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Bibliometric Analysis of the Use of Electrospun Chitosan Nanofibers in Biomedical Applications

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Abstract

In recent times, the application of Electrospun nanofibers derived from chitosan has gained substantial attraction across various biomedical domains. This surge in popularity can be attributed to their unique attributes, which encompass a high surface area-to-volume ratio, customizable pore dimensions, and impressive mechanical characteristics. The objective of this bibliometric investigation is to furnish an overarching view of the realms of application, research advancements, and emerging trends pertaining to electrospun chitosan nanofibers within the biomedical sphere. The data for this study was extracted from Scopus, covering the time span from 2006 to 2023. Following meticulous refinements involving keywords, publication years, research fields, and document types, a total of 243 publications and 1080 authors were encompassed within this analysis. Linear regression computations were conducted, foreseeing the publication of 24 articles in the year 2023. 'Carbohydrate Polymers' emerged as the most prominently featured journal with a focus on electrospun chitosan nanofibers for biomedical applications. Iran and China contributed to roughly 27.16% of the publications, with Donghua University as the most prolific institution. Tissue engineering emerged as the foremost domain for the application of electrospun chitosan nanofibers. Furthermore, numerous collaborative efforts and citations among authors, institutions, and countries are anticipated to become more prominent.

1. Introduction

In recent years, nanomaterials have been widely employed in various sectors, including biomedicine, aerospace, textiles, plastics, oil and gas, environmental conservation, and energy capture due to their fascinating characteristics, physical and chemical properties. With the progression of technology, nanomaterials have progressively gained significance in the field of biomedical uses [1]. These include areas such as wound healing [2], precise drug delivery [3], hyperthermia treatment [4], photoablation therapy [5], bioimaging [6], and bone and tissue engineering [7]. Nanofiber is one of the important types of nanomaterials due to its unique properties like exceptional stiffness and tensile strength, high surface area to weight ratios, low densities, high pore volumes, and small pore sizes [1,8,9].

Among the techniques utilized in nanofiber fabrication, electrospinning has emerged as the prevailing method to produce continuous nanofibers with various physical, chemical and biological properties [10]. Through the electrospinning process, a variety of products like membranes, fibers, and scaffolds can be generated. Diverse materials, whether organic or inorganic, natural polymers or synthetic polymers, are amenable to electrospinning. Chitosan, a biopolymer derived from the deacetylation of chitin, holds huge potential due to its exceptional attributes, notably its high biological and sorption capabilities. As a result, substantial research has been dedicated to electrospinning of chitosan-based materials to produce nanofibers. Electrospun chitosan demonstrates a variety of applications in biotechnology, food industry, and medicine [3,11].

Electrospinning of chitosan offers several advantages for biomedical applications. These advantages include biocompatibility, antimicrobial properties, controlled drug delivery, ease of functionalization, suitability for tissue engineering, and haemostatic properties [4,12]. However, the high viscosity and intricate nature contribute to the need to blend chitosan with other materials to increase the effectiveness of the electrospinning process. Among the main applications of electrospun chitosan in biomedical include wound healing [18-21], drug delivery [13-16], tissue engineering [22-27], and bone engineering [28-31].

Chitosan's wound healing properties benefit from its nanofiber structure, mirroring skin and aiding recovery. Recent progress in wound dressings, especially in fighting microbes, includes integrating diverse materials including silver nanoparticles, sericin composite nanofibers, honey, graphene oxide and poly(epsilon-caprolactone) substances [18-21]. These antibiotics, nanoparticles, and natural substances enhance the dressing's antimicrobial features, marking notable advancements in wound care [17] [20]. In the context of drug delivery, controlled release systems are crucial for allowing medications to be given precisely at the needed rate for a specific treatment environment and over a set of time [13,14]. Nanospun chitosan nanofibers exemplify this, boosting drug concentration exactly where needed, reducing the required dose [16]. This precise targeting helps enhance treatment effectiveness.

Table 1 *Materials blended with chitosan in medical applications*

Material	Application	Reference(s)
Polyvinyl acetate (PVA)	Drug delivery	[13,14,15]
Poly (ethylene oxide)	Drug delivery	[16]
Silver Nanoparticle	Antibacterial wound dressing	[17]
sericin composite nanofibers	wound dressing	[18]
Honey	wound healing	[19]
Graphene oxide	Wound dressing	[20]
Poly(epsilon-caprolactone)	Wound healing	[21]
Magnesium oxide-poly(ε-caprolactone)	Tissue engineering	[22]
Polycaprolactone nanofibers	Tissue engineering	[23,24,25]
Phosphoprotein	Tissue engineering	[26]
Biomimetic apatite fabricated polycaprolactone	Tissue engineering	[27]
Poly (glycerol sebacate) /poly(caprolactone)	Bone engineering	[28]
PLA Nano-fibers	Bone engineering	[29]
Oxidized starch	Bone engineering	[30]
Poly(caprolactone)	Bone engineering	[31]

In addition, there's been a growing focus on making chitosan nanofibers through electrospinning methods for tissue engineering. These nanofibers have higher porosity and connected fibers, providing a better surface area-to-volume ratio compared to other materials [22,23]. Their 3D structure supports cell movement, growth, and sticking offering good mechanical qualities for medical purposes [24,25]. The blending of materials such as magnesium oxide-poly(ε-caprolactone) [22], polycaprolactone nanofibers [23-25], phosphoprotein [26] and biomimetic apatite fabricated polycaprolactone [27] with chitosan formed hybrid nanofibers with unique traits, offering benefits in tissue engineering [26,27]. Meanwhile, a crucial aspect of bone tissue engineering is creating scaffolds that support bone healing [28]. These scaffolds must use materials that break down naturally, work well with the body, and have the right porous structure, size, strength, and ability to promote bone growth [29]. Guided bone regeneration (GBR) is a common surgery to fix irregularities in the jawbone, often seen in people without teeth. Different membranes, some that dissolve and some that don't, are used in GBR surgery to block soft tissue and help bone tissue grow [30,31]. Table 1 presents an overview of the polymers that were blended with chitosan for various biomedical applications.

Bibliometric analysis has proven valuable in capturing the overall research landscape and assessing the status of a field of study [9,32]. This paper aims to report a bibliometric analysis of the electrospun chitosan nanofibers and their use in biomedical applications. The collected data was further analysed based on the year of publication, publication sources, author citations and author affiliations based on countries, institutions, and relevant keywords.

