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Abstract

In this study, a scientometric analysis of the biotechnology research output of India during 2008-2017 was performed based on the information available in the SCOPUS database. This study analyses the research output of India in biotechnology research on different parameters, including the growth, global publication share and rank, the contribution of major international collaborative partners and subject areas, contribution and citation impact of the most productive authors, institutions and journals. The United States ranks first in terms of the number of publications, h-index and average citations per paper. India published a total of 5573 papers during 2008-2017, which received 80530 citations with an average of 14.45 citations per paper. Almost 48.79% of publications are in the field of biochemistry, genetics, and molecular biology. The most productive Indian institution in biotechnology research was the Indian Institute of Technology Delhi, followed by the Council of Scientific and Industrial Research and Vellore Institute of Technology. Top twenty most productive institutions contributed 30.50% share of total publications with an average of 85 publications per institute.

Keywords: Biotechnology research, Scientometric analysis, Citations, Research output, India

Abbreviations

TP Total publications

TC Total citations

ACPP Average citations per paper

RGR Relative growth rate

ICP International collaborative papers

Introduction

The 21st century is marked by the advent of biotechnology as an exceptional tool providing sustainable solutions to problems in the life science domain. Biotechnology is not a single unit; indeed, it encompasses various other disciplines such as cell biology, immunology, molecular biology, recombinant DNA technology, and bioinformatics. Biotechnology tailors molecular, cellular and genetic processes to produce valuable products and services utilizing biological tools and knowledge (Mani, S. 2004). The scope of biotechnology is increasing exponentially in the aspects of the environment, agriculture, drug delivery system, drug targeting, chemical industry, diagnostics and many more. Exploration of the human genome project, animal, and plant genome projects have also accelerated biotechnological inventions and applications. Advancement of information technology enables easy access to biotechnology research and development (R&D) information in a timely and efficient manner. In this era of biotechnology, India is holding an influential position among other countries of the world, with a tremendous potential to explore new avenues of biotechnological application for the benefit of mankind.

There are not just a few but many reasons that qualify India as one of the most potential candidate to persist in the development of biotechnology. India has one of the largest pools of qualified workforce and thus offers a vital ground for the growth of this knowledge-based industry. India is showcasing continuous academic research and development in various areas of biotechnology such as bioprocess engineering, gene manipulation of microbes and animal cells, downstream processing and plant and animal recombinant DNA technology, etc. Modern and well-equipped research laboratories in India for stem cell research, identification of new genes, gene therapies, recombinant vaccines, computational biology, artificial intelligence, etc provide fundamental infrastructure for the exploration of biotechnology. India has the second-largest population in the world. Thus, there is a huge market for biotechnology products and services in India. In 2016, the Indian biotechnology industry was valued at US $11 billion which is expected to grow to $100 billion by 2025 (Nogrady, B. 2018). The fast-paced developing economy of India is an attraction for fortune investments in all fields including biotechnology. India has a wide diversity of flora and fauna

and is also considered as the land of agriculture. It is endowed with varied climatic zones across the country that can be exploited for development in agricultural biotechnology. Advancements in the development of bio-fertilizers, bio-pesticides, genetically improved (transgenic) plants giving a new direction to plant tissue culture technology, horticulture, recycling of agricultural wastes, and livestock management are the critical indicators of utilizing biotechnology. Almost 8000 km long coastline of India offers enormous potential for marine resource development and aquaculture. The engagement of modern biotechnology in marine biology can help in the generation of the fastest moving commodities around the world. Hence, it is evident that India has suitable resources, strength, and qualified manpower to carry out biotechnology R&D activities. India has witnessed the emergence of R&D in biotechnology during the 1980s and since then has exhibited continuous growth.

In order to promote research and innovation in the biotechnology field, the Department of Biotechnology (DBT) was found in 1986. DBT is entirely dedicated to biotechnology and provides funding to various research institutions and laboratories across India for various R&D projects, procurement of the latest equipment, and organizing seminars, conferences, and workshops. To support the innovation-driven biotechnology ecosystem in India, Biotechnology Industry Research Assistance Council (BIRAC), a public sector, not-for-profit organization was set up by DBT in 2012. BIRAC has started various schemes to bridge gaps in industry-academia research and is encouraging researchers from academia and industry to work together. This has led to remarkable growth in the publication output of India in biotechnology research.

