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Research Article

Productivity, Impact, and Collaboration Patterns in Indian Nanocellulose Research for Biomedical Applications: A Bibliometric Perspective

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ABSTRACT

Background/Aim: This study presents a bibliometric analysis of Indian research on nanocellulose for biomedical applications based on 692 Scopus-indexed publications produced between 2010 and 2025. **Methodology:** Data were retrieved from the Scopus database and analysed using key bibliometric indicators, including Total Publications (TP), Total Citations (TC), Citations Per Paper (CPP), authorship patterns, and institutional productivity. Microsoft Excel was used for statistical analysis, while VOSviewer visualised thematic structures and collaboration networks. **Results:** The 692 publications accumulated 23,812 citations (CPP 34.41). While 2010–2018 contributed 13.29% of output, it received 9,333 citations, indicating strong foundational influence. Peak productivity occurred in 2025 (21.53%). Journal articles (46.10%) were the primary output, but review papers (25.00%) attracted the highest citations. Thomas P. Sabu was the most productive author, and Mahatma Gandhi University, Kerala, led in institutional productivity. **Discussion:** Keyword mapping revealed major clusters around nanocellulose materials, characterisation techniques, and biomedical applications such as drug delivery, tissue engineering, and wound healing. **Conclusion:** The analysis identifies significant contributors and thematic hotspots, providing a structured overview to inform subsequent inquiries and policy-level interventions in this evolving domain.

Keywords: Bibliometric Analysis, Biomedical Application, India, Nanocellulose, Research Productivity, Scientometric.

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INTRODUCTION

Nanocellulose has become an extremely beneficial and enduring nanomaterial that entrepreneurs as well as scientists are very interested in because of its unique physical and chemical traits. Nanocellulose comes from natural resources that are easy to find, like wood pulp or agricultural waste, or it can be made by bacteria. There are three main types of nanocellulose: Cellulose Nanocrystals (CNCs), cellulose nanofibers (CNFs), and bacterial nanocellulose (BNC) (Klemm *et al.*, 2011; Moon *et al.*, 2011; Pradeep *et al.*, 2025). These materials have nanoscale dimensions, a large surface area, great mechanical strength, adjustable surface chemistry, and great biocompatibility. Nanocellulose is especially useful in medicine because it is naturally biocompatible, biodegradable, and not very toxic (Lin & Dufresne, 2014). Recent years have seen a rapid increase in research on nanocellulose, especially in areas like drug delivery, wound healing, tissue engineering, biosensing, and antimicrobial coatings (Abitbol *et al.*, 2016; Jorfi & Foster, 2015). It can make hydrogels, films, scaffolds, and nanocomposites, which has opened up new ways to make advanced biomedical materials that work better and have more features (Dufresne, 2013).

Due to the interdisciplinary character and rapidly expanding literature in this domain, a systematic bibliometric analysis is crucial for delineating the scientific landscape, recognizing research trends, and comprehending collaborative dynamics. This methodology can yield significant insights into the progression of research, key contributors, impactful publications, and nascent fields at the intersection of nanocellulose and biomedical applications (Kappi *et al.*, 2021; Madhu *et al.*, 2025). This study seeks to deliver a thorough bibliometric assessment of the worldwide research output concerning nanocellulose in biomedical applications, utilizing data from the Scopus database. The analysis aims to identify significant contributors, collaborative networks, thematic clusters, and research hotspots, providing a structured overview to inform subsequent inquiries in this evolving domain.

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REVIEW OF LITERATURE

Biomedical research using nanocellulose has grown tremendously because it is biocompatible, sustainable, and can be used in many different ways. Bibliometric studies have been essential in delineating its research evolution, emphasizing principal contributors, trends, and thematic advancements. Kappi *et al.*, (2022) performed a comparative bibliometric analysis of nanocellulose research output from India and the global context. Their results showed that publications with more than one author had a bigger impact on research, with 11,700 citations. "Carbohydrate Polymers (UK)" was the most popular journal, publishing 253 articles and having an h-index of 28. Jacinto & Spinacé, (2019) performed a bibliometric analysis of Brazilian research on nanocellulose utilizing Web of Science data, revealing 69 active research groups. Bacterial cellulose became the main source, acid hydrolysis became the most common method, and scanning electron microscopy became the most common way to measure size. "CNPq, CAPES, and FAPESP" were some of the most important funding agencies. Ngasotter *et al.*, (2025) examined global research trends in nanochitin, noting exponential publication growth since 1992, with China and Japan as primary contributors, and emphasizing new applications in food packaging and Pickering emulsions. Zhang *et al.*, (2025) performed a bibliometric analysis of cellulose-based nanomaterials, revealing a significant increase in publications after 2015, especially in the fields of wound healing and drug delivery. Ho *et al.*, (2022) used citation analysis to follow the growth of bacterial nanocellulose research. They found that it grew steadily from 2005 to 2010 and then quickly from 2015 to 2020. Chang *et al.*, (2023) investigated bibliometric trends in nanodrug delivery systems for colorectal cancer, highlighting "colitis" and "exosomes" as pivotal themes in recent developments. Together, these studies make a strong but changing base. This bibliometric study builds on previous work by mapping the intellectual landscape, finding key contributors, and outlining the main themes in nanocellulose and biomedical research India.