2. Materials and Methods

A systematic inquiry was performed online using Scopus database on the 3rd of August 2023 using 8 keywords in the three publication fields, i.e., title, abstract, and keywords. The eight keywords used are divided into two parts: "A" and "B". "A" represents different phrases associated with biomedical and chitosan, including "biomedical", "chitosan", "application chitosan", and "nanofiber", whilst B represents phrases associated with electrospinning, including "electrospinning" and "electrospun". The inclusion criteria retrieved 243 publications, consisting of original articles, processing papers, early access, and meeting abstracts. The full record (including publication years, document types, authors, affiliations, publication titles, countries/regions, and the publishers) and cited references were exported as a '. bib file' before being collected and analysed in Microsoft Excel. Origin was used to process, analyse, and evaluate the data [7,33]. This research employs the integration of data from Scopus databases by utilizing Biblioshiny software. The bibliographic data retrieved from Scopus databases were imported into Biblioshiny to illustrate the network mapping. R package (Version:4.3.0) [34,41] was utilised to visualise the distribution of the data.

3. Results and Discussion

In this study, a total of 243 publications obtained were comprised of 146 sources. The 1080 authors were affiliated with 619 institutions from 41 countries. Table 2 summarises the details of the bibliographic data retrieved.

Table 2 *Overview of the bibliographic data retrieved*

Description	Results
Timespan	2006:2023
Sources (Journals, Books, etc)	146
Documents	243
Annual Growth Rate %	13.42
Document Average Age	6.01
Average citations per doc	50.29
References	16236
Keywords Plus (ID)	2581
Author's Keywords (DE)	534
Authors	1080
Authors of single-authored docs	6
Single-authored docs	7
Co-Authors per Doc	5.03
International co-authorships %	28.4

3.1 Publication and Trend Analysis

As shown in Fig. 1, generally the publication trend from 2006 to 2023 has been upwards on topics associated with electrospun chitosan as biomedical materials. After ten years of the first publication, the publication has increased by 8.5-fold. The regression analysis of the number of publications shows that Y=1.2497*X– 2504.1 and the correlation coefficient R^2 = 0.8555, which means that the fitting regression effect is very good. As of August 2023, 17 were recorded and predicted to reach 24 publications by the end of the year. and the predicted publication throughout the year 2023 is 24.

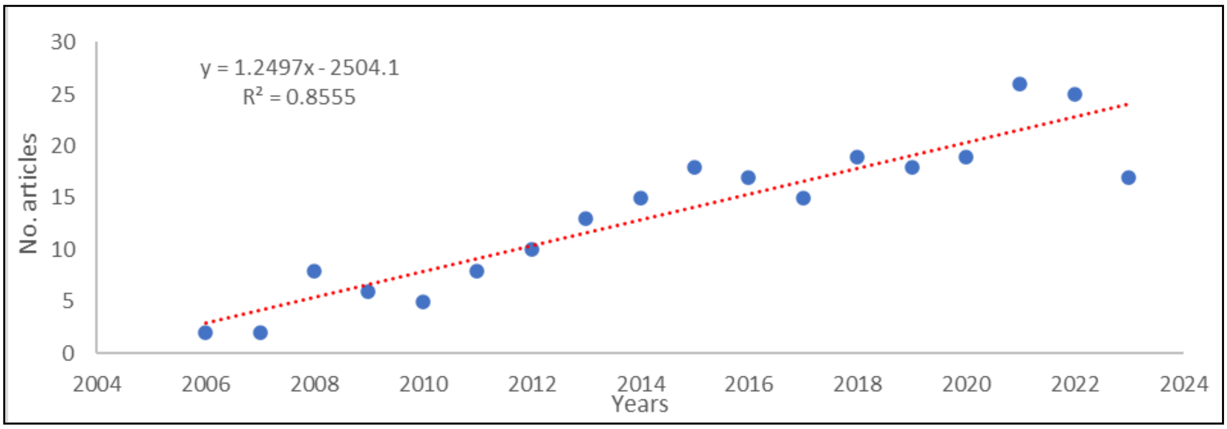


Fig. 1 *Trend of publications on topics associated with electrospun chitosan as biomedical materials from 2006 to 2023*

3.2 Source of Journal Analysis

The analysis conducted according to Bradford's Law, distributed the 243 publications from 146 journals into three zones with a ratio of 13:53:80. As shown in Table 3, the top ten journals that made up 37.67% of the total publications retrieved, are high-quality journals with a range of H-index from 18 to 3. The contents covered by these journals were principally related to chitosan, nanofibers, polymer science, electrospinning, tissue engineering, biomedical application, biocompatibility, and chemistry. The Carbohydrate Polymers was the most productive journal. The bibliographic coupling cluster result shows that the journal is the most productive and most cited journal with 1879 citations. The International Journal of Biological Macromolecules ranked second with H-index of 8, only half of the former, with 501 citations. The second runner-up is the Journal of Applied Polymer Science with 446 citations. Other journals have citations in the range of 250 to 76. The bibliographic coupling cluster in Fig. 2 illustrated that the Carbohydrate Polymer has the largest total link strength, with the number of references in common were 72. The European Journal of Pharmaceutics and Biopharmaceutics, another journal not listed as the top ten journals, comes in second with a total strength of 70.