The ascending profile of biotechnology research in India can be portrayed by the analysis of R&D output data. A few reports have been published in the past based on the scientometric analysis of the Biotechnology research output in India. Patra and Chand (2005) analyzed the research status of biotechnology in India based on publication data from Web of Science. Sevukan and Sharma (2008) examined the research output of biotechnology faculties in some central universities of India. Garg and Kumar (2014) reported a scientometric profile of Indian scientific output in life sciences. The main objective of the current analysis is to evaluate research trends within the field of biotechnology in India as reflected in its publication output during 2008-2017. The present study has the following objectives (i) to study the Indian publication output in biotechnology, its global publication share, growth rate and impact, (ii) to identify the major collaborative partners of India (iii) to study the contribution of different subject areas, (iv) to identify the contribution of most productive Indian institutions, authors and journals publishing Indian papers, (v) to identify the most cited papers in biotechnology research.

Methodology

For the purpose of the study, the publication data related to biotechnology research for the period 2008-2017 was retrieved from SCOPUS International Database [www.SCOPUS.com/search] which is one of the largest databases of peer-reviewed literature. A search was carried out in the SCOPUS database search bar under the tab of "Article title, Abstract and Keywords" using the words "biotechnology" from the period 2008-2017. The retrieved data was exported to MS-excel in CSV format containing the citations and bibliometric information. The impact of publications was assessed using parameters such as average citation per paper (ACPP) and h-index. ACPP was calculated by using the following formula,

$$\text{ACPP} = \frac{\text{Total number of citations}}{\text{Total number of publications}}$$

The h-index (Hirsch, 2005) is defined as "A scientist has index h if h of his or her N_p papers have at least h citations each and the other (N_p – h) papers have ≤h citations each".

The relative growth rate (RGR) in publications for the period 2008-2017 was measured by the model developed by Mahapatra (1985). RGR is the increase in publications/pages per unit of time. RGR is calculated as

$$\text{RGR} = (\ln N_2 - \ln N_1) / (t_2 - t_1)$$

where, N_2 and N_1 are the cumulative numbers of publications in the years t_2 and t_1.

Results and Discussion

India's publication share and rank

Table 1 list the top 10 most productive countries in biotechnology research during 2008-2017. The total global research output in biotechnology research during 2008- 2017 was 73153 out of which 11985 publications are published as open access. The global publication share of the top 10 most productive countries in biotechnology research during 2008- 2017 varies from 3.17 to 20.18%. India ranks 3rd among the top 10 most productive countries in biotechnology research during 2008-2017 with a publication share of 7.62%. The United States tops the list with a global publication share of 20.18 %. China ranks second (with a publication share of 15.90%) followed by India, South Korea, Japan, and Germany (with publication share ranging from 6.05 to 15.90%). United Kingdom, Spain, Canada, and France ranks at 7th to 10th positions, with publication share ranging from 3.17 to 5.58 %, respectively. In terms of citation quality and impact, the global ACPP varies from 13.81 to

26.17 and h-index vary from 97 to 224 during 2008-2017. The USA registered the highest citation per publication with 26.17 citations per paper followed by Spain (25.89 citations per publication), Canada (25.87 citations per publication), United Kingdom (25.41 citations per publication) and Germany (24.99 citations per publication). The USA registered the highest h- index (h=224), followed by United Kingdom (h=132), Germany and China (h=127 each), and India (h=107).

Table 1: Top 10 most productive countries in biotechnology research for the period 2008-2017.

S. no.	Country	TP	Publication share (%)	TC	ACPP	Cited	% cited	h-index
1	United States	14765	20.18	386378	26.17	11852	80.27	224
2	China	11630	15.90	165765	14.25	8559	73.59	127
3	India	5573	7.62	80530	14.45	4072	73.07	107
4	South Korea	4869	6.66	67265	13.81	4119	84.60	97
5	Japan	4707	6.43	71344	15.16	4086	86.81	97
6	Germany	4429	6.05	110691	24.99	3709	83.74	127
7	United Kingdom	4080	5.58	103657	25.41	3392	83.14	132
8	Spain	2350	3.21	60853	25.89	2046	87.06	102
9	Canada	2316	3.17	59904	25.87	1968	84.97	100
10	France	2282	3.17	56636	24.82	1907	83.57	104
	World	73153						

