Analytical Chemistry in Malaysia: A Semi-Centennial Research Perspective (1973-2022)

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To date, there is no quantitative data on published research in analytical chemistry by Malaysian scholars. This study briefly assessed scientific productivity in the domain of analytical chemistry in Malaysia using bibliometric approaches. A total of 3,259 documents, spanning five decades from 1973 to 2022, were retrieved from the Science Citation Index Expanded (SCIE) database within the Web of Science (WoS), by employing keyword searches. Five Malaysian research universities dominated the field, with the highest number of publications led by Universiti Malaya. The journal *Sensors* recorded the highest number of publications (817) and the highest h-index of 60, making it the most published journal by Malaysian scholars in this area. Visualization analysis using VOSviewer revealed seven main research clusters in Malaysia at the time: characterisation of biomolecules had gained academic attention, while nanotechnology and computational modelling related to analytical chemistry had shown much progress and become major research areas. This study should be helpful for scholars deciding on research prospects in analytical chemistry.

Keywords: Bibliometric; Science Citation Index Expanded; scientometric; VOSviewer; Web of Science Core Collection

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Analytical chemistry is a discipline that "*studies and uses instruments and methods to separate, identify, and quantify matter*" [1]. It explores the qualitative and/or quantitative determination of the chemical composition of materials and develops tools (*i.e.*, methods, instruments) used to assess chemical compositions. Qualitative analysis characterises the identity of a sample, while quantitative analysis evaluates its mass or concentration. This discipline is one of the subjects listed in the 254 categories of the Science Citation Index Expanded (SCIE) in the Web of Science (WoS). Other chemistry-related categories listed in the SCIE include multidisciplinary chemistry, organic chemistry, inorganic & nuclear chemistry, physical chemistry, applied chemistry, medicinal chemistry, and electrochemistry [2]. The SCIE is a citation index within the WoS as part of its Core Collection, which was initially created by Eugene Garfield in 1964 [3] and is now curated by Clarivate Analytics.

The SCIE database covers more than 9,626 notable journals across 254 disciplines from 1900 to the present [2]. It is regarded as the world's leading and most prestigious journal index by academicians and researchers in the field of science and technology due to its rigorous inclusion process and high impact [4,5,6]. The SCIE has stringent inclusion criteria to ensure that the database maintains a high standard of academic integrity and reliability. Apart from being globally recognised as a leading citation index, the SCIE plays a crucial role in the academic research landscape. It is widely used in literature reviews, citation tracking, and identifying emerging trends in various scientific disciplines. Additionally, SCIE metrics are often used in evaluating the performance of researchers and institutions, thus influencing decisions related to hiring, tenure, and funding [4].

Bibliometric analysis, a term first coined by Alan Pritchard in 1969 [7], is a thorough mathematical and statistical method for analysing large volumes of scientific publications indexed in a scientific database such as the SCIE. It enables researchers to quantitatively examine a particular scientific field's productivity and evolutionary nuances, while simultaneously revealing the emerging areas in that field [8]. Previous bibliometric studies have examined the productivity of Malaysian scholars in various scientific fields indexed in the SCIE, *e.g.*, toxicology [9], rheumatology [10], and computer science [11]. Some papers explored the productivity of a more specific research theme in Malaysia, for instance, the bibliometric evaluation of second-generation antipsychotic drugs [12], nonsteroidal anti-inflammatory drugs [13], and coronavirus disease (COVID-19) [14]. However, quantitative data on the profile of published research in analytical chemistry does not exist to date, and understanding the state of this knowledge domain is essential in planning future research efforts, particularly in Malaysia.

Few bibliometric studies have focused on analytical chemistry, an important branch of chemistry. For instance, Paón and co-authors [15] examined in depth the status of Spanish analytical chemistry for a decade from 1990 to 1999 by retrieving data from Chemical Abstracts. A study by Téllez and Vadillo [16] presented the landscape of this domain on a global scale from 2000-2007. By employing data from WoS, they found that the field of analytical chemistry was dominated by the USA, China, and Spain during that period. Another work by Waaijer and Palmblad [17] explored the bibliometric mapping of a specific journal, *Analytical Chemistry*, between 1929 and 2012, emphasising the scientific publication of mass spectrometry techniques.