OBJECTIVES OF THE STUDY

- To examine the growth trajectory and temporal distribution of Indian research on Nanocellulose for biomedical applications during the period 2010–2025.
- To analyse publication patterns by document type, identifying their respective contributions to research productivity and citation impact.
- To evaluate authorship patterns and collaborative behaviour using bibliometric indicators such as degree of collaboration and collaboration coefficient.
- To identify the most productive and influential authors, and institutions, based on publication output and citation performance.
- To map research themes and knowledge structure through keyword co-occurrence and thematic clustering analysis.
- To examine the extent and nature of national and international collaboration countries in Indian nanocellulose-based biomedical research.
- To highlight emerging trends and research gaps, providing directions for future research and policy-level interventions.

METHODOLOGY

The present study employs a quantitative bibliometric approach to examine Indian research trends in nanocellulose for biomedical applications. Bibliographic data were retrieved from the Scopus database, chosen for its comprehensive coverage of peer-reviewed literature and citation indexing. A systematic search was conducted using relevant keywords and Boolean operators applied to the title, abstract, and keywords, with the following search string:

((TITLE-ABS-KEY("nanocellulose" OR "nano cellulose" OR "cellulose nanocrystals" OR "CNCs" OR "cellulose nanofibers" OR "CNFs" OR "bacterial nanocellulose" OR "nanostructured cellulose" OR "nanofibrillated cellulose" OR "biocellulose") AND TITLE-ABS-KEY("biomedical applications" OR "drug delivery" OR "tissue engineering" OR "wound healing" OR "biosensors" OR "scaffold" OR "regenerative medicine" OR "bioimaging" OR "medical devices" OR "therapeutic applications" OR "biocompatibility" OR "biomaterials" OR "nanomedicine")) AND (EXCLUDE (PUBYEAR,2026)) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (AFFILCOUNTRY,"India"))).

A total of 692 records were downloaded and screened to remove duplicates and irrelevant documents. The cleaned dataset was organized in Microsoft Excel for tabulation and computation of key bibliometric indicators, including Total Publications (TP), Total Citations (TC), Citations Per Paper (CPP), Relative Citation Index (RCI). VOSviewer was used for visualization and network analyses, including co-authorship and country collaborations, and keyword co-occurrence.

Annual Productivity

Table 1 illustrates the year-wise publication productivity of India in nanocellulose research for biomedical applications during 2010–2025, comprising 692 publications that collectively received 23,812 citations, with an overall CPP of 34.41. The formative phase (2010–2013) contributed only 14 publications (2.01%), yet recorded disproportionately high citation impact (CPP ranging from 47.29 to 619.00), indicating influential early Indian studies. The intermediate growth phase (2014–2017) produced 58 publications (8.39%) with consistently high CPP values (75.11–109.50), reflecting consolidation of research quality. A pronounced expansion is evident from 2018 onwards, with 620

Table 1: Annual production of publications and citation performance.

Year	TP	%TP	TC	CCP	Year	TP	%TP	TC	CCP
2010	1	0.14	619	619.00	2019	25	3.61	1719	68.76
2011	3	0.43	30	10.00	2020	51	7.37	2645	51.86
2012	3	0.43	163	54.33	2021	68	9.83	3592	52.82
2013	7	1.01	331	47.29	2022	101	14.60	3605	35.69
2014	8	1.16	876	109.50	2023	87	12.57	1551	17.83
2015	15	2.17	1146	76.40	2024	119	17.20	1050	8.82
2016	9	1.30	676	75.11	2025	149	21.53	317	2.13
2017	26	3.76	2372	91.23	2010-2018	26	13.29	9333	358.96
2018	20	2.89	3120	156.00	2019-2025	600	86.71	14479	24.13
-	-	-	-	-	Grand Total	692	100.00	23812	34.41

TP: Total Publication; **%TP:** Total Percentage; **TC:** Total Citations; **CCP:** Citation Per Publication.

Table 2: Scholarly Document Type.

Document Type	TP	%TP	TC
Article	319	46.10	10121
Review	173	25.00	12655
Book chapter	165	23.84	756
Conference paper	19	2.75	199
Book	12	1.73	56
Erratum	2	0.29	3
Editorial	1	0.14	22
Short survey	1	0.14	0
Grand Total	692	100.00	23812

TP: Total Publication; **%TP:** Total Percentage; **TC:** Total Citations.

publications (89.60%) published during 2018–2025, of which 575 publications (83.09%) appeared between 2020 and 2025 alone. The peak output occurred in 2025 (149 publications; 21.53%), followed by 2024 (119 publications; 17.20%) and 2022 (101 publications; 14.60%). Although the CPP declined sharply from 156.00 in 2018 to 2.13 in 2025, this trend largely reflects citation latency and rapid growth in publication volume. Overall, the statistical pattern indicates a clear shift in Indian research from a low-volume, high-impact exploratory stage to a high-volume, maturing research phase in nanocellulose-based biomedical applications.

