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Original Article

Comparative Mapping of World and Indian Nanocellulose Research Output during the last Decade: A Scientometric Study

Mallikarjun Kappi[1], Murthy Chavali[2], Chaman Sab M[3], KK Mueen Ahmed[4,*]

[1]Government First Grade College, Jagalur, Davanagere, Karnataka, INDIA.
[2]Office of the Dean (Research) and Division of Chemistry, Department of Sciences, Faculty of Sciences and Technology, Alliance University, Bengaluru, Karnataka, INDIA.
[3]A.R.G. College of Arts and Commerce, Davanagere Karnataka, INDIA.
[4]Phcog.Net, No. 9, Vinnse Tower, Wheeler Road Extension, St. Thomas Town, Bangalore, Karnataka, INDIA.

ABSTRACT

Aim: The present study aims to trace out the comparative mapping of World and Indian Nanocellulose research output. **Methodology:** The Science Citation Index (SCI) of Web of Science (WoS) core collection was used data extraction of World and Indian Nanocellulose publications in the last ten years. The study was included the year wise research productivity of the World and India, Authorship pattern, Degree of Collaboration (DC), Collaboration Index (CI), most preferred sources, prolific authors, organizations, countries and keywords. MS excel, VOSViewer and R software package were used for tabulation and mapping. **Results:** A total of 3458 documents consisting of journal articles 3062, review papers 238, etc. The study reflects that Authors of multi-authored documents have more research impact with 11700 citations. The topmost preferred journal was Carbohydrate Polymers (UK) published 253 publications with a 28-*h* index. The most productive author was Wang X, Linkoping University, Sweden contributed 28 publications with 846 citations and *h* index value of 11.

Key words: Nanocellulose research output, Scientometric, International collaboration, VOSviewer, Web of Science.

Correspondence

Dr. KK Mueen Ahmed,
Phcog.Net, No. 9, Vinse Towers, Wheeler Road Extension, St. Thomas Town, Bangalore- 560084, Karnataka, INDIA.

Email id: mueen.ahmed@gmail.com

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INTRODUCTION

Nanocellulose is a cellulose-based nanomaterial, which is sustainable and has great innovation potential.[1-4] Nanocellulose has become a research field in many countries, including the world's leading cellulose producers such as the United States, Canada, Finland, Sweden, and Brazil.[4] Nanocellulose research involves different disciplines since its properties and behaviours have made it possible to use it as reinforcing agents in composite materials, packaging materials, transparent optical paper for electronic devices, deforming agents in cosmetics and food and bio-artificial implants and bandages.[1-3,5,6]

Nanocellulose is a general term that refers to cellulose nanofibrils and cellulose nanocrystals.[3,5,7] The main difference between the two celluloses in nanoscale size is the degree of crystallinity, which affects the mechanical and functional properties of the final product.[2,3,8] There are several cell species grown in nanocellulose biomaterials such as hydrogels, sponges, electrospun nanofibers, composites and membranes.[9] Cellulose nanocrystals are shorter rod-shaped crystalline cellulose, while cellulose nanofibrils are alternating long chains of amorphous and crystalline cellulose. Both types of nanocellulose can be obtained from renewable resources, including natural fibres, plants, pulp and forests, and agricultural residues. In this case, mechanical methods and chemical/enzymatic methods are used to obtain cellulose nanofibrils and cellulose nanocrystals, respectively. Furthermore, cellulose nanocrystals can be biosynthesized by bacteria and are therefore also called bacterial cellulose.[3-5]