India's publication output and growth rate in biotechnology research

During 2008-2017, India's cumulative publication output in biotechnology research was 5574, with an average citation per publication of 14.25 and an annual mean relative growth rate of 0.33. India's publication output was highest in the year 2016, at 868 and lowest in the year 2008, at 284. It can be seen that the relative growth rate drop from 0.79 in 2009 to 0.18 in 2015 but rose in 2016 to 0.20 subsequently dropping to a value of 0.15 in 2017.

Table 2: India's publication output and growth rate in biotechnology research during 2008-2017

Year	TP	Cumulative	RGR	Mean RGR	Cited	% Cited	Un-cited
2008	284	284		0.33	226	79.58	58

2009	343	627	0.79		289	84.26	54
2010	394	1021	0.49		326	82.74	68
2011	532	1553	0.42		451	84.77	81
2012	576	2129	0.32		473	82.12	103
2013	619	2748	0.26		506	81.74	113
2014	560	3308	0.19		459	81.96	101
2015	640	3948	0.18		470	73.44	170
2016	868	4816	0.20		478	55.07	390
2017	757	5573	0.15		397	52.44	360

Publications can be categorized as articles, reviews, book chapters, conference papers, etc as shown in Table 3. Most of the publications were published as an original article (3650 publications) with a publication share of 65.49 % followed by review papers, book chapters, conference papers, books, editorials, short surveys, notes, erratums and letters with publication share ranging from 0.38 to 15.65%.

Table 3: Types of publications

Type of Publications	TP	Publication share (%)
Article	3650	65.49
Review	872	15.65
Book Chapter	501	8.99
Conference Paper	149	2.67
Book	188	3.37
Editorial	92	1.65
Short Survey	38	0.68
Note	35	0.63
Erratum	25	0.45
Letter	21	0.38
Retracted	2	0.04

International collaborative publications

The United States was the major collaborative partner of India in biotechnology research during 2008-2017 (304 collaborative publications) accounting for 5.47% of India's publication

output followed by South Korea (304 collaborative publications), Australia (88 collaborative publications), Canada (72 collaborative publications), Saudi Arabia (70 collaborative publications), Germany (68 collaborative publications), United Kingdom (65 collaborative publications), China (61 collaborative publications), France (61 collaborative publications) and Japan (53 collaborative publications).

Table 4: Contribution of major collaborative partners in India's publication output in biotechnology research during 2008-2017

S. no.	Country	ICP	Publication share (%)
1	United States	305	5.47
2	South Korea	130	2.34
3	Australia	88	1.58
4	Canada	72	1.29
5	Saudi Arabia	70	1.26
6	Germany	68	1.22
7	United Kingdom	65	1.17
8	China	61	1.09
9	France	61	1.09
10	Japan	53	0.95

Most productive subject areas

As reflected in the SCOPUS database, top 10 most productive subject areas in biotechnology research during 2008-2017 were biochemistry, genetics and molecular biology (2719 publications), immunology and microbiology (1587 publications), agricultural and biological sciences (1348 publications), chemical engineering (1256 publications), environmental science (1177 publications), engineering (664 publications), pharmacology, toxicology and pharmaceutics (555 publications), medicine (474 publications), energy (458 publications) and chemistry (311 publications).

Table 5: Most productive subject areas in biotechnology research during 2008-2017

S. no.	Subject area	TP	Publication share (%)
1	Biochemistry, Genetics and Molecular Biology	2719	48.79
2	Immunology and Microbiology	1587	28.48

3	Agricultural and Biological Sciences	1348	24.19
4	Chemical Engineering	1256	22.54
5	Environmental Science	1177	21.12
6	Engineering	664	11.91
7	Pharmacology, Toxicology and Pharmaceutics	555	9.96
8	Medicine	474	8.51
9	Energy	458	8.22
10	Chemistry	311	5.58