Document Classification

Table 2 shows the document-wise distribution of Indian publications on nanocellulose in biomedical applications, totaling 692 records with 23,812 citations. Journal articles dominate the output (319; 46.10%) and account for 10,121 citations, reflecting their primary role in reporting original research. Review articles, comprising 173 publications (25.00%), received the highest citation count (12,655 citations), indicating their strong scholarly influence in consolidating and guiding research in this field. Book chapters represent 23.84% of the output but attracted relatively fewer citations, while other document types such as conference papers, books, and editorials contribute marginally. Overall, the distribution highlights the prominence of articles in productivity and the exceptional citation impact of review literature in Indian nanocellulose-based biomedical research.

Authorship Pattern

Table 3 illustrates the authorship pattern of Indian publications on nanocellulose in biomedical applications, based on 692 publications that received 23,812 citations, and clearly indicates the predominance of collaborative research. Single-authored papers are very limited (20; 2.89%; 842 citations), whereas a substantial share of the output is concentrated in three-author (128; 18.50%), four-author (106; 15.32%), and two-author (105; 15.17%) contributions. Papers authored by five to eight researchers account for 250 publications (36.12%), with particularly high citation impact observed for eight-authored papers (3,582 citations). The presence of Mega-Authored Papers (10; 1.45%) further reflects instances of extensive collaboration. This dominance of multi-authored work is substantiated by a high Collaboration Co-efficient (CC) of 0.971, computed using the formula proposed by Subramanyam (1983), confirming that Indian research in this field is predominantly team-oriented and collaborative in nature.

Top Authors

Analysis of author contributions in nanocellulose research for biomedical applications reveals distinct patterns of productivity and impact. Among 2,629 authors, 46 authors with five or more publications contributed 358 papers (51.73% of total output) and 16,496 citations. Thomas P. Sabu (Mahatma Gandhi University, Kerala, India) stands out as both the most productive and most impactful author, with 38 publications, 2,392 citations, a CPP

Table 3: Authorship Pattern.

Authors	TP	%TP	TC	CC
SA	20	2.89	842	0.971
2	105	15.17	3815	
3	128	18.50	4065	
4	106	15.32	2615	
5	83	11.99	2907	
6	67	9.68	2009	
7	66	9.54	1474	
8	34	4.91	3582	
9	30	4.34	902	
10	23	3.32	561	
11	10	1.45	340	
12	10	1.45	286	
MAP	10	1.45	414	
Grand Total	692	100.00	23812	

TP: Total Publication; **%TP:** Total Percentage; **TC:** Total Citations; **SA:** Single-Author; **MAP:** Mega-authored Papers; **CC:** Collaboration Co-efficient.

of 62.95, and an RCI of 1.37. Other highly productive authors include Ashok Pandey (13 publications; CPP = 46.23; RCI = 1.00), R. Reshmy (13 publications; CPP = 37.69; RCI = 0.82), R. A. Ilyas (12 publications; CPP = 45.58; RCI = 0.99), Binod G. Parameswaran (11 publications; CPP = 44.82; RCI = 0.97), and Eapen Philip (11 publications; CPP = 42.73; RCI = 0.93), reflecting sustained scholarly output (Table 4).

From an impact perspective, several authors exhibit exceptionally high citation intensity despite relatively modest productivity. These include Vijay Kumar Thakur (5 publications; 753 citations; CPP = 150.60; RCI = 3.27), Hanieh Kargarzadeh (5 publications; 710 citations; CPP = 142.00; RCI = 3.08), Laly A. Pothan (6 publications; 725 citations; CPP = 120.83; RCI = 2.62), and Deepu A. Gopakumar (8 publications; 628 citations; CPP = 78.50; RCI = 1.70). Collectively, these authors contributed 24 publications but received 2,816 citations, indicating a highly concentrated citation impact. Ashok Pandey also features among the top impactful authors, highlighting both consistent productivity and scholarly influence (Table 4).

Table 4: Top productive and impactful authors.

Top 6 six productive authors						
Sl. No.	**Author**	**Affiliation**	**TP**	**TC**	**CCP**	**RCI**
1	Thomas P Sabu	Mahatma Gandhi University, Kerala, India	38	2392	62.95	1.37
2	Ashok Pandey	Indian Institute of Toxicology Research, Uttar Pradesh, India	13	601	46.23	1.00
3	R Reshmy	Providence College of Engineering, Kerala, India	13	490	37.69	0.82
4	R. A. Ilyas	Universiti Teknologi Malaysia, Johor, Malaysia	12	547	45.58	0.99
5	Binod G Parameswaran	National Institute for Interdisciplinary Science and Technology, Kerala, India	11	493	44.82	0.97
6	Eapen Philip	Bishop Moore College, Kerala, India	11	470	42.73	0.93
Top 6 six impactful authors						
Sl. No.	**Author**	**Affiliation**	**TP**	**TC**	**CCP**	**RCI**
1	Thomas P Sabu	Mahatma Gandhi University, Kerala, India	38	2392	62.95	1.37
2	Vijay Kumar Thakur	University of Petroleum and Energy Studies, Uttarakhand, India	5	753	150.60	3.27
3	Laly A Pothan	Mahatma Gandhi University, Kerala, India	6	725	120.83	2.62
4	Hanieh Kargarzadeh	Institute - Center for Molecular and Macromolecular Studies of the Polish Academy of Sciences, Lodz, Poland	5	710	142.00	3.08
5	Deepu A Gopakumar	Cochin University of Science and Technology, Kerala, India	8	628	78.50	1.70
6	Ashok Pandey	Indian Institute of Toxicology Research, Uttar Pradesh, India	13	601	46.23	1.00

TP: Total Publication; **TC:** Total Citations; **CCP:** Citation Per Publication: **RCI:** Relative Citation Index.