Table 3 *Core journals where articles on electrospun chitosan for biomedical are published and cited by the scientific community*

Element	H-index	G-index	M-index	TC	NP	PY_start
Carbohydrate Polymers	18	20	1.125	1879	20	2008
International Journal of Biological Macromolecules	9	10	0.9	501	10	2014
Journal of Applied Polymer Science	8	9	0.471	446	9	2007
Polymers	5	8	0.714	149	8	2017
Advanced Drug Delivery Reviews	4	4	0.235	1820	4	2007
International Journal of Nanomedicine	4	4	0.571	111	4	2017
Marine Drugs	4	4	0.308	250	4	2011
Pharmaceutics	4	5	0.8	113	5	2019
Acs Applied Materials and Interfaces	3	3	0.5	76	3	2018
Biomedical Materials (Bristol)	3	3	0.429	92	3	2017

*TC- total citation, *NP-number publications

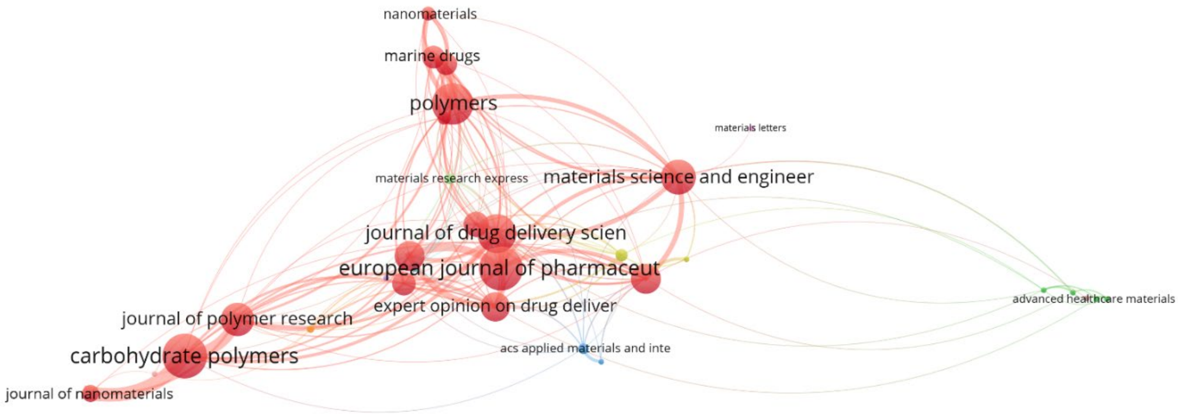


Fig. 2 *Bibliographic coupling cluster of electrospun chitosan for biomedical by journal*

3.3 Contribution of Country

Geographically, there were 41 countries contributed to the publications and citations. The number of publications, frequency, science corresponding publication (SCP), and medical corresponding publication (MCP) of the top ten countries are illustrated in Table 4. Iran and China both shared the highest number of publications with 33 documents that made up 13.58% of the total publications, followed by USA (22; 9.05%), India (9; 3.70%), Korea (8; 3.29%), and Egypt (6; 2.47%). Fig. 3 highlights the publication from different countries over time. Compared to other countries, China produced significant number of publications that clearly seen from 2010 to 2022 period while Korea and India exhibited the smallest increase of publications. Both Korea and India total publications from 2006-2023 were 61 and 70 accordingly. Fig. 4 shows the cluster map that highlights the joint effort between various countries. The size of the circles represents the level of research output, with larger circles indicating higher output. The thickness of the lines indicates the number of collaborations. The United States (USA) has the highest total link strength of 2081, with 16 links, followed by India with a link strength of 1117 and 16 links, Egypt with a link strength of 1096 and 16 links, and United Kingdom with a link strength of 1018 and 16 links.

Table 4 *Top countries/regions of publications about Electrospun chitosan for biomedical*

Country	Articles	SCP	MCP	Freq	MCP ratio
Iran	33	24	9	0.136	0.273
China	33	27	6	0.136	0.182
Saudi Arabia	5	0	5	0.021	1
USA	26	22	4	0.107	0.154
Germany	5	1	4	0.021	0.8
Malaysia	4	1	3	0.016	0.75
India	11	9	2	0.045	0.182
Korea	10	8	2	0.041	0.2
Italy	6	4	2	0.025	0.333

3.4 Contribution of Institution

In the analysis of institution contributions, 329 institutes were included and those with more than 5 publications were highlighted in Fig. 5(a). The Donghua University, contributed the highest number of publications, with a total publication of 29, followed by King Saud University (22), Beijing University of Chemical Technology (18), University of Debrecen (18), and Institute of Polymers Iran (14). For publication over time, Donghua University has had the most significant increase from the year of 2009 to 2019 with 23 publications. Institutions from China was focusing on alternative materials for biomedical applications. In contrast, Institute of Polymers Iran, exhibited the smallest increase from year 2006 to 2023 with no new publication since 2013 (Fig. 5(b)).

