries, namely Canada, Sweden, Denmark, Singapore, China, Brazil, Spain, and Greece, each contributed one author to the study. The original publications of the authors in question range from 1980 to 2009. Among the 15 authors, eight have served as first authors, eight as co-authors, and one as the last author. Janusz B. Pawliszyn is a prominent figure among the researchers discussed, with a remarkable total publication count of 771, an h-index of 112, and an impressive citation count of 53,395 in the field of microextraction techniques and drug research. Furthermore, it is worth noting that three additional authors have accumulated more than 400. It is noteworthy to mention that three of the leading authors have their origins in Iran, which is indicative of the country's significant standing as the second most prolific contributor in this specific field. The calculation of the H-index takes into account the total number of citations accumulated by authors. The H-index, a widely used statistic, is employed to assess the influence of citations on publication output. It may serve as a metric for evaluating the accomplishments of authors.

Author Keywords

The present bibliometric investigation focuses on microextraction techniques and drug analysis, specifically examining the co-occurrence of author keywords. The optimization of the analysis approach was achieved by creating a thesaurus file, which facilitated the consolidation of synonymous terms into a single, comprehensive phrase. Figure 3 presents a graphical depiction of the author's keyword analysis conducted over a period of ten years, from 2014 to 2023. The analysis encompasses a comprehensive set of 3647 keywords. Within the vast assortment of keywords, a specific subset of 28 terms fulfilled the criterion of being included in VOSviewer's dataset at least five times. The visual representation in the picture utilizes the size of each bubble to convey two important characteristics: the frequency of occurrence of a keyword and the level of its relationships with other keywords. The study revealed that the most often mentioned keyword, appearing a total of 122 times, was "sample preparation techniques". The "microextraction techniques" category exhibited a notable frequency of 105 occurrences, closely following the previous category. The significance of sample preparation and microextraction techniques in this field is highlighted, emphasizing their essentiality as crucial components in contemporary sample preparation methodologies. These techniques provide significant advantages to enhancing time efficiency, minimizing solvent usage, achieving cost-effectiveness, and effectively detecting trace analytes in complicated sample matrices, which frequently contain high molecular mass molecules.

Terminology and Concept

According to the data presented in Fig. 3, the keyword 'sample preparation techniques' was observed with the highest frequency, occurring a total of 122 times and generating 119 connections with other keywords. Significantly, it demonstrated the greatest range in size when compared to all other author keywords. Furthermore, it was discovered that there is widespread use of more

Table 4. List of the 15 most Productive Authors in Microextraction Technique and Drug Research

	Author	Scopus author ID	Year of 1st publication*	TP	h-index	TC	Current affiliation	Country
1	Yamini, Yadollah	7006759211	1994[a]	455	73	20430	Tarbiat Modares University	Iran
2	Pawliszyn, Janusz B.	56981758200	1982[b]	771	112	53,395	University of Waterloo, Waterloo, Canada	Canada
3	Kabir, Abuzar	7005744830	2001[b]	174	36	3,791	Florida International University	USA
4	Furton, Kenneth G.	7004543580	1985[a]	262	44	6,791	Florida International University.	USA
5	Abdel Rehim, Mohamed Abdel	7003923945	1990[a]	133	44	5,705	Stockholms universitet	Sweden
6	Pedersen-Bjergaard, Stig	7004215215	1992[a]	246	61	12,802	Det Sundhedsvidenskabelige Fakultet, Copenhagen, Denmark	Denmark
7	Seidi, Shahram	35099361400	2009[b]	145	38	4,728	K. N. Toosi University of Technology, Tehran, Iran	Iran
8	Lee, Hian Kee	55666413800	1980[a]	442	78	19,760	National University of Singapore, Singapore City, Singapore	Singapore
9	Ouyang, Gangfeng	55609199000	2001[b]	394	55	12,278	Sun Yat-Sen University, Guangzhou, China	China
10	Queiroz, M. E.C.	7102888789	1994[b]	110	34	3,102	Universidade de São Paulo, Sao Paulo, Brazil	Brazil
11	Borrull-Ballarín, Francesc	35595650000	1979[a]	430	70	17,039	Universitat Rovira i Virgili, Tarragona, Spain	Spain
12	Baczek, Tomasz	6701398105	1999[b]	289	34	4,521	Gdanski Uniwersytet Medyczny, Gdańsk, Poland	Poland
13	Farajzadeh, Mir Ali Ali	6603835240	1995[b]	380	50	8,039	University of Tabriz, Tabriz, Iran	Iran
14	Samanidou, Victoria F.	7003896015	1985[c]	318	45	7,014	Aristotle University of Thessaloniki, Thessaloniki, Greece	Greece
15	Bojko, Barbara	6603360252	2003[b]	132	37	4,183	Ludwik Rydygier Collegium Medicum in Bydgoszcz, Bydgoszcz, Poland	Poland