The present work attempts to examine the profile of scientific publications related to analytical chemistry research in Malaysia using bibliometric analysis by summarising the publication patterns of this discipline and briefly elucidating temporal research trends. Understanding temporal research trends is crucial because it highlights the evolution of areas of focus within analytical chemistry over time. By examining these trends, researchers can identify the techniques that have gained prominence and areas that have undergone significant advancement. This knowledge can suggest future research directions by highlighting emerging fields, guiding resource allocations, and pinpointing gaps that require further investigation in Malaysia.

EXPERIMENTAL

Data Source

The bibliometric data source was retrieved on July 3, 2023, from the SCIE database within Clarivate Analytics' WoS (https://www.webofknowledge.com/). For the inclusion criteria, the time span was set from 1970 to 2022. Document types were restricted to original research articles (*Article*, *Note*) and review articles (*Review*) only. The following advanced search query was used: (WC=*Chemistry, Analytical* AND CU=*Malaysia* AND PY=(*1970-2022*)), where WC is the WoS category, CU is the country, and PY is the publication year. On the day of the data retrieval, the WoS database was last updated on July 2, 2023.

Data Analysis

Data analysis was performed on the same day as the data retrieval to avoid bias due to periodical database updates [18]. Retrieved data were imported to a spreadsheet in Microsoft Excel 2019 to reveal research patterns regarding scientific output characteristics. Data on total publications (TP), total citations (TC), and the *h*-index were referred directly to the database. The average number of citations per publication was expressed as the TP ratio (TC/TP). Data for co-authorship networking and thematic keyword appearances were imported in .txt format. Co-authorship and keyword co-occurrence analyses were conducted using VOSviewer version 1.6.18 [19]. Keywords used for co-occurrence analyses were Author Keywords (provided by the authors) and Keywords Plus (generated by the WoS).

RESULTS AND DISCUSSION

The Scientific Output of Analytical Chemistry Research in Malaysia

Based on the retrieved records, the first papers on analytical chemistry were published by Malaysians in 1973, with three reported studies. Two articles were related to the use of atomic absorption spectrometry (AAS) for detecting antimony in galena [20] and silver in sulfide minerals [21]. Another study discussed the spectrophotometric determination of uranium (VI) [22]. This early research highlights the initial focus on developing and applying analytical techniques to address specific mineralogical and geochemical challenges. The use of AAS and spectrophotometry in these studies underscores the importance of precise and accurate analytical methods in chemistry, even at the early stages in Malaysia. These foundational works set the stage for further advancements and diversification of research topics in the years to follow. Documents from 1973 to 2022 were examined to assess the analytical chemistry research output over the past 50 years.

A total of 3,259 publication records were retrieved from the SCIE using the search query described in the methodology, of which 2,870 records were original research articles while the remaining 389 were review articles. Of the 3,259 documents, 74,901 citations were recorded. Original research articles had an average of 19.26 citations per article, while review articles had an average of 50.63 citations per article. Furthermore, all records had an average of 23 citations per item, with an *h*-index of 99. The *h*-index was initially proposed by Jorge Hirsch in 2005 as a measure of a researcher's scientific output based on the number of publications (*h*) by that researcher cited h times or more [23]. Therefore, an *h*-index of 99 means that 99 papers had been cited at least 99 times.