Examining nanocellulose-related research topics can provide insights into today's technical challenges for nanomaterial, such as increasing production scale to minimize costs, characterizing sources, and mechanical properties. Surface modification to reduce water absorption and improve adhesion between nanomaterials and the polymeric matrix, thermal degradation, and biocompatibility with tissues has also become research objectives.[10,11] studied the bibliometric analysis and visualization of research trends on nanocellulose and its use in medical engineering using the Scopus database during 2006 – 2021. The study identifies the highly productive author, country citation analysis and co-authorship pattern.[4] examined the scientific and technological trends of developments in nanocellulose based on scientometric and patent indicators obtained from the Science Citation Index and Derwent Innovations Index in 2001-2010.[12] studied the mapping of the Brazilian groups of Nanocellulose scientific research output using the WoS database during 1945–2018. The study analysed the 69 Brazilian groups. Among them, bacterial cellulose was the most common source.[13] conducted bibliometric study on Nanocellulose using CWTS Web of Science database. Twelve research areas were identified, mapped and associated with current research challenges on nanocellulose.[14] analysed the growth pattern of Nanoscience and Nanotechnology literature in India during 1990–2009 (20 years). They measure the performance based on several parameters, country annual growth rate, authorship pattern, collaborative index, collaborative coefficient, modified collaborative coefficient, subject profile etc.[15] analysed the 17,133 COVID-19 research publications were published across the world from the web of science database the study included various bibliometrics.

This study aims to propose a delineation procedure to retrieve relevant research areas directed to a specific topic. Nanocellulose was selected as a

Table 1: Main Information of the study.

Description	Results
Main Information about Data	
Timespan	2011:2020
Sources (Journals, Books, etc)	724
Documents	3458
Average years from publication	4.14
Average citations per document	22.4
Average citations per year per doc	3.891
References	117362
Document Types	
Article	3062
Article; early access	21
Article; proceedings paper	53
Correction	4
Correction; early access	1
Editorial material	4
Letter	1
Meeting abstract	62
Review	238
Review; book chapter	7
Review; early access	5
Document Contents	
Keywords Plus (ID)	6894
Author's Keywords (DE)	8048
AUTHORS	
Authors	11768
Authors of single-authored documents	68
Authors of multi-authored documents	11700
Authors Collaboration	
Single-authored documents	71
Documents per Author	0.294
Authors per Document	3.4
Co-Authors per Documents	5.02
Collaboration Index	3.45

case, but of course, it can be used for other topics. The approach involves research areas identified in Web of Science publications. Table 1 displays the main information of the study.

Objectives of the Study

The main objective of this work is to identify the year-wise published research work on nanocellulose growth in the world and compare it with India, scientometrically. Also, to examine the authorship pattern whilst analysing the most productive journals, authors, organizations and countries along with the most occurred keywords.

METHODOLOGY

The study data was retrieved from the web of science database using the search query " TS= (Nano cellulose) Timespan: 2011-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI. A total of 3458 records were found, in that Indian contribution was 317 papers. The downloaded data was entered into an Excel sheet for analysis and tabulation according to the study objectives. For visualisation mapping, VOSviewer and bibliometrix *R*-package were used.

Analysis and Interpretation of Data

Year-wise distribution of Nanocelluloseresearch output

Table 2 and Figure 1 shows the World and India's year-wise research output in Nanocellulose during 2011 – 2020. A total of 3458 papers were published, among, India has contributed 317 papers. The highest papers (World 671; India 66) were published in 2020 and the least number of papers (World 132; India 07) were recorded in 2011. The study shows the year-wise growth of Nanocellulose publications were in increasing trend.

Authorship pattern, Degree of Collaboration (DC), Collaboration Index (CI)

In recent years most countries have realized the impotence of scientific research to their social-economic growth and have begun to implement programs to encourage and support the cooperation of researchers and scientists at the national and international levels. It can be defined as the number of multi-author publications in a subject published in a year and the total number of papers (multi-author and single-author papers) published in a year. Degree of collaboration proposed by (Subramanyam, 1983) as bellow:

Table 2: Year-wise Research Output of Nano Cellulose Research during 2011 – 2020 (World and India).