The co-authorship network groups 22 authors into four distinct clusters, reflecting collaborative patterns in Indian nanocellulose research for biomedical applications. Cluster 1 (red), the largest group with eight authors such as Chirayil, Cintil Jose; Gopakumar, Deepu A.; Grohens, Yves; Kalarikkal, Nandakumar; Kargarzadeh, Hanieh; Pasquini, Daniel; Pothan, Laly A.; and Sabu, Thomas P. indicates a well-established and closely connected research team. Cluster 2 (green) includes seven authors such as Awasthi, Mukesh Kumar; Madhwa, Aryan D.; Pandey, Ashok; Parameswaran, Bindu G.; Philip, Eapen; Reshmy, R.; and Sindhu, Ravendran suggesting another active collaborative group. Cluster 3 (blue) comprises four authors of Li, Xingping; Maji, Pradip K.; Saini, V.; and Yadav, Chandravati such as representing a smaller yet cohesive partnership. Cluster 4 (yellow), with three authors—Dalvi, Yogesh B.; Mathew, Tiju Joseph; and Unni, Rekha such as reflects an emerging collaborative unit. These clusters demonstrate the presence of focused research groups contributing to the development of nanocellulose applications in the biomedical domain (Figure 1).

Top Affiliations

Of the 1,619 organizations identified in the dataset, 48 institutions meet the threshold of five or more publications. As shown in Table 5, the top 40 affiliations collectively produced 441 publications, accounting for 63.73% of the total research output, and received 19,290 citations. In contrast, the remaining 251 publications, representing 36.27% of the output, accounted for 23,812 citations. In terms of research productivity, Mahatma Gandhi University, Kerala, India ranks first, contributing 43 publications and receiving 4,116 citations, with a CPP of 95.72. This is followed by the Indian Institute of Technology Roorkee, Roorkee, UK, India (29 publications; 953 citations; CPP = 32.86), Academy of Scientific and Innovative Research (ACSIR), Uttar Pradesh, India (18 publications; CPP = 27.78), Bishop Moore College, Kerala, India (18 publications; CPP = 81.17), Chandigarh University, Punjab, India (18 publications; CPP = 12.06), and the Indian Institute of Technology, New Delhi, India (17 publications; CPP = 34.94), reflecting sustained institutional productivity.

In terms of impact perspective, several institutions exhibit exceptionally high citation intensity despite relatively modest publication counts. The Centre of Innovative and Applied Bioprocessing, Mohali, Punjab, India leads in citation impact with a CPP of 175.33 from six publications, followed by the Institute – Centre for Molecular and Macromolecular Studies of the Polish Academy of Sciences, Lodz, Poland (CPP = 142.00; five publications) and Newman College, Kerala, India (CPP = 125.77; 13 publications). The Shiv Nadar Institution of Eminence

Table 5: Top productive and impactful affiliation.

Top 6 Productive Affiliations				
Sl. No.	**Authors**	**TP**	**TC**	**CCP**
1	Mahatma Gandhi University, Kerala, India	43	4116	95.72
2	Indian Institute of Technology Roorkee, Roorkee, UK, India	29	953	32.86
3	Academy Of Scientific and Innovative Research (ACSIR), UP, India	18	500	27.78
4	Bishop Moore College, Kerala, India	18	1461	81.17
5	Chandigarh University, PB, India	18	217	12.06
6	Indian Institute of Technology, New Delhi, India	17	594	34.94
Top 6 Impactful Affiliations				
Sl. No.	**Authors**	**TP**	**TC**	**CCP**
1	Centre of Innovative and Applied Bioprocessing, Mohali, PB, India	6	1052	175.33
2	Institute - Centre for Molecular and Macromolecular Studies of The Polish Academy of Sciences, Lodz, Poland	5	710	142.00
3	Newman College, Kerala, India	13	1635	125.77
4	Shiv Nadar Institution of Eminence Deemed to Be University, Greater Noida, UP, India	6	682	113.67
5	Mahatma Gandhi University, Kerala, India	43	4116	95.72
6	Bishop Moore College, Kerala, India	18	1461	81.17

TP: Total Publication; **TC:** Total Citations; **CCP:** Citation Per Publication.

Deemed to Be University, Greater Noida, Uttar Pradesh, India (CPP = 113.67; six publications) also demonstrates high-impact research performance, substantially exceeding the overall average CPP of 43.74 observed among the top 40 affiliations.