*Role in co-authorship, superscripts. [a]First author. [b]Co-author. [c]Last author.

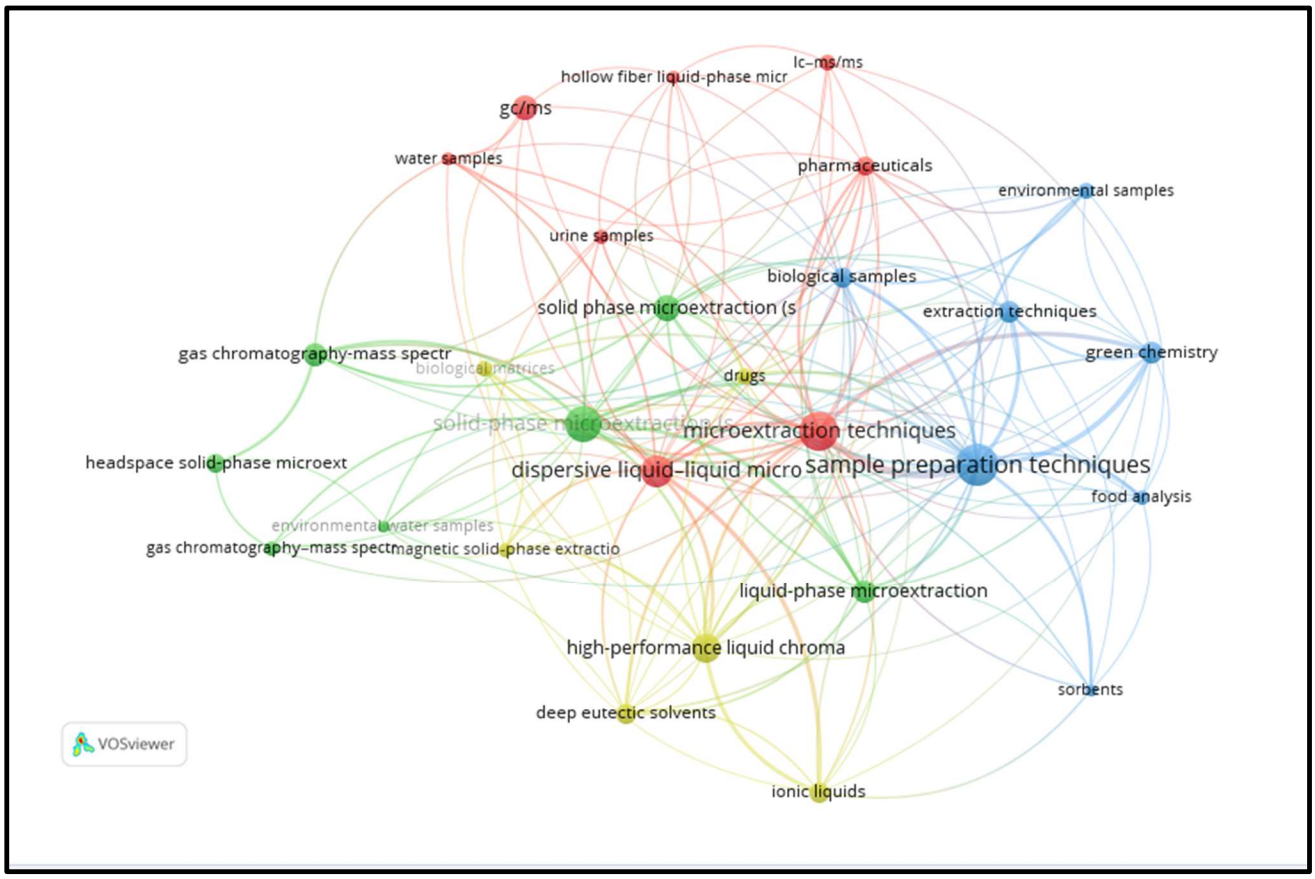


Fig. 3. A screenshot of the bibliometric map created based on author keywords co-occurrence with a prerequisite of a minimum of 5 co-occurrences.

general keywords such as ‘microextraction techniques', with a total of 105 occurrences and 92 links. The author's keywords are of significance as they are closely aligned with the main objective of this research, as seen by the exclusive inclusion of publications in Table 1 that center on the application of microextraction techniques in sample preparation. Various author keywords were frequently employed in relation to microextraction techniques and drug research. These keywords encompassed terms such as ‘solid phase microextraction' (92 occurrences, 55 links), 'high-performance liquid chromatography' (57 occurrences, 50 links), 'green chemistry' (34 occurrences, 41 links), and 'dispersive liquid-liquid microextraction' (74 occurrences, 51 links).

Topic of Interest

The degree of association between two keywords is an important indicator for assessing their frequency of occurrence in scholarly articles. Figure 3 provides a visual representation of the intensity of the link between two author keywords, as established by the utilization of bibliometric analysis. As an illustration, the author's keywords "sample preparation" exhibit link strengths of 29 with "microextraction technique," 8 with "solid phase micro-extractions," and 6 with "liquid phase micro-extraction," indicating a substantial correlation between them. The sample preparation stage of the analysis is often the most critical and demanding phase, both in terms of the duration and the intricacy of isolating the desired analyte from the surrounding matrix. Moreover, each matrix poses unique challenges. Accurate quantification of medications and their byproducts in physiological fluids is essential for evaluating and comprehending the extent to which they are absorbed, distributed, metabolized, and eliminated in scientific