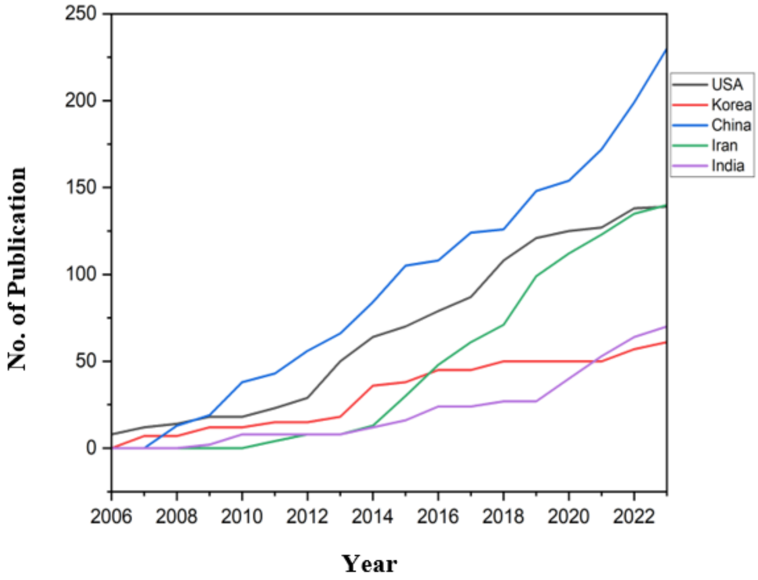


Fig. 3 *Publication produced by country from 2006 to 2023*

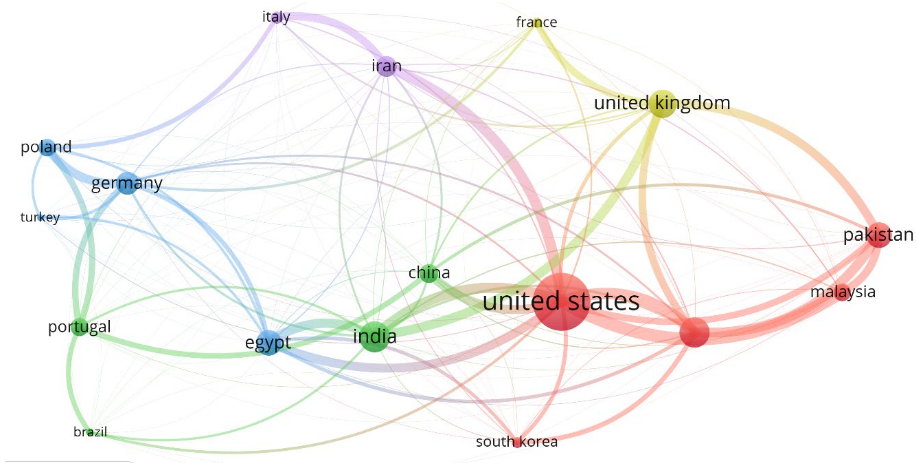
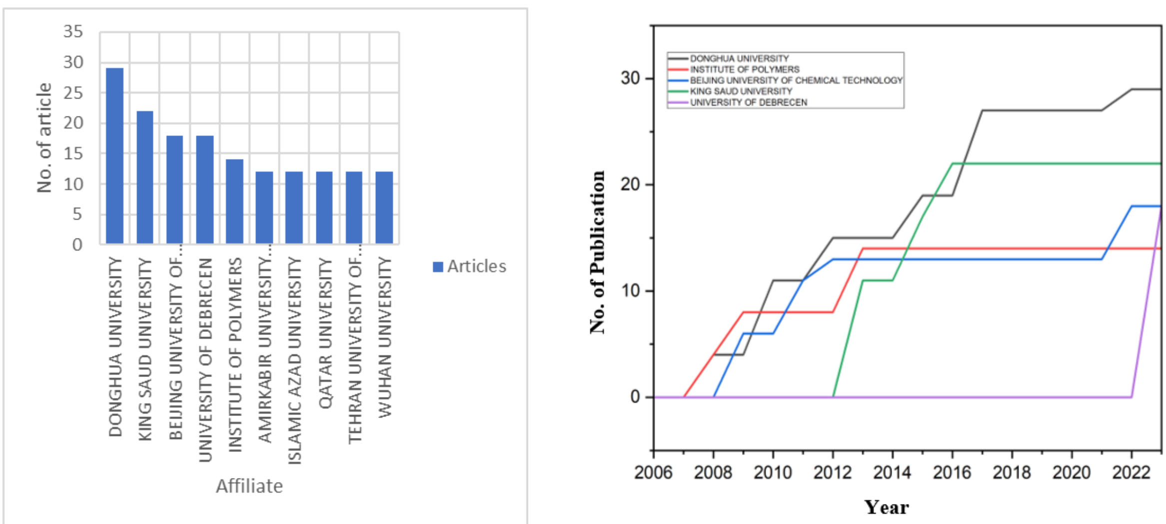


Fig. 4 *Bibliographic coupling cluster of electrospun chitosan for biomedical by country*



(a) **(b)**

Fig. 5 *(a) Institutes with the number of articles; (b) Publication produced by institution from 2006-2023*

3.5 Contribution of Author

The 243 articles had a combined total of 1080 authors. Among them, 15 authors have published more than three articles on electrospun chitosan for biomedical applications. Table 5 reports the top 10 most productive authors. Chen Y (China), Li X (China), Nie J (China), Wang L (China), and Webster Tj (USA) hold the highest H-index of 4, while Webster Tj (USA) has the most cited document which is 490. Following them are Ramakrishna S (India) with 467 total citations, Li X (China) with 283 total citations, and Ignatova M (Russia) with 243 total citations. The analysis shows that most of the authors are from China. Fig. 6 depicts the cooperation network between authors with more than three publications. The analysis reveals that Wang L. (China), has the highest extensive cooperation network, with 43 links and a total link strength of 99. The other authors have a varying number of links, ranging from 10 to 41, and total strengths ranging from 19 to 75.

Table 5 *Top ten authors of publications about electrospun chitosan for biomedical*

Author	H-index	G-index	M-index	TC	NP	PY_start
Chen Y	4	5	0.8	89	5	2019
Li X	4	6	0.25	283	6	2008
Nie J	4	4	0.267	211	4	2009
Wang L	4	5	0.364	177	5	2013
Webster Tj	4	4	0.5	490	4	2016
Deng H	3	3	0.25	182	3	2012
Ignatova M	3	3	0.2	243	3	2009
Manolova N	3	3	0.2	243	3	2009
Nazockdast H	3	3	0.6	78	3	2019
Ramakrishna S	3	4	0.188	467	4	2008

*TC: Total citations, NP: Number of publications, PY: Publication year

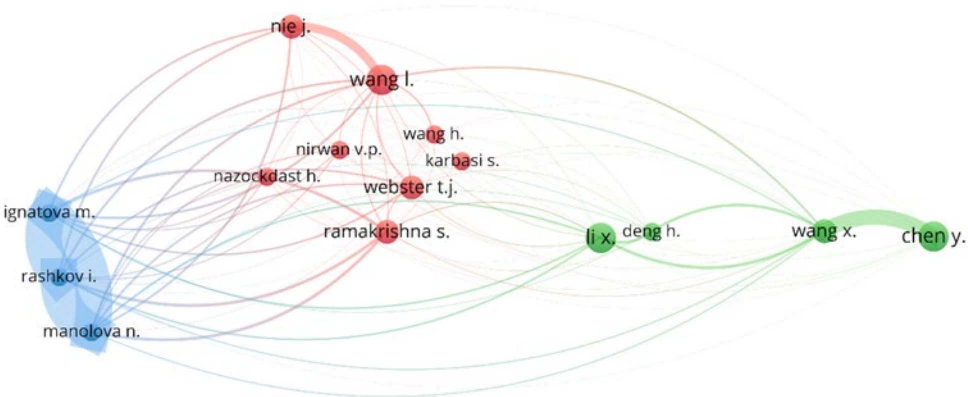
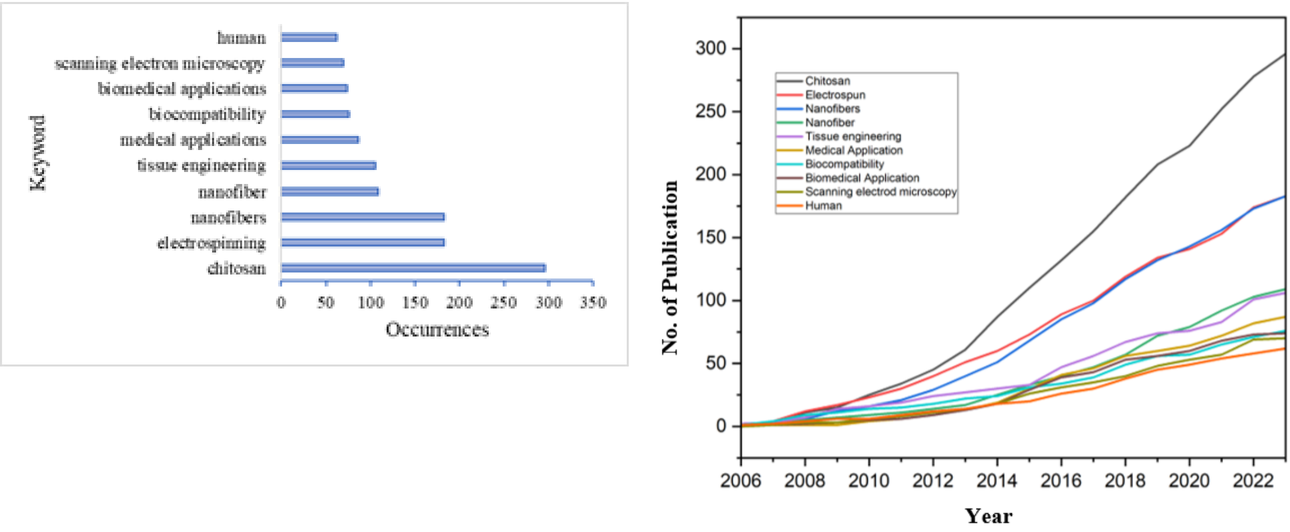