Top Leading Countries

Table 6 presents a comparative assessment of country-wise research performance in nanocellulose for biomedical applications, revealing marked disparities between publication output, citation impact, and collaboration strength. India dominates in terms of productivity with 692 publications, accounting for 50.87% of the total output, yet attains a comparatively modest citation impact (TC = 23,812; CPP = 34.41; TLS = 433), contributing only 17.91% of total citations. In contrast, the top 15 contributing countries collectively produced 340 publications (49.13%) but garnered a substantially higher citation share of 82.09% (TC = 19,548; CPP = 57.49; TLS = 756), underscoring stronger research influence and international collaboration. Among individual countries, the United States leads in publication output (TP = 49; TC = 1,763; CPP = 35.98; TLS = 96), followed closely by Malaysia (TP = 44; CPP = 43.84; TLS = 103) and South Korea (TP = 38; CPP = 40.58; TLS = 78). China (CPP = 50.09) and the United Kingdom (CPP = 61.05) demonstrate balanced performance in both output and impact, while France (CPP = 141.83), Brazil (CPP = 139.62), and Canada (CPP = 126.05) stand out for exceptionally high citation intensity despite relatively lower publication counts.

The analysis revealed five distinct clusters comprising 15 countries. Cluster 1 (red) includes China, India, Saudi Arabia, and South Korea, indicating strong research activity from Asian countries with growing and established contributions in nanocellulose-based biomedical research. Cluster 2 (green), consisting of Australia, Indonesia, and Malaysia, reflects collaborative research efforts from Oceania and Southeast Asia, particularly in biomaterials and medical applications. Cluster 3 (blue) comprises Canada, Sweden, and the United Kingdom, countries well known for advanced research infrastructure and significant contributions to nanocellulose development and biomedical innovations. Cluster 4 (yellow) includes Taiwan, Thailand, and the United States, representing a mix of Asian and North American leadership in nanotechnology-driven biomedical research. Finally, Cluster 5 (purple), consisting of Brazil and France, highlights contributions from South America and Europe, forming a smaller yet important cluster in the global research landscape of nanocellulose and its biomedical applications (Figure 2).

Top 15 Cited Works

The top 15 cited papers (Table 7) demonstrate that review articles and methodological studies have played a crucial role in shaping

Table 6: Top 15 leading countries collaboration with India.

Sl. No.	Country Name	TP	TC	CCP	TLS
1	United States	49	1763	35.98	96
2	Malaysia	44	1929	43.84	103
3	South Korea	38	1542	40.58	78
4	China	35	1753	50.09	73
5	Saudi Arabia	28	611	21.82	63
6	United Kingdom	21	1282	61.05	48
7	Canada	19	2395	126.05	40
8	France	18	2553	141.83	44
9	Australia	16	628	39.25	44
10	Indonesia	14	751	53.64	33
11	Brazil	13	1815	139.62	26
12	Sweden	12	498	41.50	26
13	Taiwan	12	396	33.00	33
14	Thailand	11	773	70.27	25
15	Iran	10	859	85.90	24
	Grand total of top 15 countries	340	19548	57.49	756
	Grand total of Indian Publications	692	23812	34.41	
	Share of top 15 countries	49.13	82.09		
	Total Share of India	50.87	17.91		

TP: Total Publication; **TC:** Total Citations; **CCP:** Citation Per Publication: **TLS:** Total Link Strength.

Table 7: Top-cited papers.

Sl. No.	Authors	Title	Journal	Year	TC
1	Thomas, B., Raj, M.C., B, A.K., Joy, J., Moores, A., Drisko, G.L. and Sanchez, C.,	Nanocellulose, a versatile green platform: from biosources to materials and their applications.	Chemical reviews	2018	1402
2	George, J. and Sabapathi, S.N.,	Cellulose nanocrystals: synthesis, functional properties, and applications.	Nanotechnology, science and applications	2015	835
3	Sharma, A., Thakur, M., Bhattacharya, M., Mandal, T. and Goswami, S.,	Commercial application of cellulose nano-composites–A review.	Biotechnology Reports	2019	675
4	Cherian, B.M., Leão, A.L., De Souza, S.F., Thomas, S., Pothan, L.A. and Kottaisamy, M.,	Isolation of nanocellulose from pineapple leaf fibres by steam explosion.	Carbohydrate polymers	2010	619
5	Kargarzadeh, H., Mariano, M., Gopakumar, D., Ahmad, I., Thomas, S., Dufresne, A., Huang, J. and Lin, N.,	Advances in cellulose nanomaterials.	Cellulose	2018	447
6	Kalia, S., Boufi, S., Celli, A. and Kango, S.,	Nanofibrillated cellulose: surface modification and potential applications.	Colloid and Polymer Science	2014	418
7	Rana, A.K., Frollini, E. and Thakur, V.K.,	Cellulose nanocrystals: Pretreatments, preparation strategies, and surface functionalization.	International Journal of Biological Macromolecules	2021	352
8	Mondal, S.,	Preparation, properties and applications of nanocellulosic materials.	Carbohydrate polymers	2017	346
9	Joseph, B., Sagarika, V.K., Sabu, C., Kalarikkal, N. and Thomas, S.,	Cellulose nanocomposites: Fabrication and biomedical applications.	Journal of Bioresources and Bioproducts	2020	341
10	Sharma, R., Jafari, S.M. and Sharma, S.,	Antimicrobial bio-nanocomposites and their potential applications in food packaging.	Food control	2020	338
11	Mishra, R.K., Sabu, A. and Tiwari, S.K.,	Materials chemistry and the futurist eco-friendly applications of nanocellulose: Status and prospect.	Journal of Saudi Chemical Society	2018	335
12	Nagarajan, K.J., Ramanujam, N.R., Sanjay, M.R., Siengchin, S., Surya Rajan, B., Sathick Basha, K., Madhu, P. and Raghav, G.R.,	A comprehensive review on cellulose nanocrystals and cellulose nanofibers: Pretreatment, preparation, and characterization.	Polymer Composites	2021	301
13	Zinge, C. and Kandasubramanian, B.,	Nanocellulose based biodegradable polymers.	European Polymer Journal	2020	258
14	Koul, B., Poonia, A.K., Yadav, D. and Jin, J.O.,	Microbe-mediated biosynthesis of nanoparticles: Applications and future prospects.	Biomolecules	2021	252
15	Khawas, P. and Deka, S.C.,	Isolation and characterization of cellulose nanofibers from culinary banana peel using high-intensity ultrasonication combined with chemical treatment.	Carbohydrate polymers	2016	232