investigations. The unique characteristics of each substance being analyzed and the surrounding environment often dictate the most suitable technique for extracting it. Scientists have made substantial advancements in enhancing the sensitivity and precision of non-exhaustive microextraction methods while extracting from complex biological matrices. Microextraction techniques are based on the concept of using minimal quantities of solvents [28, 29]. Microextraction techniques are distinguished by their long-lasting nature, versatility, absence of solvents, and cost-effectiveness. Many microextraction methods can be automated using standard laboratory analysis. An ideal sample preparation method should be highly efficient and require a minimal number of procedural steps. The four main techniques used for sample preparation in these matrices are liquid-liquid extraction (LLE) [30,31], solid-phase extraction (SPE) [32,33], protein precipitation (PP) [34], and direct injection [35]. However, these conventional approaches have some inherent limitations because they involve complex and time-consuming operations, as well as relying on large amounts of material and organic solvents. Furthermore, the implementation of these methods through automation poses other difficulties. Therefore, there is a substantial need for the development of inventive microextraction methods that are straightforward, swift, and solvent-free. These procedures should employ decreased sample and solvent volumes, often in the microliter range or lower, and possess wide applicability for sample analysis. Currently, a diverse array of microextraction techniques is utilized for the preparation of samples from biological fluids and other biological matrices. The purpose of these procedures is to enhance compatibility with contemporary analytical instruments, minimize the utilization of hazardous chemicals, and diminish the quantity of biofluids or reagents needed [3,36,37].