Fig. 6 *Bibliographic coupling cluster of electrospun chitosan for biomedical by authors*

3.6 Keywords Analysis

Keywords reveal the core intentions and outcomes of an article; therefore, a cluster analysis of keywords can offer a glimpse into the current and future research trends. Fig. 7(a) reveals that keywords such as "chitosan," "nanofibers," and "electrospinning" appear frequently, indicating their significance in the realm of electrospun chitosan for biomedicals. These keywords represent three distinct dimensions of research in this field. Moreover, the figure highlights prominent research areas within "electrospun biomedical materials," including "wound healing," "tissue regeneration," "tissue engineering," and "drug delivery," among others. The investigation of nanofibers typically involves extensive focus on preparation processes and property characterization. Fig. 7(b), which illustrates the keyword time-frequency graph. This visualization indicates a significant increase on “chitosan” over time. “nanofibers” come in second as it gradually increases over time. The least popular word is “human” which only appeared 45 times from 2006 to 2022.



(a) (b)

Fig. 7 *Most relevant keywords related to electrospun chitosan in biomedical applications. (a) Occurrences; (b) Frequency from 2006-2023*

3.7 Future Trend

Predicting future trends is a crucial aspect of bibliometric analysis as it enables researchers to focus the prospective relevance of a research domain. In this study, a regression analysis method has been used to forecast future trends over five years, ranging from 2024 to 2028. The selected parameters for forecasting encompass the number of articles produced, publications per country, and publications per affiliation. As illustrated in Fig. 8, the predictive trend indicates a consistent increase in the production of articles over the next five years. Specifically, by 2028, the projected number of articles on electrospun chitosan nanofibers is estimated to reach 30, making up a total of 138 articles in 5 years, affirming the sustained viability and importance of this research domain in the foreseeable future.

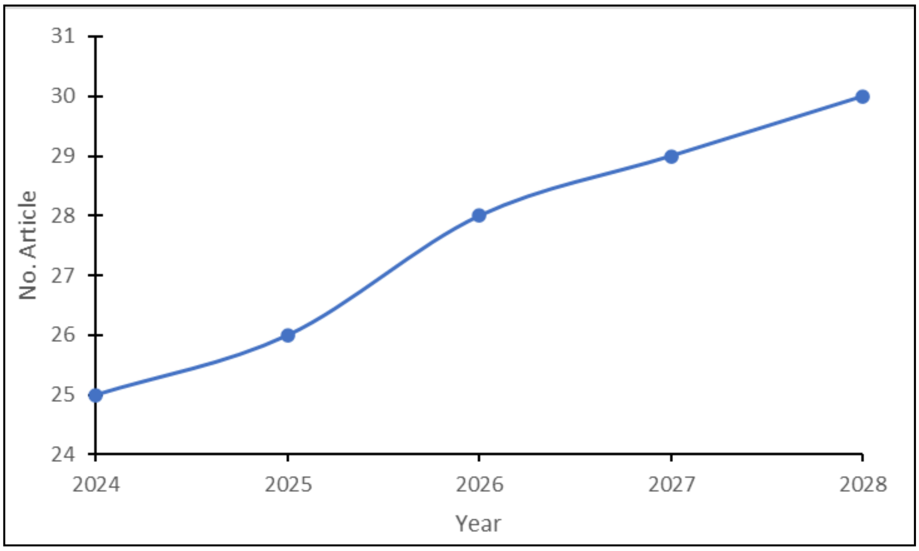


Fig. 8 *Prediction of the number of articles that will be produced from 2024-2028*

From Fig. 9, China maintained as the country projected to contribute the highest number of publications, forecasted at 51 over the upcoming five years. This observation underscores China's persistent focus on biomedical research, particularly within the realm of electrospun nanofibers. Conversely, among the top five countries, Korea and India are anticipated to have the lowest contributions, each totalling 15 publications.