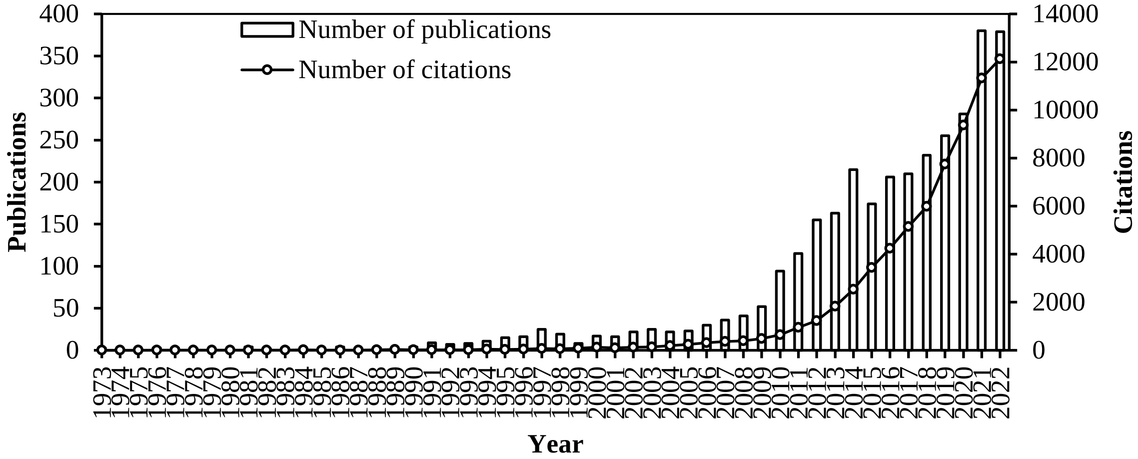

Figure 1. Number of annual publications and citations from 1973 to 2022.

Figure 1 shows the number of publications of related documents from 1973 to 2022. From 1973 to 1992, the scientific output was quite sporadic, with less than ten papers per year. Starting from 2011, the number of publications surpassed 100 and peaked at 380 articles in 2021. Overall, the number of publications showed an exponential growth trend. From 2012 onwards, the citation counts exceeded 1,000 and were highest in 2022, with 12,131 citations. Citation counts are a standard measure of the impact of a paper, *i.e*., the more citations an article receives, the more relevant the work is to the scientific community [24]. Given the steadily increasing trend over the last few years, scientific output is predicted to continue rising in the following years.

Distribution of Highly Productive Malaysian Institutions and International Collaborative Network

There were 8,802 authors from 2,092 institutions (local and abroad), contributing to the 3,259 publications in this study. Table 1 lists the top ten institutions that published the most papers related to analytical chemistry indexed in the SCIE database until 2022. The top five positions were dominated by the five Malaysian research universities (RU), led by Universiti Malaya with 647 papers, followed by Universiti Sains Malaysia (592) and Universiti Teknologi Malaysia (501), while Universiti Putra Malaysia and Universiti Kebangsaan Malaysia each had 496 publications. Two private universities were listed among the top ten prolific institutions, *i.e*., Universiti Teknologi Petronas (143) and Monash University Malaysia (93), ranked seventh and ninth, respectively.

Universiti Malaya also recorded the highest total number of citations, average citations per publication, and *h*-index, compared to other institutions. Interestingly, Universiti Malaysia Perlis registered a higher average number of citations per article (25.51 per item) than the other four research universities, indicating that the published articles received more significant citations. Therefore, the articles published by Universiti Malaysia Perlis in analytical chemistry indirectly showed a higher research impact than those from the other four research universities.

Table 1. The top ten institutions in Malaysian analytical chemistry research, based on the number of publications indexed in the Science Citation Index Expanded (SCIE) database.

Rank	Institution	TP	TC	TC/TP	*h*-index
1	Universiti Malaya	647	21,651	33.46	70
2	Universiti Sains Malaysia	592	12,457	21.04	49
3	Universiti Teknologi Malaysia	501	11,762	23.48	52
=4	Universiti Putra Malaysia	496	11,031	22.24	50
=4	Universiti Kebangsaan Malaysia	496	10,099	20.36	45
6	Universiti Malaysia Perlis	170	4,337	25.51	36
7	Universiti Teknologi Petronas	143	1,850	12.94	25
8	Universiti Teknologi Mara	110	2,305	20.95	22
9	Monash University Malaysia	93	1,592	17.12	21
10	Universiti Malaysia Pahang	86	1,500	17.44	24

TP: total no. of publications; TC: total citations; TC/TP: average citations per publication; IF: journal impact factor (based on 2022 Journal Citation Reports™).