Most productive Indian institutions

The research performance of the top 20 most productive Indian institutions in biotechnology research during 2008-2017 is given in Table 6. These 20 institutions account for 30.50% (1700 publications) of India's total publication output in biotechnology during 2008-2017 with an average of 85 publications per institute. The highest number of papers were published by Indian Institute of Technology Delhi (165 publications) followed by Council of Scientific and Industrial Research (159 publications), Vellore Institute of Technology (113 publications), Indian Agricultural Research Institute (112 publications) and Banaras Hindu University (109 Publications). National Institute for Interdisciplinary Science and Technology registered the highest average citation per publication with 36.61 citations per paper followed by Institute of Chemical Technology (34.12 citation per publication), Council of Scientific and Industrial Research India (26.58 citation per publication), Central Food Technological Research Institute India (25.14 citation per publication) and Indian Institute of Chemical Technology (24.98 citation per publication). The average citation per publication of these 20 institutions was 19.72. Council of Scientific and Industrial Research registered the highest h-index (h=34), followed by the Indian Institute of Technology, Kharagpur (h=30), Indian Institute of Chemical Technology, and Indian Institute of Technology Delhi (h=27), and National Institute for Interdisciplinary Science and Technology (h=26 each). The average h-index of these 20 institutions was 19.5.

Table 6: Research profile of most productive Indian institutions in biotechnology research during 2008-2017

S. no.	Name of the institute	TP	TC	ACPP	Cited	% Cited	h-index
1	Indian Institute of Technology Delhi	165	3253	19.72	146	88.48	27
2	Council of Scientific and Industrial Research	159	4227	26.58	142	89.31	34

3	Vellore Institute of Technology	113	849	7.51	61	53.98	13
4	Indian Agricultural Research Institute	112	1882	16.80	100	89.29	19
5	Banaras Hindu University	109	1829	16.78	83	76.15	22
6	Indian Institute of Technology, Kharagpur	105	2521	24.01	92	87.62	30
7	University of Delhi	100	2158	21.58	83	83.00	24
8	Indian Council of Agricultural Research	86	635	7.38	64	74.42	10
9	Indian Institute of Chemical Technology	85	2123	24.98	69	81.18	27
10	National Institute for Interdisciplinary Science and Technology	79	2892	36.61	72	91.14	26
11	Anna University	77	1417	18.40	52	67.53	19
12	Aligarh Muslim University	77	1669	21.68	61	79.22	17
13	Bhabha Atomic Research Centre	63	1040	16.51	55	87.30	18
14	Indian Institute of Technology, Bombay	59	704	11.93	39	66.10	11
15	Institute of Chemical Technology	57	1945	34.12	50	87.72	20
16	Savitribai Phule Pune University	54	1242	23.00	46	85.19	19
17	Osmania University	51	1113	21.82	36	70.59	14
18	Central Food Technological Research Institute India	50	1257	25.14	41	82.00	16
19	Jadavpur University	50	568	11.36	42	84.00	14
20	Amity University, Uttar Pradesh	49	421	8.59	31	63.27	10

Most productive authors

The list of most productive authors in biotechnology research during 2008-2017 is given in Table 7. These ten productive authors have together contributed a total of 287 papers to the biotechnology research output of India, with an average of 28.7 publications per author. The most active author in biotechnology research in India is Pandey A. with 79 publications, 2608 citations, and h-index of 25. Three authors have published a higher number of papers than the group average of 28.7. These are Pandey A. (79 publications), Rathore A.S. (31 publications), and Venkata Mohan S. (30 publications). Sukumaran R.K registered the highest citation per publication of 55 followed by Madamwar D. (46.25), Binod P. (45.6) and

Singhal R.S. (41.4). These ten productive authors have received a total of 9537 citations with an average citation per publication of 32.8.