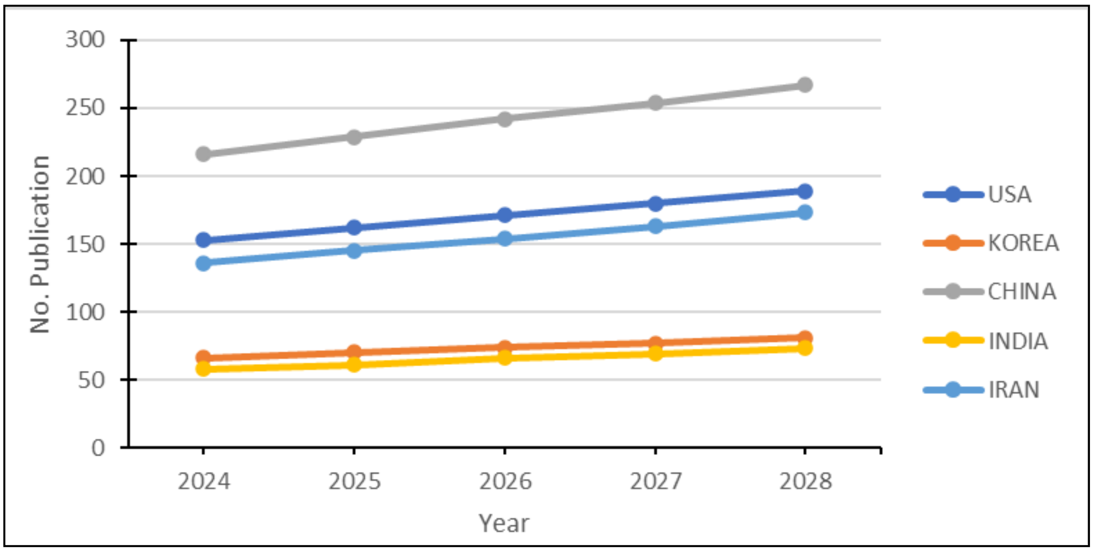


Fig. 9 *Prediction of the number of articles that will be produced by country from 2024-2028*

Fig. 10 delineates the projected publication outputs by affiliations, with Donghua University and King Saud University forecasted to yield the highest number of publications, totalling 7 each on the topic of electrospun nanofibers. In contrast, the University of Debrecen is anticipated to have the lowest publication output, projected at 1 publication over the upcoming five-year period. This data holds immense value for nascent researchers seeking to establish connections and commence their investigations in this specialized domain. These predictive trends not only affirm the sustained relevance of electrospun chitosan nanofibers in biomedical applications but also provide valuable insights for prospective researchers, guiding them in identifying key affiliations and countries that are pivotal in this evolving field.

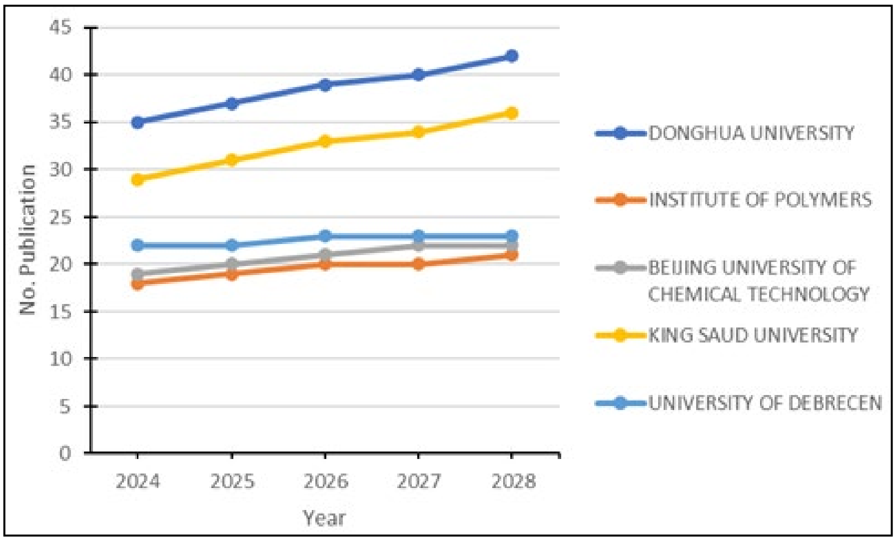


Fig. 10 *Prediction of the number of articles that will be produced by authors affiliated with the respective institutions from 2024-2028*

Predicting popular keywords is crucial for spotting future research trends and ensuring the research's credibility. According to Fig. 11, “chitosan” is expected to remain a significant topic for the next 5 years, possibly leading to 369 publications by 2028, up from the count in 2024. While it is predicted that there were only 16 new publications related to “human”, other keywords such as “tissue engineering”, “medical applications”, “biocompatibility” and “biomedical application” are all within the context of human applications.