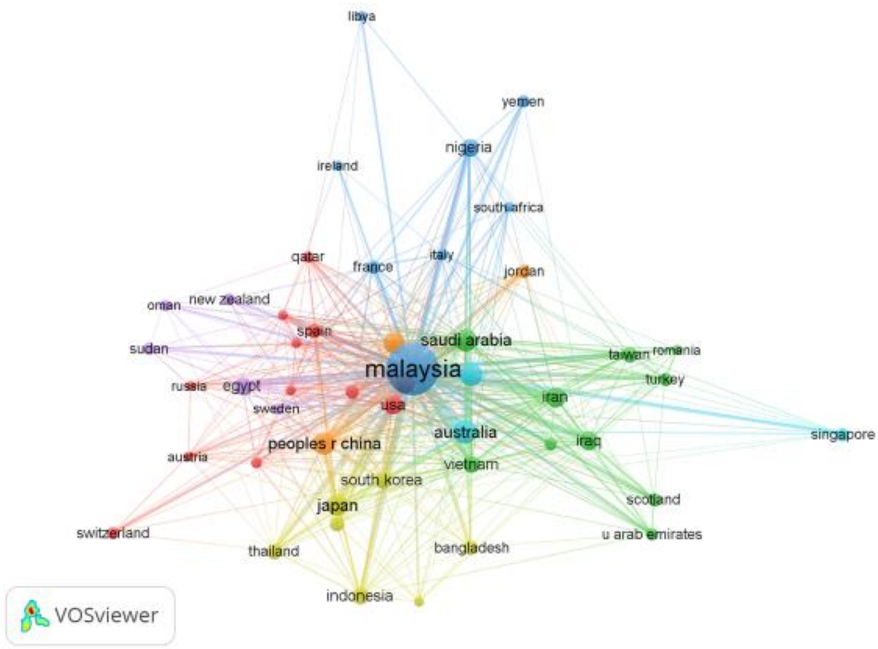

Figure 2. International co-authorship networks of Malaysian researchers in analytical chemistry with publications of more than ten ($n \geq 10$) visualised by VOSviewer from 1973 to 2022. Circle size denotes the number of publications from each country.

Figure 2 shows the global country co-authorship network mapped using VOSviewer. By setting the threshold number of publications as ten ($n \geq 10$), researchers from 48 of the 97 countries that co-authored with Malaysians met the criteria. A line was established when two countries had a collaborative relationship. The thickness of each line reflects the number of co-authorships between the countries. Different colours represent different collaboration clusters. Malaysian researchers actively collaborated with their international peers, which enhanced the quality and impact of their research. Such collaborations often lead to joint publications and higher citation rates.

Multiple lines of cooperative relationships (more than ten) were established between Malaysia and other countries. The countries that collaborated with Malaysia on more than 100 publications include Saudi Arabia (241), Australia (203), India (197), China (176), England (173), Pakistan (157), Japan (144), Iran (127), and the United States of America (120). As a developing nation, international collaboration plays a crucial role in advancing analytical chemistry in Malaysia. By partnering with researchers from diverse backgrounds and expertise, Malaysian scientists benefit from knowledge transfer, access to advanced technologies and innovative methodologies. These collaborations foster a dynamic research environment that can accelerate the discovery and application of new analytical techniques, drive innovation, and enhance the global scientific community's collective understanding of analytical chemistry.

Core Journals Published by Malaysian Scholars

Based on the Journal Citation Reports™ 2022 data (published in June 2023), there were 86 journals indexed in the SCIE under the analytical chemistry category. The 3,259 publications retrieved in this study were published in 112 journals (note that some journals may have discontinued indexing in 2023). The top ten core journals with the highest number of publications are displayed in Table 2. More than half of the total number of articles (56.06 %) were published by the top ten journals. *Sensors* had the most publications, with 817 papers (25.07 %), followed by *the Journal of Thermal Analysis and Calorimetry* (213, 6.57 %), and *Sensors and Actuators B: Chemical* (164, 5.03 %). *Sensors* also recorded the highest *h*-index of 60, indicating that at least 60 of the papers published were cited no less than 60 times. Four titles, *i.e*., *Sensors, Sensors and Actuators B: Chemical*, *Micromachines*, and *Biosensors & Bioelectronics*, are journals with a specific focus on sensor technology which makes them an ideal platform for disseminating specialised research findings. This indicates that most analytical chemists in Malaysia published papers related to sensor research and development.

Table 2. The top ten journals that published analytical chemistry research articles by Malaysian scholars, based on the number of publications indexed in the Science Citation Index Expanded (SCIE) database.