Year	NP		Percentage		TC		ACPA		*h* index	
	World	India	World (% of 3458)	India (% of 317)	World	India	World	India	World	India
2011	132	07	3.817	2.208	6702	778	50.770	112.570	42	06
2012	202	15	5.842	4.732	10823	721	53.580	48.070	57	13
2013	206	23	5.957	7.256	8990	782	43.630	34.000	50	14
2014	212	19	6.131	5.994	8740	637	41.230	33.530	49	13
2015	251	16	7.259	5.047	7328	509	29.200	31.810	45	12
2016	345	30	9.977	9.464	10234	626	29.660	20.870	51	13
2017	395	47	11.423	14.826	8507	1046	21.540	22.260	45	19
2018	445	44	12.869	13.880	8082	893	18.160	20.300	40	18
2019	599	50	17.322	15.773	5624	398	9.390	7.960	29	11
2020	671	66	19.404	20.820	2419	253	3.610	3.830	19	07

NP: Number of Publications; TC: Total Citations; ACPA: Average Citation per Paper;

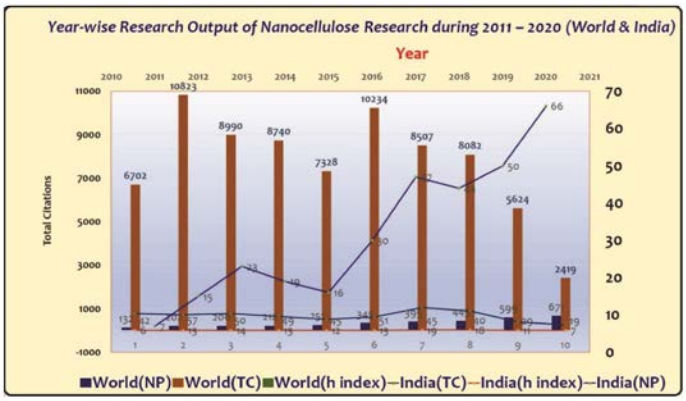

Figure 1: Year-wise research output of nanocellulose research during 2011 – 2020 (World and India).

Table 3: **Authorship pattern.**

No of Authors	NP	% of 3458	Cumulative	Cumulative %	DC
1	071	2.053	071	2.053	
2	327	9.456	398	11.510	
3	575	16.628	973	28.138	
4	635	18.363	1608	46.501	
5	610	17.640	2218	64.141	
6	464	13.418	2682	77.559	0.979468
7	335	9.688	3017	87.247	
8	174	5.032	3191	92.279	
9	112	3.239	3303	95.518	
10 and more	155	4.482	3458	100.000	

NP: Number of Publications; DC: Degree of Collaboration

$$C = \frac{Nm}{Nm + NS} \qquad C = \frac{3387}{3387 + 71} \qquad C = 0.9795$$

Where C is the degree of collaboration, Nm is the number of multi-authored papers, and Ns is the number of single-authored papers. In the current study, the value of DC during the study period was 0.9794. Table 3 gives the authorship pattern and degree of collaboration of *research output of nano cellulose research during 2011 – 2020.*

Most productive Journals in Nano Cellulose Research

Journals are observed as one of the main sources of information and have become the fastest and most effective resource for disseminating research results. The higher rate of occurrence of journals in the subject area can measure the growth of knowledge in the field of Nano Cellulose. The acceptable fact is that in the field of science, to meet the rapid growth of information, new journals are appearing faster and faster. Table 4 shows the 20 most preferred journals used by the researcher.

The top 20 most preferred journals accounted for (TP=1301; 37.62%) share of the total Nano Cellulose research output during the study period. Therefore, the rate of highly cited articles varies from journal to journal. The topmost preferred journal was Carbohydrate Polymers (UK) published 253 publications with 28 *h* index, followed by Cellulose (Romania) produced 228 publications with 32 *h* index, International Journal of Biological Macromolecules (Netherlands) published 140 publications with 31 *h* index, RSC Advances (UK) published 78

Table 4: **Most productive journals in nano cellulose research during 2011 – 2020.**