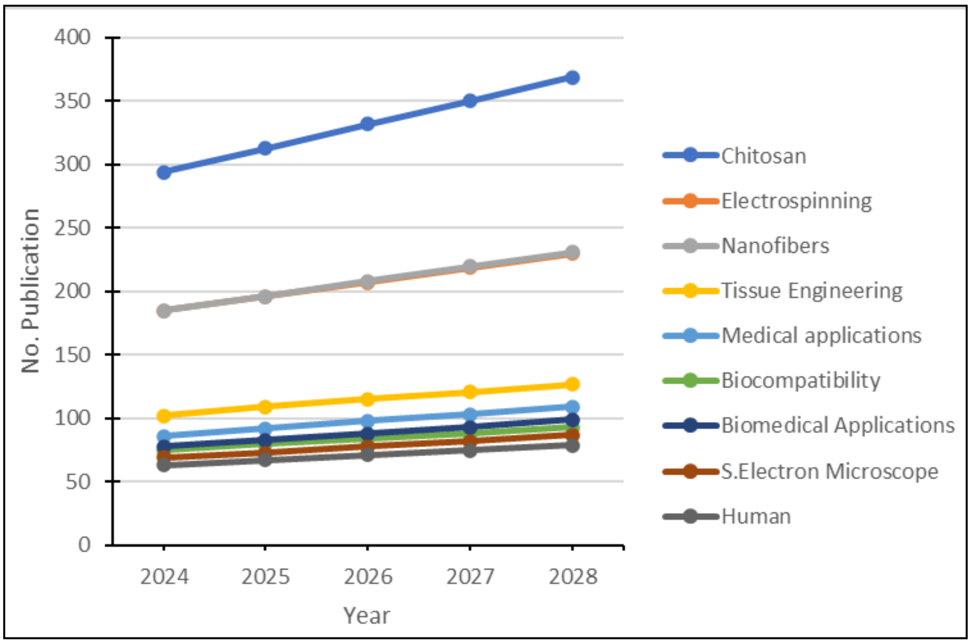


Fig. 11 *Prediction of the most relevant keyword utilised from 2024-2028*

4. Conclusions

The objective of this study is to conduct a comprehensive examination of electrospun chitosan for biomedical applications over the past 16 years using bibliometric analysis. Our main finding indicates that there has been a consistent increase in research publications, signifying a growing interest in electrospun chitosan for biomedical applications. Out of the total publications, the top 10 core journals have contributed 37.67%, with the journal "Carbohydrate Polymers" being the most productive with 1879 citations. In terms of country/region contributions, Iran and China have published the most papers and have the highest h-index. USA, China, Korea, and India have also displayed commendable performance, although there is a large gap between their output compared to Iran and China. Regarding institutes, Donghua University has demonstrated significant strengths in terms of publication quantity. Among authors, Webster Tj stands out as the most prolific, having the highest number of publications and H-index. Meanwhile, Li X which has fewer publications received high G-index. An analysis of keyword frequency reveals that chitosan, nanofibers, electrospinning, and drug delivery are prominent topics in applied research. Furthermore, the keyword analysis of research publications helps us comprehend the shift in research trends from fabrication studies to tissue engineering. Future trend shows promising data as publications for the top 10 countries will steadily increase across the next 5 years with China producing the highest number of publication and Korea and India produce the least amount of publication. "chitosan" keyword is predicted as the most relevant keyword in electrospun chitosan for biomedical while "human" keyword is less popular compared to other keywords.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *M. Asyraf M. Amin, Suhaila Mohd Omar;* ***data collection:*** *M. Huzaifilyasir Kamal Bashah, M. Asyraf M. Amin;* ***analysis and interpretation of results:*** *M. Asyraf M. Amin, Mohd Hamzah Mohd Nasir, Suhaila Mohd Omar;* ***draft manuscript preparation:*** *M. Asyraf M. Amin****,*** *Suhaila Mohd Omar, Wan Kartini Wan Abdul Khodir. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Rasouli, R., Barhoum, A., Bechelany, M., & Dufresne, A. (2019). Nanofibers for biomedical and healthcare applications. Macromolecular bioscience, 19(2), 1800256. https://doi.org/10.1002/mabi.201800256

[2] Hamdan, S., Pastar, I., Drakulich, S., Dikici, E., Tomic-Canic, M., Deo, S. K., ... & Daunert, S. (2017). Nanotechnology-driven therapeutic interventions in wound healing: potential uses and applications. ACS Central Science, 3(3), 163-175. https://doi.org/10.1021/acscentsci.6b00371

[3] Senapati, S., Mahanta, A. K., Kumar, S., & Maiti, P. (2018). Controlled drug delivery vehicles for cancer treatment and their performance. Signal transduction and targeted therapy, 3(1), 7. https://doi.org/10.1038/s41392-017-0004-3

[4] Farzin, L., Saber, R., Sadjadi, S., Mohagheghpour, E., & Sheini, A. (2022). Nanomaterials-based hyperthermia: A literature review from concept to applications in chemistry and biomedicine. Journal of Thermal Biology, 104, 103201. https://doi.org/10.1016/j.jtherbio.2022.103201

[5] Zhang, P., Han, T., Xia, H., Dong, L., Chen, L., & Lei, L. (2022). Advances in Photodynamic Therapy Based on Nanotechnology and Its Application in Skin Cancer. Frontiers in Oncology, 12. https://doi.org/10.3389/fonc.2022.836397

[6] Shaikh, S., Younis, M., & Yuan, L. (2022). Functionalized DNA nanostructures for bioimaging. Coordination Chemistry Reviews, 469, 214648. https://doi.org/10.1016/j.ccr.2022.214648

[7] Webster, T.J & Ahn,E.S. (2006). Nanostructured Biomaterials for Tissue Engineering Bone. Adv Biochem Engin/Biotechnol 103: 275–308. DOI 10.1007/10_021

[8] Abdel-Aziz, H. M. M., Hasaneen, M. N. A., & Omer, A. M. (2019). Impact of engineered nanomaterials either alone or loaded with NPK on growth and productivity of French bean plants: Seed priming vs foliar application. South African Journal of Botany, 125, 102–108. https://doi.org/10.1016/j.sajb.2019.07.005

[9] Abid, M. Bin, Wahab, R. A., Salam, M. A., Gzara, L., & Moujdin, I. A. (2023). Desalination technologies, membrane distillation, and electrospinning, an overview. In Heliyon (Vol. 9, Issue 2). Elsevier Ltd. https://doi.org/10.1016/j.heliyon.2023.e12810

[10] Islam, M. S., Ang, B. C., Andriyana, A., & Afifi, A. M. (2019). A review on fabrication of nanofibers via electrospinning and their applications. SN Applied Sciences, 1(10), 1248. https://doi.org/10.1007/s42452-019-1288-4

[11] Mengistu Lemma, S., Bossard, F., & Rinaudo, M. (2016). Preparation of pure and stable chitosan nanofibers by electrospinning in the presence of poly (ethylene oxide). International journal of molecular sciences, 17(11), 1790. https://doi.org/10.3390/ijms17111790

[12] Long, Y.-Z., Yan, X., Wang, X.-X., Zhang, J., & Yu, M. Electrospinning: The setup and procedure. In Electrospinning: Nanofabrication and Applications; Elsevier: Amsterdam, The Netherlands, 2019; pp. 21–52.

[13] Jalvandi, J., White, M., Gao, Y., Truong, Y. B., Padhye, R., & Kyratzis, I. L. (2017). Polyvinyl alcohol composite nanofibres containing conjugated levofloxacin-chitosan for controlled drug release. Materials Science and Engineering: C, 73, 440-446. https://doi.org/10.1016/j.msec.2016.12.112

[14] Yang, S., Lei, P., Shan, Y., & Zhang, D. (2018). Preparation and characterization of antibacterial electrospun chitosan/poly (vinyl alcohol)/graphene oxide composite nanofibrous membrane. Applied Surface Science, 435, 832-840. https://doi.org/10.1016/j.apsusc.2017.11.191

[15] Arkoun, M., Daigle, F., Heuzey, M. C., & Ajji, A. (2017). Mechanism of action of electrospun chitosan-based nanofibers against meat spoilage and pathogenic bacteria. Molecules, 22(4), 585. https://doi.org/10.3390/molecules22040585

[16] Abdelgawad, A. M., Hudson, S. M., & Rojas, O. J. (2014). Antimicrobial wound dressing nanofiber mats from multicomponent (chitosan/silver-NPs/polyvinyl alcohol) systems. Carbohydrate polymers, 100, 166-178. https://doi.org/10.1016/j.carbpol.2012.12.043