In addition, the bibliometric analysis revealed that the author keywords "sample preparation technique" and "green chemistry" demonstrate a significant collective link strength of 14, indicating a strong correlation. The observed co-occurrence signifies the convergence of the sample preparation technique and green chemistry within the field of study. The process of incorporating environmentally friendly practices into the preparation and analysis of analytical procedures has entailed the utilization of techniques that necessitate smaller sample sizes, as well as lower quantities of solvents and reagents. Consequently, this has led to a decrease in the generation of waste materials and has sparked the advancement of environmentally sustainable solvents, commonly referred to as "green" solvents, which are intended for both extensive industrial applications and individual laboratory tests. The implementation of green methodology has led to the advancement of analytical instrumentation that is more sensitive, selective, and energy-efficient [38]. These instruments are designed to be compatible with green solvents and microsample preparation processes. Hence, it is apparent that the four processes of green analytical chemistry, namely sampling, sample preparation, analysis, and assessment of environmental impact, exhibit interdependence. Therefore, it is imperative for the advancement of green analytical chemistry methodologies to consider all four elements. This leads to enhanced human safety, reduced energy consumption, and waste generation, while also fulfilling economic and analytical prerequisites [39,40].

The author's keywords "sample preparation technique" and "biological sample" demonstrate a strong correlation with a link strength of 7, indicating a significant linkage between these terms. The observed co-occurrence indicates the significant association between the "sample preparation technique" and the "biological sample" within the field of scientific research. The importance of sample preparation techniques in the realm of biological samples is emphasized, as precise and customized approaches are necessary for the processing and analysis of complex biological materials. The analysis of biological samples necessitates the careful consideration of sampling, sample storage, and sample processing, as these factors have significant importance. Blood, plasma, and urine exhibit a higher level of complexity compared to other matrices primarily because they contain proteins, salts, and a diverse range of organic molecules that share similar chemical properties with the analytes under investigation. Moreover, Carbohydrates, proteins, lipids, salts, and other naturally occurring components are typically found in significant quantities in most biological samples. The presence of matrix effects can hamper the detection of desired trace analytes, making their removal the main objective of sample preparation before analysis [3,41]. Consequently, the techniques employed for

the retrieval of biological samples have posed significant challenges. Modifications to the sample pretreatment methods have the potential to address the problem at hand [2,42]. The primary objective of sample preparation is to eliminate interfering components, such as proteins, salts, and lipids, while simultaneously enhancing the concentration of the analytes [43,44].

Additionally, the research findings have revealed a link strength of 6 between the author keywords "sample preparation" and "drug analysis." The traditional methods employed in laboratories for sample preparation and drug analysis are characterized by lengthy protocols, frequently resulting in restricted sensitivity and specificity. Furthermore, the utilization of these techniques requires the use of specialized equipment and highly skilled operators, resulting in significant expenses and limited accessibility in numerous areas. The procedure of sample preparation is crucial in the analysis of different drugs in biological sample matrices, as it enables the successful analysis of therapeutic medications in various biological sample matrices [3,45, 46]. In order to achieve accurate identification and consistent quantification of drugs in complicated mixtures, it is imperative to first eliminate unwanted interferences and concentrate the analytes of interest. The consideration of an efficient analytical approach for a specific sample necessitates the careful evaluation of the successful integration of sample preparation procedures and subsequent separation and determination methods. Another crucial criterion for the sample preparation technique in pharmaceutical analysis it is imperative to carefully examine the appropriate mix of sample preparation techniques and subsequent high-performance separation and determination methods prior to engaging in actual analytical scenarios. The ability to handle a large number of samples efficiently and at a reasonable cost is often necessary in hospital settings. Additionally, the time required for the complete analysis, particularly in emergency clinical scenarios involving drug analysis, must be carefully taken into account [3,47].