Source	NP	TC	*h*_ index	*g*_ index	*m*_ index
Carbohydrate Polymers	253	12489	58	102	5.273
Cellulose	228	4592	32	57	2.909
International Journal of Biological Macromolecules	140	2642	31	42	2.818
RSC Advances	78	1385	22	32	2.200
Composites Science and Technology	60	1815	24	41	2.182
Bioresources	59	1018	16	31	1.455
Abstracts of Papers of The American Chemical Society	53	0	0	0	0.000
ACS Applied Materials and Interfaces	50	1955	25	44	2.778
Journal of Applied Polymer Science	47	675	16	24	1.455
Polymers	44	358	11	16	1.833
ACS Sustainable Chemistry and Engineering	36	856	17	29	2.125
Industrial Crops and Products	32	817	17	28	1.889
Chemical Engineering Journal	31	1192	17	31	1.700
Composites Part B-Engineering	31	871	16	29	1.455
Materials Science and Engineering C-Materials for Biological Applications	30	732	15	26	1.364
Nanomaterials	30	181	8	11	2.000
Fibers and Polymers	27	308	11	16	1.100
Composites Part A-Applied Science and Manufacturing	26	826	17	26	1.700
Biomacromolecules	23	677	14	23	1.273
Food Hydrocolloids	23	1329	15	23	1.364

NP: Number of Publications; TC: Total Citations

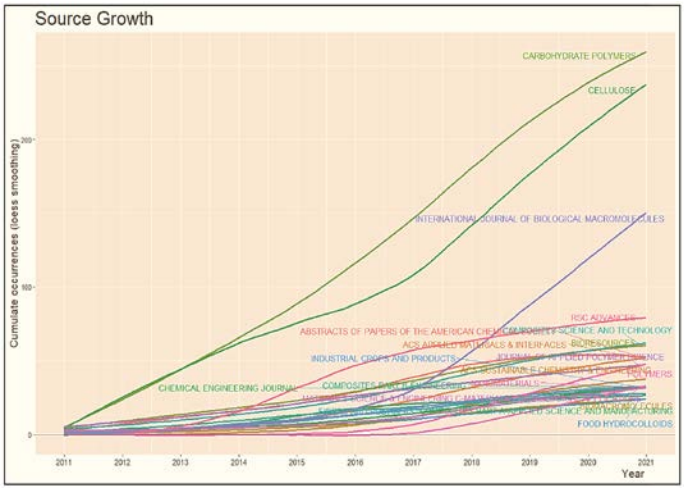

Figure 2: Most productive journals of nano cellulose research productivity.

Table 5: Most productive authors.

Author	Organization	Country	NP	TC	h_index	g_index	m_index
Wang X	Linkoping University	Sweden	28	846	11	28	1.100
Zhang Y	Beihang University	China	28	781	11	27	1.100
Li J	Northeast Forestry University	China	24	559	11	23	1.222
Liu Y	Inner Mongolia Agricultural University	China	22	317	8	17	1.143
Ni YH	University New Brunswick	Canada	20	538	13	20	1.857
Zhang H	Henan Polytech University	China	20	310	10	17	1.000
Chen L	New Jersey Institute of Technology	USA	19	461	13	19	1.857
Li L	Nanjing Forestry University	China	18	171	7	12	0.636
Rojas OJ	Aalto University	Finland	18	1108	12	18	1.091
Dufresne A	University Grenoble Alpes	France	16	1906	12	16	1.091
Montazer M	Amirkabir University of Technology	Iran	16	777	12	16	1.091
Fortunati E	University Perugia	Italy	15	1713	12	15	1.200
Liu J	Zhengzhou University	China	15	240	8	15	1.143
Zhang Q	Sichuan University	China	15	224	8	14	0.727
Berglund LA	KTH Royal Institute of Technology	Sweden	14	864	10	14	0.909
Kumar A	Indian Institute of Technology Roorkee	India	14	178	7	13	0.875
Li Y	University Shanghai Science and Technology	China	14	366	7	14	0.636
Wang J	Anhui University	China	14	217	8	14	0.800
Zhang X	Monash University	Australia	14	350	8	14	0.889
An XY	Tianjin University Science and Technology	China	13	384	10	13	1.429

NP: Number of Publications; TC: Total Citations

publications with 22 *h* index. The 5 journals were produced more than 1815 citations during the study period (Table 4). In that Carbohydrate Polymers placed top in terms of total citations 12489 (16.12%), followed by Cellulose 4592 (5.92%), International Journal of Biological Macromolecules published 2642 citations Figure 2 shows the source growth.