Indian research on nanocellulose for biomedical applications. The most cited work by Thomas *et al.* (2018), published in *Chemical Reviews* with 1,402 citations, presents nanocellulose as a sustainable and versatile material platform. Other highly cited reviews by George and Sabapathi (2015) and Sharma *et al.* (2019) focus on the synthesis, properties, and applications of cellulose nanomaterials. Several influential studies emphasize extraction techniques and surface modification methods, notably Cherian *et al.* (2010) and Kalia *et al.* (2014), which provided essential methodological foundations for subsequent biomedical research. Contributions by Joseph *et al.* (2020) and Sharma *et al.* (2020) highlight the expanding application of nanocellulose in biomedical and antimicrobial contexts. The prominence of journals such as *Chemical Reviews*, *Carbohydrate Polymers*, and *Cellulose* further reflects the interdisciplinary character of this research. Collectively, these highly cited works establish the conceptual and methodological basis supporting biomedical applications of nanocellulose.

Top Keywords

Table 8 highlights the dominant thematic orientation of Indian research on nanocellulose for biomedical applications through keyword frequency and network connectivity. Core material-centric terms such as *Nanocellulose* (Occ. 294; TLS 6446) and *Cellulose* (Occ. 285; TLS 6789) exhibit the highest occurrences and link strengths, indicating their central conceptual role in the research network. Strong emphasis on biological suitability is evident from highly connected terms like *Biocompatibility* (Occ.

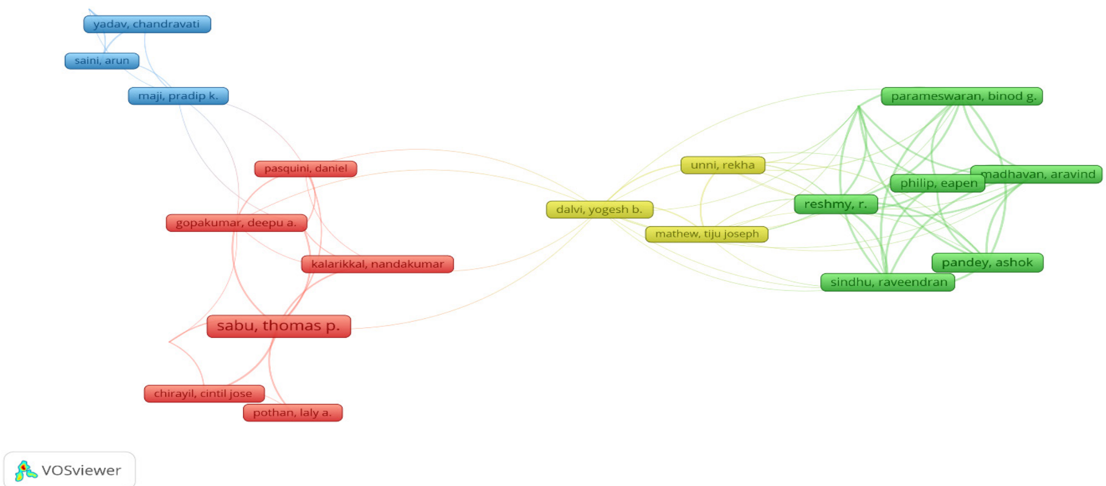

Figure 1: Authorship Collaboration.

Table 8: Trending Keywords.

Keyword	Occ.	TLS	keyword	Occ.	TLS
Nanocellulose	294	6446	Chitosan	48	1670
Cellulose	285	6789	Antimicrobial Activity	36	1300
Biocompatibility	182	4564	Cytotoxicity	35	1415
Nano-Cellulose	149	3082	Hydrogels	35	758
Nanocomposites	110	2378	Drug Release	34	1143
Fourier Transform Infrared Spectroscopy	105	3000	Antibacterial Activity	33	1373
Scanning Electron Microscopy	100	2944	Cell Proliferation	32	1226
Tissue Engineering	84	2496	Cell Viability	31	1331
Drug Delivery System	81	2504	Morphology	29	709
Controlled Drug Delivery	76	1598	Porosity	28	966
Biomedical Applications	69	1467	Bacterial Nanocellulose	22	615
Scaffolds (Biology)	63	1656	Polyvinyl Alcohol	21	727
Wound Healing	56	1854	Mechanical Properties	19	356
Biomaterials	54	1883	Regenerative Medicine	10	377
Cellulose Nanofibers	53	1267	X-Ray Diffraction	9	255

Occ.-Occurrences; **TLS:** Total Link Strength.