Table 7: Most productive authors in biotechnology research during 2008-2017

S. no.	Author name	TP	Current affiliation	TC	ACPP	h-index
1	Pandey A.	79	Indian Institute of Toxicology Research, Lucknow	2608	33.01	25
2	Rathore A.S.	31	Indian Institute of Technology Delhi, Department of Chemical Engineering	1057	34.10	16
3	Venkata Mohan S.	30	Kyung Hee University, Department of Environmental Science and Engineering, Seoul	969	32.30	20
4	Sukumaran R.K.	25	National Institute for Interdisciplinary Science and Technology, Microbial Processes and Technology Division, Thiruvananthapuram	1376	55.00	15
5	Singhal R.S.	22	Institute of Chemical Technology, Mumbai, India	911	41.40	13
6	Rathore A.S.	21	Indian Institute of Technology Delhi, Department of Chemical Engineering, New Delhi	129	6.14	7
7	Satyanarayana T.	21	Netaji Subhas Institute of Technology, Division of Biological Sciences and Engineering, New Delhi	278	13.24	10
8	Binod P.	20	National Institute for Interdisciplinary Science and Technology, Microbial Processes and Technology Division, Thiruvananthapuram	912	45.60	12
9	Madamwar D.	20	Sardar Patel University, Post-Graduate Department of Biosciences, Vallabh Vidyanagar	925	46.25	13
10	Govindwar S.P.	18	Hanyang University, Seoul, South Korea	372	20.67	9

Most productive journals

Top 15 most productive journals publishing Indian papers in biotechnology research during 2008-2017 together contributed 1854 papers to India's total publication output with a publication share of 33.27. The highest number of papers were published in *Bioresource Technology* (419), followed by the *Iioab Journal* (244) and *Journal of Plant Biochemistry and Biotechnology* (233). Among these most productive journals, *Biotechnology Advances* registered the highest average citation per publication of 105.17, followed by *Critical Reviews in Biotechnology* (40.49) and *Bioresource Technology* (37.38). *Bioresource Technology* received the highest h-index (h=63) followed by *Biotechnology Advances* (h=33) *and Applied Microbiology and Biotechnology* (h=25).

Table 8: Most productive journals publishing Indian papers in biotechnology during 2008-2017

S. no.	Journal name	TP	TC	ACPP	Cited	% Cited	h-index
1	*Bioresource Technology*	419	15661	37.38	413	98.57	63
2	*Iioab Journal*	244	80	0.33	42	17.21	4
3	*Journal of Plant Biochemistry And Biotechnology*	232	1416	6.10	201	86.64	14
4	*Current Trends in Biotechnology and Pharmacy*	115	163	1.42	38	33.04	4
5	*Biotechnology and Bioprocess Engineering*	113	1488	13.17	106	93.81	22
6	*Journal of Microbiology and Biotechnology*	106	1684	15.89	105	99.06	23
7	*Applied Microbiology and Biotechnology*	88	2120	24.09	79	89.77	25
8	*Journal of Bioscience and Bioengineering*	84	1343	15.99	82	97.62	21
9	*Applied Biochemistry and Biotechnology*	81	1334	16.47	71	87.65	20
10	*Plant Cell Biotechnology and Molecular Biology*	78	51	0.65	21	26.92	3
11	*Research Journal of Biotechnology*	74	33	0.45	12	16.22	3

12	*Plant Biotechnology Reports*	68	930	13.68	65	95.59	17
13	*Journal of Industrial Microbiology and Biotechnology*	60	1553	25.88	55	91.67	17
14	*Biotechnology Advances*	47	4943	105.17	47	100	33
15	*Critical Reviews in Biotechnology*	45	1822	40.49	45	100	24

Most cited papers

Most cited papers in biotechnology research in India during 2008-2017 are shown in Table 9. These highly cited papers contribute 9.23% to the total citation count of India during 2008-2017. These 15 most cited papers were published in 10 journals including 3 papers each in *Bioresource Technology* and *Biotechnology Advances*, 1 paper each in *Advances in Colloid and Interface Science*, *Analytica Chimica Acta*, C*hemosphere*, *Environment International*, *Journal of Hazardous Materials*, *Journal of Industrial Microbiology and Biotechnology*, *Marine Drugs* and *The Scientific World Journal*, respectively. Of these 15 papers, 13 were published as review papers and two as articles.