Most Productive Authors in Nanocellulose Research Output

Table 5 shows, the list of the most productive author's with13 or more highly cited articles, surprisingly most of the authors (10) from China and contributed 203 publications. The most productive author was Wang X, Linkoping University, Sweden contributed 28 publications with 846 citations and *h* index value of 11, followed by Zhang Y, Beihang University, China produced (NP;28, TC=781, *h* index = 11), The papers published by Dufresne A, were most often cited 1906 citations. Figure 3 shows the most productive authors with their most prolific author's co-citation network during the study period.

Most Productive Organisations

Dataset analysis revealed that 2723 institutions contributed to Nano cellulose research publishing. The top 20 institutions in the area of research were identified and are presented in Table 6. These to 20 institutions produced 1010 (33.61%) of the total publications and the remaining 2723 institutions produced (67.39%) papers. Chinese Academy of Sciences has been identified as the leading institute in the area with 88 (2.545%) papers, followed by Islamic Azad University, Iran produced 77 (2.082%) papers, Centre National De La RechercheScientifique (CNRS), France produced 72 (2.082%) papers, CommunauteUniversity

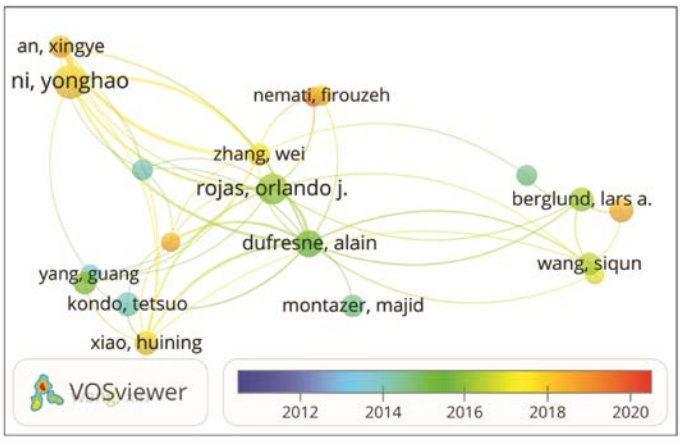

Figure 3: VOSviewer top 20 authors and co-authors and citation network.

Grenoble Alpes, France has received highest citations 2686 (ACPA; 65.510%) followed by Aalto University, Finland 2148 with ACPA 39.780%). The lowest citations per publication (ACPA; 14.140%) is seen on the papers published by Nanjing Forestry University, China. Figure 4 shows the most productive institutions collaboration network.

Collaborative Association Among Leading Countries

Table 7 considered the level of collaboration among leading countries in publishing research work. China has got the topmost productive country in this study. Country publication strength is calculated using the number

Table 6: Most productive organizations.

Institutes	Country	NP	% of 3458	TC	ACPP	*h* index
Chinese Academy of Sciences	China	88	2.545	1917	22.030	25
Islamic Azad University	Iran	77	2.227	1633	21.210	23
Centre National De La RechercheScientifique (CNRS)	France	72	2.082	3210	44.580	26
South China University of Technology	China	67	1.938	1395	20.820	20
Indian Institute of Technology System	India	66	1.909	1419	21.500	22
Nanjing Forestry University	China	59	1.706	834	14.140	17
Royal Institute of Technology	Sweden	58	1.677	1989	34.290	21
Aalto University	Finland	54	1.562	2148	39.780	24
National Research Centre (NRC)	Egypt	54	1.562	1399	25.910	24
Donghua University	China	43	1.243	1121	26.070	18
Sichuan University	China	42	1.215	1363	32.450	19
CommunauteUniversite Grenoble Alpes	France	41	1.186	2686	65.510	20
Northeast Forestry University China	China	41	1.186	779	19.000	17
University Of North Carolina	US	37	1.07	1484	40.110	17
Amirkabir University of Technology	Iran	36	1.041	1095	30.420	18
Jiangnan University	China	36	1.041	712	19.780	12
North Carolina State University	US	36	1.041	1477	41.030	17
Tianjin University Science Technology	China	36	1.041	851	23.640	18
University of New Brunswick	Canada	36	1.041	985	27.360	17
Beijing Forestry University	China	31	0.896	494	15.940	12