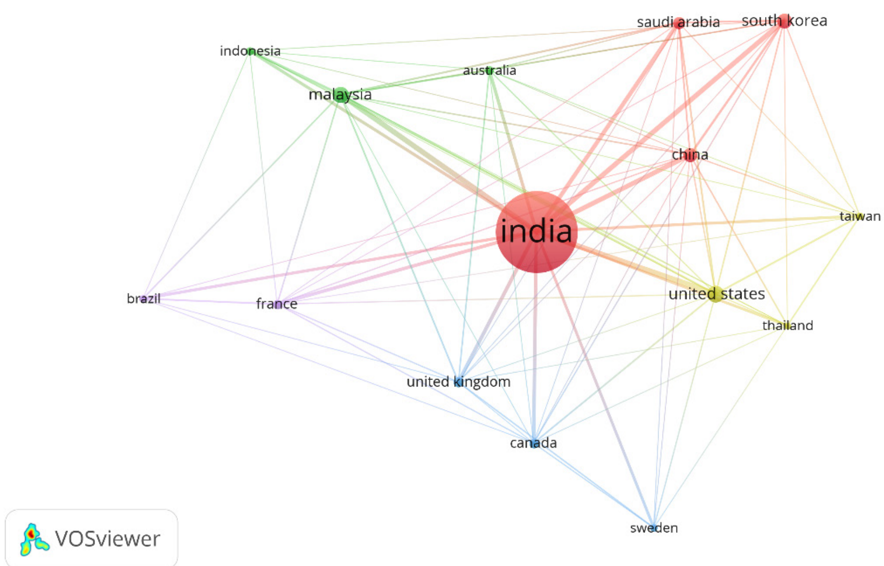

Figure 2: Collaborative Countries.

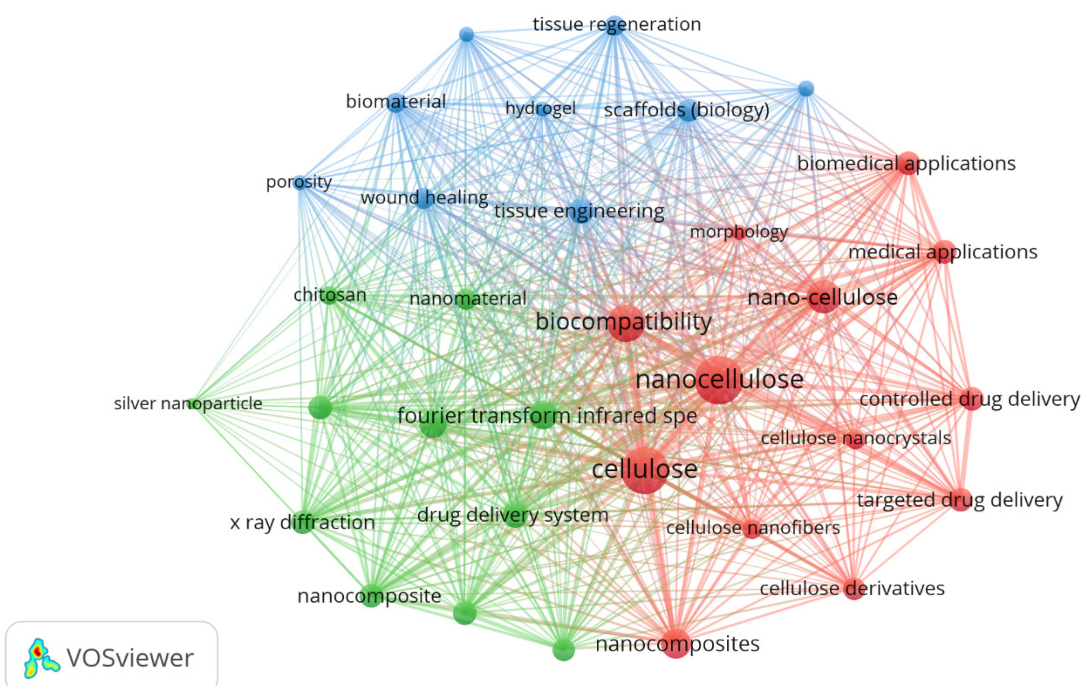

Figure 3: Top Keywords.

182; TLS 4564), *Tissue Engineering* (Occ. 84; TLS 2496), *Wound Healing* (Occ. 56; TLS 1854), and *Scaffolds* (Occ. 63; TLS 1656), reflecting the translational focus towards regenerative medicine.