Rank	Journal (*Publisher*)	IF	Quartile[a]	TP	TC	TC/TP	*h*-index
1	Sensors (*MDPI*)	3.9	Q2	817	18,811	23.02	60
2	Journal of Thermal Analysis and Calorimetry (*Springer*)	4.4	Q1	213	3,851	18.08	34
3	Sensors and Actuators B: Chemical (*Elsevier*)	8.4	Q1	164	5,846	35.65	43
4	Journal of Radioanalytical and Nuclear Chemistry (*Springer*)	1.6	Q4	117	1,089	9.31	16
5	Micromachines (*MDPI*)	3.4	Q2	99	911	9.2	18
6	Talanta (*Elsevier*)	6.1	Q1	90	2,442	27.13	28
7	Communications in Soil Science and Plant Analysis (*Taylor & Francis*)	1.8	Q3	85	809	9.52	15
8	Journal of Chromatography A (*Elsevier*)	4.1	Q2	82	3,426	41.78	33
=9	Biosensors & Bioelectronics (*Elsevier*)	12.6	Q1	80	5,537	69.21	43
=9	Journal of Analytical and Applied Pyrolysis (*Elsevier*)	6	Q1	80	4,262	53.28	36

TP: total no. of publications; TC: total citations; TC/TP: average citations per publication; IF: journal impact factor (based on 2022 Journal Citation Reports™).
[a]Indexed journal quartile/tier in the category of Analytical Chemistry (based on 2022 Journal Citation Reports™).

Half of the titles were ranked in Q1, which shows that most of the papers published by Malaysian authors were of high quality and in the top 25 % of the journals indexed by the SCIE. In terms of citation impact, *Biosensors & Bioelectronics* recorded the highest average citations per publication, with 69.21 citations per article. Only two source titles were ranked in the low 50[th] percentile (Q3 and Q4) and received the lowest average citations per publication of less than 10, *i.e.*, *Communications in Soil Science and Plant Analysis* (Q3) and *Journal of Radioanalytical and Nuclear Chemistry* (Q4), with an average of 9.52 and 9.31 citations, respectively. This suggests that deciding on a high-impact journal is crucial for gaining citations for a published article. Publishing in such a journal ensures that the research reaches a broad and relevant audience, thereby increasing the likelihood of being read and cited.

Thematic Cluster of Analytical Chemistry Research in Malaysia

Keywords provide information about the central idea of an article. Thus, keyword analysis can be employed to identify evolving research fronts related to the knowledge domain [24,25]. Of the 14,709 recorded keywords, 386 had a frequency greater than 10 (n > 10), and these were used for analysis. These keywords were separated into seven major groups with different colours representing different analytical chemistry research clusters in Malaysia, as shown in Figure 3(a). The temporal evolution of the analysed keywords is shown in Figure 3(b).

The red cluster represented the general development of analytical methods with the occurrence of various methodological keywords such as "*performance liquid-chromatography*", "*mass-spectrometry*", "*solid-phase extraction*", "*gas chromatography*", and "*tandem mass-spectrometry*". Some of the keywords in the cluster related to tested specimens were "*urine*", "*blood plasma*", "*human plasma*", "*pharmaceuticals*", "*pesticides*", and "*organophosphorus pesticides*".

The green cluster was characterised as an environmental research cluster that deals with the detection of pollutants with keywords related to "*heavy-metals*", "*chemometrics*", "*water*", "*oil palm*", and "*phenolic-compounds*". In this cluster, there were also occurrences of the keyword "*bacteria*" with a strong association with "*mass spectrometry*", "*identification*", and "*quorum sensing*", which were related to the identification of bacteria in the environment via MALDI-TOF mass spectrometry.

The purple cluster was associated with the development of various sensors. These included sensing materials developed from "*polymer*", "*graphene*", "*polyaniline*", "*nanoparticles*", and "*nanocomposites*". Among these keywords, "*sensor*" exhibited the strongest linkage with "*nanoparticles*", signifying that nanoparticle-based sensors were the most reported in this cluster. The blue cluster was related to biosensor research and was closely aligned with the purple cluster. Similarly, the keyword "*biosensor*" also displayed a strong connection with "*nanoparticles*", demonstrating the research interest in developing sensors from nanomaterials. At the same time, "*biosensor*" was strongly associated with "*gold nanoparticles*", "*immunosensor*", "*aptamer*", and "*DNA*".