NP: Number of Publications; TC: Total Citations; ACPP: Average Citation per Paper:

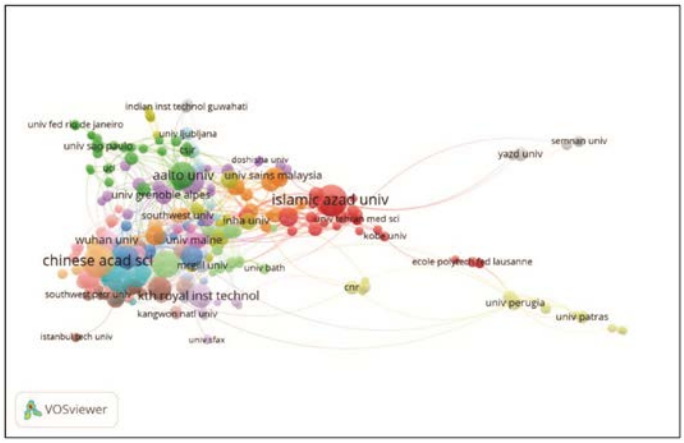

Figure 4: VOSviewer most productive institutions network visualization.

of papers published in collaboration by geometric mean (square root of publications) of the total papers published by two countries. China has published 1043 (TC=17127 and ACPA-17.58%) publications and ranked First, followed by the USA with 423 (TC=8284, ACPA-31.740) publications, India has produced 317 (TC=5902, ACPA-21.310%) papers published, Iran published 314 papers (TC=5776, ACPA-21.000%). China has received the highest citations with 17127. Figure 5 shows the most productive countries collaboration and citations network during the study period.

Most Preferred Keywords

Table 8 shows the most occurred keywords used by the authors during the study period. A total of 8,048 keywords reached the threshold of being included in the map more than 5 times (Figure 6).

Table 7: Most productive countries.

Country	NP	TC	ACPP
China	1043	17127	17.580
USA	423	8284	31.740
India	317	5902	21.310
Iran	314	5776	21.000
Malaysia	109	3551	41.290
Canada	174	3435	30.950
France	109	3341	56.630
Sweden	120	2876	37.350
Italy	105	2783	37.110
Japan	160	2351	19.760
Finland	108	2250	35.160
South Korea	161	2106	15.830
Spain	89	1712	33.570
Egypt	111	1657	19.270
United Kingdom	105	1290	22.240
Brazil	89	1072	14.290
Germany	83	959	26.640
Turkey	71	804	14.110
Australia	50	778	15.250
Belgium	21	688	68.800

NP: Number of Publications; TC: Total Citations; ACPP: Average Citation per Paper.

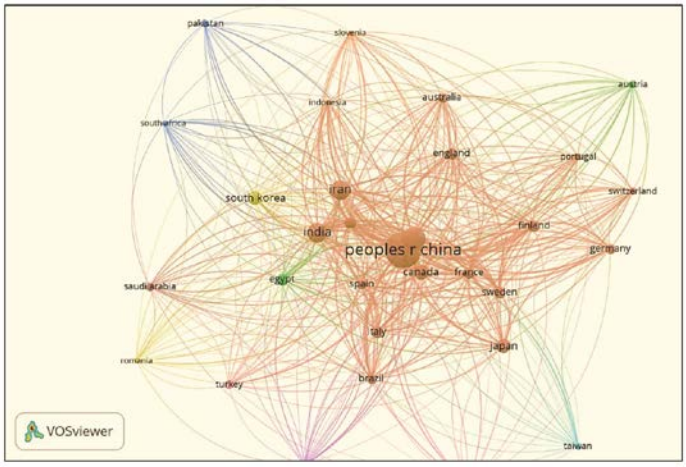

Figure 5: VOSviewer most productive countries network visualization.