The VOS viewer keyword co-occurrence map illustrates the conceptual structure of Indian research on Nanocellulose for biomedical applications through three prominent thematic clusters (Figure 3). The cluster 1 *(red)* centres on Nanocellulose (Occ.-294; TLS-6446), cellulose (Occ.-285; TLS-6789), nano-cellulose (Occ.-149; TLS-3082), cellulose nanofibers (Occ.-53; TLS-1267), and cellulose nanocrystals (Occ.-43; TLS-1209), closely linked with controlled drug delivery (Occ.-76; TLS-1598), targeted drug delivery (Occ.-71; TLS-1550), and biomedical applications (Occ.-69; TLS-1467), indicating a strong emphasis on material development for therapeutic delivery systems. The cluster 2 *(green)* groups characterization and composite-related terms such as Fourier Transform Infrared Spectroscopy (Occ.-105; TLS-300), X-ray diffraction (Occ.-9; TLS-255), nanocomposite (Occ.-71; TLS-2209), chitosan (Occ.-48; TLS-1670), and silver nanoparticle (Occ.-18; TLS-613), reflecting the focus on physicochemical analysis and hybrid material formation to enhance functional performance. The cluster 3 *(blue)* is dominated by application-oriented terms including biocompatibility (Occ.-182; TLS-4564), tissue engineering (Occ.-84; TLS-2496), wound healing (Occ.-56; TLS-1854), scaffolds (biology) (Occ.-63; TLS-1656), hydrogel (Occ.-32; TLS-1116), and biomaterial (Occ.-54; TLS-1883), highlighting the translational orientation toward regenerative medicine. Dense interlinkages among clusters, particularly around biocompatibility and nanocellulose, demonstrate strong integration between material characterization, composite development, and biomedical application domains, confirming the interdisciplinary and application-driven nature of this research field.

DISCUSSION

The scientometric evidence indicates a distinct progression in Indian research on nanocellulose for biomedical applications from an initial phase of limited but highly influential studies to a recent phase characterized by substantial growth in publication output. During 2010–2018, only 92 publications (13.29%) were produced; however, these works received 9,333 citations with a notably high CPP of 358.96, underscoring the foundational contribution of early investigations. In contrast, the period 2019–2025 accounts for 600 publications (86.71%) with a CPP of 24.13, reflecting rapid expansion in research activity and the effect of citation latency associated with recent publications. The highest annual productivity is observed in 2025 (149 publications; 21.53%), followed by 2024 and 2022.

The document-type distribution shows that journal articles (46.10%) form the primary channel of research dissemination, while review articles (25.00%) account for the largest share of citations (12,655), indicating their significant role in consolidating knowledge and guiding subsequent studies. The authorship pattern demonstrates a strong collaborative culture, supported by a high Collaboration Co-efficient of 0.971 and the predominance of multi-authored papers, particularly those involving three to eight authors. Co-authorship network analysis further reveals four coherent author clusters comprising 22 key contributors, reflecting structured and sustained research collaborations.

Institutional analysis highlights that the top 40 affiliations contribute 63.73% of the total publications, with Mahatma Gandhi University emerging as the leading contributor in both productivity (43 publications) and impact (CPP = 95.72). Several institutions with fewer publications exhibit exceptionally high CPP values, indicating focused research excellence. Although India contributes 50.87% of the total global publications in this domain, its share of citations (17.91%) suggests the need for broader international engagement to enhance research visibility and impact.

Highly cited papers are predominantly reviewed and methodological studies published in reputed journals such as *Chemical Reviews*, *Carbohydrate Polymers*, and *Cellulose*, which have established the conceptual and technical foundation for biomedical applications of nanocellulose. The keyword co-occurrence and network visualization analyses identify three interrelated thematic clusters linking nanocellulose materials, physicochemical characterization techniques (e.g., FTIR, SEM, XRD), composite development, and application areas including drug delivery, tissue engineering, scaffolds, hydrogels, and wound healing. The close interconnections among these themes demonstrate that Indian research in this field is interdisciplinary in nature and increasingly oriented toward translational biomedical applications.

CONCLUSION

This bibliometric assessment of 692 Scopus-indexed publications (2010–2025) demonstrates the steady evolution and growing maturity of Indian research on nanocellulose for biomedical applications. Early contributions, though limited in volume, exerted high citation influence and established the foundational concepts of the field, while the sharp rise in publications after 2019 peaking in 2024-2025 reflects expanding research capacity and sustained scholarly interest. Journal articles account for the majority of output, whereas review papers achieve greater citation impact, underscoring the complementary roles of experimental research and knowledge consolidation. The high Collaboration Coefficient (0.971) and clustered co-authorship networks highlight the strongly collaborative nature of this domain, with a small number of institutions contributing disproportionately to output and citation impact, indicating focused research excellence. Although India leads globally in publication volume, its relatively lower citation shares points to the need for enhanced international collaboration, improved research visibility, and stronger engagement with global research networks. The thematic landscape reveals an integrated research focus spanning nanocellulose synthesis, characterization, composite fabrication, and biomedical applications such as drug delivery, tissue engineering, hydrogels, scaffolds, and wound healing. Future research should prioritize translational and application-oriented studies, including clinical validation, biocompatibility and safety assessment, standardization and scalability of fabrication processes, regulatory alignment, and the development of advanced functionalized nanocellulose systems through interdisciplinary and international collaborations to strengthen global impact.

ABBREVIATIONS

TP: Total Publication; **%TP:** Total Percentage; **TC:** Total Citations; **RCI:** Relative Citation Index; **SA:** Single-Author; **MAP:** Mega-authored Papers; **CC:** Collaboration Co-efficient; **Occ.**-Occurrences; **TLS:** Total Link Strength.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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