The yellow cluster was generally linked to chemical adsorption, with the keyword "*adsorption*" showing the highest centrality. One of the significant studies in this cluster analysed the behaviour of cellulosic material (potentially from cellulosic waste) as an adsorbent, where the central keyword "*adsorption*" displayed significant associations with "*cellulose*", "*waste*", "*activated carbon*", and "*pyrolysis*".

The orange cluster was the smallest cluster with the least number of grouped keywords, and was connected to the performance study of nanofluid (colloidal suspensions of nanoparticles) sensing related to "*thermal conductivity*", "*thermal physical properties*", "*transfer enhancement*", and "*viscosity*". Lastly, the cyan cluster was connected to computational modelling and neural-network use in analytical chemistry, with the occurrence of various keywords such as "*models*", "*optimization*", "*ANN*", "*neural-network*", and "*system*".

(a)

(b)

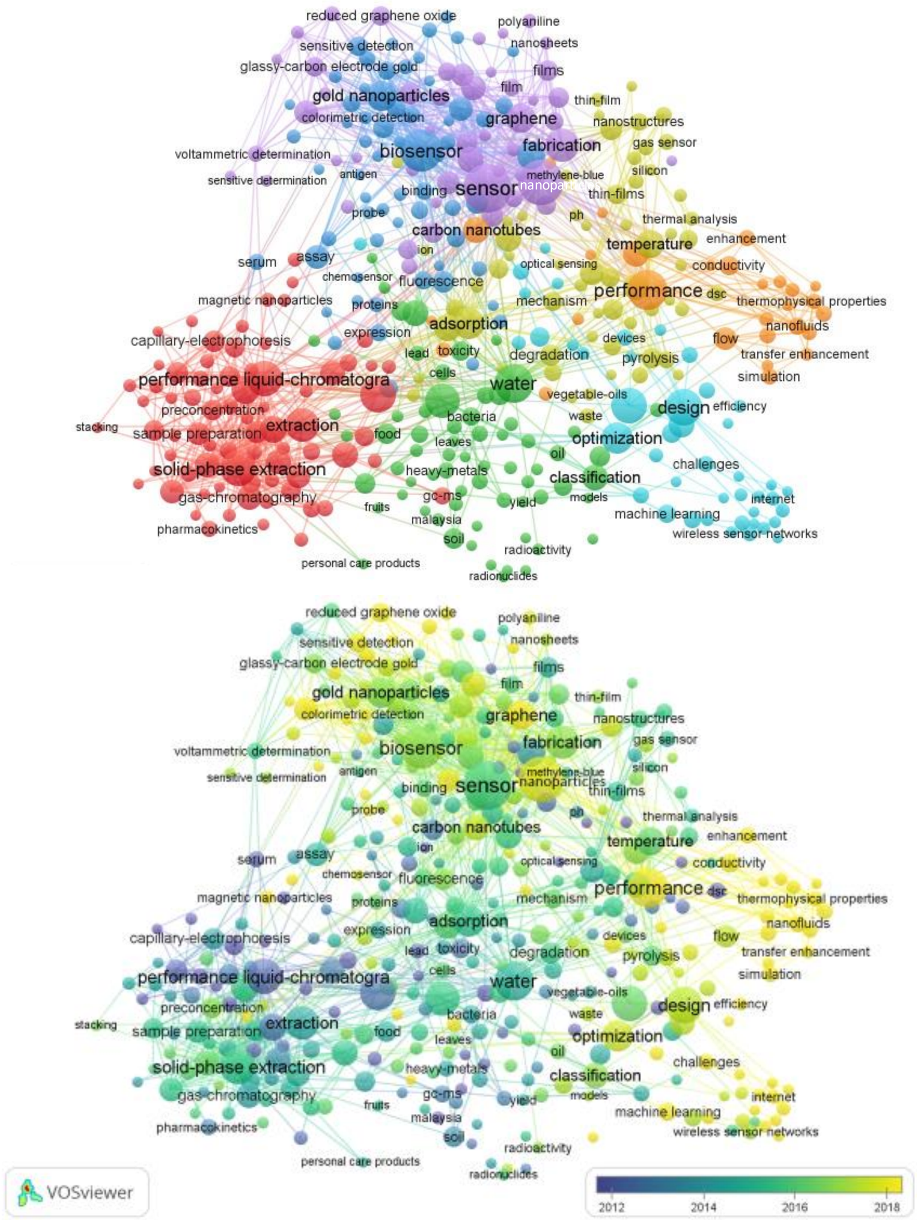

Figure 3. Keyword co-occurrence ($n \geq 10$) clusters in analytical chemistry research (a) and its temporal evolution (b) in Malaysia from 1973 to 2022, as visualised by VOSviewer. The circle size signifies the frequency of the occurrence of each keyword. The distance between the circles denotes the degree of relatedness of each keyword.

The temporal evolution of keywords is shown in Figure 3(b), where the lighter colours signify newly emerging keywords, whereas the darker ones occurred earlier. Figure 3(b) shows a shift in trends from the analysis of smaller molecules to the analysis of more complicated biomolecules. For instance, the keywords "*gases*", "*hydrocarbon*", and "*heavy metals*" are darker, while the biological keywords "*proteomics*", "*protein*", and "*DNA*" are lighter in colour. These biological terms started gaining popularity in 2016. Hence, this signifies that the current research interest in biomolecules is gaining more academic attention.

More recently, the development of nanomaterials, *i.e*., nanoparticle sensors (purple cluster) and the study of nanofluid-based sensors (orange cluster), showed significant progress since 2018 and has become the current research interest in Malaysia. At the same time, the cyan cluster showed a similar emerging trend since 2018. The increasing interest in these fields is potentially driven by the government's efforts to establish the National Nanotechnology Centre (NNC) (previously known as the National Nanotechnology Directorate) to coordinate and implement national nanotechnology initiatives since 2011. Therefore, analysis of these keywords implies that analytical research related to nanotechnology and computational chemistry is currently trending in Malaysia.