Table 8: Most preferred keywords.

Keyword	Occurrences	Total link strength
Cellulose	510	2583
Nanoparticles	448	2385
Mechanical-properties	356	2092
Nanocomposites	327	1884
Composites	307	1795
Fibers	249	1387
Films	239	1313
Nanocrystals	203	1168
Adsorption	197	1137
Fabrication	191	1090
Nanofibers	183	1042
Nanocellulose	169	1050
Chitosan	163	951
Water	162	876
Composite	139	770
Morphology	139	855
Bacterial Cellulose	138	774

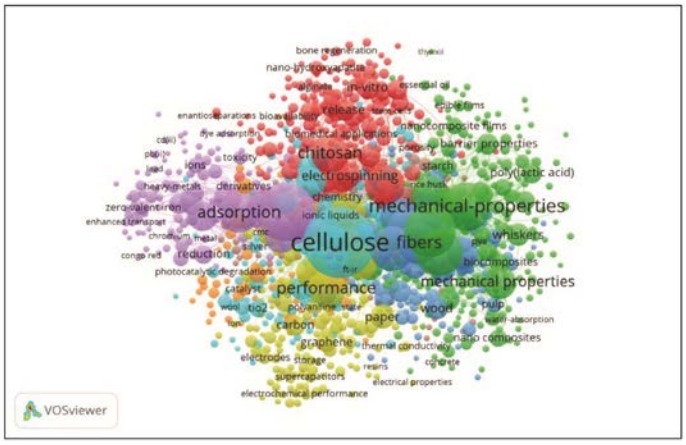

Figure 6: Most preferred keywords.

The size of the circle indicates the number of articles that appear for each keyword, and the colour indicates the cluster of keywords based on the number of common appearances. Generally, the larger the size of the circle, the more frequently the keyword appears. If they co-occur in the evaluated publication more frequently, they are two words close to each other. The smaller the distance between two keywords, the more the keywords appear at the same time. Six main categories are representing six different perspectives. The top most keywords with the highest frequency are Cellulose (510), Nanoparticles (448), Mechanical-properties (356), and Nanocomposites (327).

DISCUSSION AND CONCLUSION

The present study presents a scientometric analysis of nanocellulose papers published during 2011–2020 for the World and India comparative study. Most of the publications had come in an article from with an increasing number of publications as time proceeds. Multi-authorship is the general trend of nanocellulose research. The multi-authorship and collaboration have increased as time proceeds. Most of the prolific authors are from China. The citation pattern also follows general trends, e.g., the number of citations increases as the number of authors increases or multi-authored papers got more citations. Most of the highly cited papers came from the medical or physical field. The most collaborative countries which published research papers with China, USA, India and Iran etc. The Chinese Academy of Sciences (China), Islamic Azad University (Iran), Centre National De La RechercheScientifique (CNRS) France are the most collaborating organisations. Most of the prolific journals from the UK, Romania, etc. During the ten years study, period scholars from Nanocellulose publications published 3458. Data indicates that the highest numbers of records were published in the form of journal articles, followed by review papers. Multi-authored paper dominates during the study period years. Single authored paper acquires a very smaller number of publications.

The current research direction of this research can be used to formulate policies that encourage future research and development. It is required that the government and other funding agencies give the foremost priority to research in this area. Nanocellulose, which currently can be produced on an industrial scale in tons per day, can be used in various fields of our life, such as Nanocomposite materials, biomedical products, wood adhesives, super capacitors, electronic component stencils, batteries, catalytic media, electro active polymers, continuous fibres and textiles, food coatings, barrier/separation membranes, antimicrobial films, paper products, cosmetics, cement and many other emerging uses.[11,16] Research in this field can develop more programs to supplement the gap between theory, experiment and research Expertise in the application of synthetic fibres. Further, suggestions include mapping the main institutions and companies involved in the nanocellulose issue and investigating their focus of activities. Future research includes international collaboration to determine the research results of India in this field and mapping the research results of other prolific countries.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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