Table 9: Most cited papers in biotechnology research in India during 2008-2017

S. no.	Title	Authors	Year	Journal title	TC
1	Biocharas a sorbent for contaminant management in soil and water: A review	Ahmad M., Rajapaksha A.U., Lim J.E., Zhang M., Bolan N., Mohan D., Vithanage M., Lee S.S., Ok Y.S.	2014	Chemosphere	887
2	Biological synthesis of metal nanoparticles by microbes	Narayanan K.B., Sakthivel N.	2010	Advances in Colloid and Interface Science	685
3	Chemistry and biological activities of flavonoids: An overview	Kumar S., Pandey A.K.	2013	The Scientific World Journal	684
4	Bioconversion of lignocellulosic biomass: Biochemical and	Kumar R., Singh S., Singh O.V.	2008	Journal of Industrial Microbiology	641

	molecular perspectives			and Biotechnology	
5	Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent - A critical review	Mohan D., Sarswat A., Ok Y.S., Pittman C.U.	2014	Bioresource Technology	585
6	Synthesis of metallic nanoparticles using plant extracts	Mittal A.K., Chisti Y., Banerjee U.C.	2013	Biotechnology Advances	548
7	Potential applications of enzymes immobilized on/in nano materials: A review	Ansari S.A., Husain Q.	2012	Biotechnology Advances	507
8	Glucose oxidase - An overview	Bankar S.B., Bule M.V., Singhal R.S., Ananthanarayan L.	2009	Biotechnology Advances	437
9	An overview of enzymatic production of biodiesel	Ranganathan S.V., Narasimhan S.L., Muthukumar K.	2008	Bioresource Technology	409
10	Bioethanol production from rice straw: An overview	Binod P., Sindhu R., Singhania R.R., Vikram S., Devi L., Nagalakshmi S., Kurien N., Sukumaran R.K., Pandey A.	2010	Bioresource Technology	400
11	Plant growth promoting rhizobacteria and endophytes accelerate phytoremediation of metalliferous soils	Ma Y., Prasad M.N.V., Rajkumar M., Freitas H.	2011	Biotechnology Advances	391
12	Role of organic amendments on enhanced	Park J.H., Lamb D., Paneerselvam P., Choppala G., Bolan N.,	2011	Journal of Hazardous Materials	340

	bioremediation of heavy metal(loid) contaminated soils	Chung J.-W.			
13	Bioremediation approaches for organic pollutants: A critical perspective	Megharaj M., Ramakrishnan B., Venkateswarlu K., Sethunathan N., Naidu R.	2011	Environment International	324
14	Recent advances in ZnO nanostructures and thin films for biosensor applications: Review	Arya S.K., Saha S., Ramirez-Vick J.E., Gupta V., Bhansali S., Singh S.P.	2012	AnalyticaChimicaActa	315
15	Astaxanthin: Sources, extraction, stability, biological activities and its commercial applications - A review	Ambati R.R., Moi P.S., Ravi S., Aswathanarayana R.G.	2014	Marine Drugs	285

Conclusion

Scientometric analysis of biotechnology research in India based on SCOPUS records shows that in recent years, India has observed a remarkable growth in publications in biotechnology research. Researchers in India published a total of 5573 papers during 2008-2017, with a global publication share of 7.62%. India held the third position by the number of publications in biotechnology research during 2008-2017. The United States was the major collaborative partner of India, followed by South Korea and Australia. Most of the publications were related to biochemistry, genetics, and molecular biology (48.79%) followed by immunology and microbiology (28.48%) and agricultural and biological sciences (24.19%). Pandey A. published the highest number of papers (79) followed by Rathore A.S. (31) and Venkata Mohan S. (30). The 10 most productive authors together contributed a total of 287 papers with an average citation per publication of 32.8. Among institutions, the highest number of papers were published by the Indian Institute of Technology Delhi (165 publications) followed by Council of Scientific and Industrial Research (159 publications) and Vellore Institute of Technology (113 publications). Most preferred journals by Indian authors were Bioresource Technology, Iioab Journal, and Journal of Plant Biochemistry and Biotechnology.

Various agencies and organisations such as Council of Scientific and Industrial Research (CSIR), University Grants Commission (UGC), Department of Biotechnology (DBT), Department of Science and Technology (DST), Indian Council of Agricultural Research (ICAR) etc. are providing financial support to researchers for carrying out their research projects and are strengthening and modernizing the infrastructure of biotechnology research in India. The average citation per publication received by India during 2008-2017 is less as compared to developed countries such as United States, United Kingdom, Germany, Spain etc. Thus, there is a need to increase the quality of research. Furthermore, there is also a need to increase the international collaborative research which can directly influence the quality and impact of the publications.

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