[17] Zhao, R., Li, X., Sun, B., Zhang, Y., Zhang, D., Tang, Z., ... & Wang, C. (2014). Electrospun chitosan/sericin composite nanofibers with antibacterial property as potential wound dressings. International journal of biological macromolecules, 68, 92-97. https://doi.org/10.1016/j.ijbiomac.2014.04.029

[18] Sarhan, W. A., Azzazy, H. M., & El-Sherbiny, I. M. (2016). Honey/chitosan nanofiber wound dressing enriched with Allium sativum and Cleome droserifolia: enhanced antimicrobial and wound healing activity. ACS applied materials & interfaces, 8(10), 6379-6390. https://doi.org/10.1021/acsami.6b00739

[19] Mahmoudi, N., & Simchi, A. (2017). On the biological performance of graphene oxide-modified chitosan/polyvinyl pyrrolidone nanocomposite membranes: In vitro and in vivo effects of graphene oxide. Materials Science and Engineering: C, 70, 121-131. https://doi.org/10.1016/j.msec.2016.08.063

[20] Zhou, X., Wang, H., Zhang, J., Li, X., Wu, Y., Wei, Y., ... & Zhao, Q. (2017). Functional poly (ε-caprolactone)/chitosan dressings with nitric oxide-releasing property improve wound healing. Acta biomaterialia, 54, 128-137. https://doi.org/10.1016/j.actbio.2017.03.011
[21] Rijal, N. P., Adhikari, U., Khanal, S., Pai, D., Sankar, J., & Bhattarai, N. (2018). Magnesium oxide-poly (ε-caprolactone)-chitosan-based composite nanofiber for tissue engineering applications. Materials Science and Engineering: B, 228, 18-27. https://doi.org/10.1016/j.mseb.2017.11.006
[22] Sultana, T., Amirian, J., Park, C., Lee, S. J., & Lee, B. T. (2017). Preparation and characterization of polycaprolactone–polyethylene glycol methyl ether and polycaprolactone–chitosan electrospun mats potential for vascular tissue engineering. Journal of biomaterials applications, 32(5), 648-662. https://doi.org/10.1177/0885328217733849
[23] Semnani, D., Naghashzargar, E., Hadjianfar, M., Dehghan Manshadi, F., Mohammadi, S., Karbasi, S., & Effaty, F. (2017). Evaluation of PCL/chitosan electrospun nanofibers for liver tissue engineering. International Journal of Polymeric Materials and Polymeric Biomaterials, 66(3), 149-157. https://doi.org/10.1080/00914037.2016.1190931
[24] Mahoney, C., Conklin, D., Waterman, J., Sankar, J., & Bhattarai, N. (2016). Electrospun nanofibers of poly (ε-caprolactone)/depolymerized chitosan for respiratory tissue engineering applications. Journal of Biomaterials Science, Polymer Edition, 27(7), 611-625. https://doi.org/10.1080/09205063.2016.1144454
[25] Liang, H., Sheng, F., Zhou, B., Pei, Y., Li, B., & Li, J. (2017). Phosphoprotein/chitosan electrospun nanofibrous scaffold for biomineralization. International journal of biological macromolecules, 102, 218-224. https://doi.org/10.1016/j.ijbiomac.2017.04.022
[26] Wen, P., Zong, M. H., Linhardt, R. J., Feng, K., & Wu, H. (2017). Electrospinning: A novel nano-encapsulation approach for bioactive compounds. Trends in Food Science & Technology, 70, 56-68. https://doi.org/10.1016/j.tifs.2017.10.009
[27] Rad, M. M., Khorasani, S. N., Ghasemi-Mobarakeh, L., Prabhakaran, M. P., Foroughi, M. R., Kharaziha, M., ... & Ramakrishna, S. (2017). Fabrication and characterization of two-layered nanofibrous membrane for guided bone and tissue regeneration application. Materials Science and Engineering: C, 80, 75-87. https://doi.org/10.1016/j.msec.2017.05.125
[28] Shen, R., Xu, W., Xue, Y., Chen, L., Ye, H., Zhong, E., ... & Yan, Y. (2018). The use of chitosan/PLA nano-fibers by emulsion eletrospinning for periodontal tissue engineering. Artificial cells, nanomedicine, and biotechnology, 46(sup2), 419-430. https://doi.org/10.1080/21691401.2018.1458233
[29] Nourmohammadi, J., Ghaee, A., & Liavali, S. H. (2016). Preparation and characterization of bioactive composite scaffolds from polycaprolactone nanofibers-chitosan-oxidized starch for bone regeneration. Carbohydrate polymers, 138, 172-179. https://doi.org/10.1016/j.carbpol.2015.11.055
[30] Sharifi, F., Atyabi, S. M., Norouzian, D., Zandi, M., Irani, S., & Bakhshi, H. (2018). Polycaprolactone/carboxymethyl chitosan nanofibrous scaffolds for bone tissue engineering application. International journal of biological macromolecules, 115, 243-248. https://doi.org/10.1016/j.ijbiomac.2018.04.045
[31] Adeli, H., Khorasani, M. T., & Parvazinia, M. (2019). Wound dressing based on electrospun PVA/chitosan/starch nanofibrous mats: Fabrication, antibacterial and cytocompatibility evaluation and in vitro healing assay. International journal of biological macromolecules, 122, 238-254. https://doi.org/10.1016/j.ijbiomac.2018.10.115
[32] Webster, T. J., & Ahn, E. S. (2007). Nanostructured biomaterials for tissue engineering bone. Tissue engineering II: basics of tissue engineering and tissue applications, 275-308.
[33] Origin pro ver 2022, https://www.originlab.com/origin
[34] Gu, Z.; Gu, L.; Eils, R.; Schlesner, M.; Brors, B. Circlize implements and enhances circular visualization in R. Bioinformatics 2014,30, 2811–2812.
[35] Chen, Y., Yeung, A. W., Pow, E. H., & Tsoi, J. K. (2021). Current status and research trends of lithium disilicate in dentistry: A bibliometric analysis. The Journal of Prosthetic Dentistry, 126(4), 512-522. https://doi.org/10.1016/j.prosdent.2020.08.012