The bibliometric analysis reveals that the author keywords "sample preparation technique" and "sorbents" exhibit a link strength of 6, indicating a significant correlation between them. This co-occurrence serves to emphasize the fundamental correlation between the "sample preparation technique" and "sorbents" within the context of scientific research. This statement underscores the significance of sorbents as essential elements of sample preparation techniques, serving a crucial function in extracting and concentrating analytes from complex matrices. The interactions among these essential terms underscore the practical importance of sorbents within the field of sample preparation techniques. Regarding sorbent-based microextraction techniques, several approaches were introduced, namely solid-phase microextraction (SPME) [48,49], solid-phase dynamic extraction (SPDE) [50-52], microextraction by packed sorbents (MEPS) [53], and polymer monolithic microextraction (PMME) [54]. Sorbents play a critical role in enhancing the effectiveness and specificity of sample preparation techniques, especially in disciplines such as analytical chemistry and environmental research. The dependency between the "sample preparation technique" and "sorbents" is shown by their co-occurrence, emphasizing the necessity of both components for obtaining efficient and accurate sample preparation. This correlation demonstrates the essential significance of sorbents in ensuring the precise examination of various sample types, ranging from environmental samples to biological specimens. The simultaneous presence of these keywords highlights the significant importance of "sample preparation technique" and "sorbents" in the development of research, particularly in fields where sample preparation has an essential role within analytical procedures. The collaboration partnership of the two author keywords facilitates the achievement of reliable and excellent results for researchers, which leads to significant contributions to the development of several scientific fields [55,56].

Limitation of Study

The bibliometric analysis centered on the examination of empirical research published in journal articles, with a specific focus on the time period spanning from 2014 to 2023. The temporal constraints imposed by this limited time frame may lead to the exclusion of data from previous years, regardless of the possibility of continuous study on the "microextraction technique and drug" for a longer duration. In addition, this particular search method may fail to consider the incorporation of many categories of scholarly articles, such as literature reviews, and may inadvertently

ignore other significant sources of information, such as book chapters and conference proceedings, potentially constraining the scope of the data collection. Furthermore, the process of data mining was limited to the utilization of the Scopus database, hence imposing intrinsic constraints on the breadth and depth of the search outcomes. In order to mitigate these constraints and facilitate a more thorough examination in subsequent studies, it is recommended to adopt a more expansive approach. This involves combining the contents of many databases, including Web of Science (WOS) and PubMed, without imposing temporal limitations, resulting in a more comprehensive comprehension of the topic.

CONCLUSION

In conclusion, a comprehensive bibliometric analysis has provided valuable insights into the growing field of microextraction techniques and their significant contribution to drug research. Over a period of ten years, specifically from 2014 to 2023, an extensive study was conducted on 1321 documents sourced from 157 journals within the Scopus database. This analysis aimed to offer a thorough perspective on the rapid progression of microextraction techniques in the field of drug analysis. The rate of publication growth has seen significant acceleration over the past decade, and it is expected to persist in an upward trend. A number of countries, scholarly journals, academic institutions, and scholars have focused their attention on this subject matter, resulting in a substantial increase in publications within the field of literature. As of present, China, Iran, and Spain have demonstrated notable scientific performance and extensive international collaborations in this particular area of research. These countries have exhibited an impressive number of publications and have established robust partnerships with other countries. The majority of the articles published were disseminated through respected journals that had high impact factors. Specifically, five of these journals were classified in Quartile 1 (Q1), while the remaining journals were categorized in Quartile 2 (Q2) based on the 2021 SJR (Scimago Journal & Country Rank) journal ranking. Bibliometric analysis not only offers an extensive overview of the present state of research but also serves as a beneficial tool for researchers to expand their awareness and maintain a constant understanding of the most recent developments in research. This tool enables the identification of new research fields through the analysis of keyword occurrences, prominent researchers, significant institutions, and countries.

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