Future Direction of Analytical Chemistry in Malaysia

As nanotechnology and computational chemistry continue to emerge in analytical chemistry, their combined efforts are expected to drive significant innovation in Malaysia. The integration of computational chemistry and nanosensors represents a powerful approach to developing advanced analytical tools with enhanced sensitivity, specificity, and functionality [26,27]. Computational chemistry techniques, such as molecular dynamics and quantum mechanics calculations, are used to model the interactions between analytes and nanomaterials [28]. This helps in designing nanosensors with optimal sensitivity and selectivity. Simulations can predict the behaviour of nanomaterials under different conditions, thereby guiding the design of nanosensors that can operate effectively in various environments.

One of the future challenges for nanoscale sensing technology is to bridge the gap between different scales in computational models and accurately predict the behaviour of nanosensors in the real world. Therefore, addressing challenges related to real-world implementation of laboratory-scale research is vital. Manufacturing nanosensors for widespread use is worth further focus for scalability research, and this requires support from the government through grants and research programs for potential commercialisation. The government should also ensure that the nanosensors produced meet regulatory standards and are safe for use in various applications [27].

CONCLUSION

This is the first study that highlights the status and temporal trends of analytical chemistry research in Malaysia. A total of 3,259 documents were retrieved from the SCIE, of which 8,802 authors published papers in 112 journals and collaborated with researchers from 97 countries. Given the growth in research over the last few years, it is envisaged that related scientific production will continue to expand in the future. Nanotechnology and computational chemistry have emerged as popular topics in Malaysian analytical chemistry research. This study not only establishes a baseline for future research assessments, but also highlights the vibrant and evolving nature of such research in Malaysia. This emphasises the importance of continued research and development of nanoparticle sensing systems, aided by computational simulations, to drive further advancements in this field. Future research should evaluate the scientific production and research trends of this knowledge domain, concurrent with bibliometric data sources retrieved from the Scopus database. Simultaneous complementary evaluation of both databases may provide a more comprehensive overview of the development of this discipline in Malaysia.

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