Quaiser Saquib
Mohammad Faisal
Abdulaziz A. Al-Khedhairy
Abdulrahman A. Alatar *Editors*

Green Synthesis of Nanoparticles: Applications and Prospects

Springer

Green Synthesis of Nanoparticles: Applications and Prospects

Quaiser Saquib • Mohammad Faisal •
Abdulaziz A. Al-Khedhairy •
Abdulrahman A. Alatar
Editors

Green Synthesis of Nanoparticles: Applications and Prospects

Springer

Editors
Quaiser Saquib
Department of Zoology, College of Science
King Saud University
Riyadh, Saudi Arabia

Mohammad Faisal
Department of Botany & Microbiology, College of Science
King Saud University
Riyadh, Saudi Arabia

Abdulaziz A. Al-Khedhairy
Department of Zoology, College of Science
King Saud University
Riyadh, Saudi Arabia

Abdulrahman A. Alatar
Department of Botany & Microbiology, College of Science
King Saud University
Riyadh, Saudi Arabia

ISBN 978-981-15-5178-9 ISBN 978-981-15-5179-6 (eBook)
https://doi.org/10.1007/978-981-15-5179-6

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

It gives us immense pleasure to introduce the book entitled *Green Synthesis of Nanoparticles: Applications and Prospects*. This book is a blend of a number of ideas and perspectives for the synthesis of nanoparticles (NPs) employing biological materials. Our sincere thanks to all the contributors, who enthusiastically accepted our invitation and agreed to embellish chapters on the aforementioned topic. We also extend our exceptional thanks to the King Saud University for providing all support.

Research in NPs have gained enormous attention owing to their unique physicochemical properties. However, the use of toxic chemicals for NPs production via chemical methods have narrowed their wider applications. Consequently, the green method was developed for synthesizing NPs via the biological approach. In this context, the manipulation of nucleation and growth stages of NPs synthesis deserves special attention because it helped the nanotechnologists to produce varying types of NPs. Therefore, researchers tend to show enormous interest towards the synthesis of inorganic and organic NPs, enabling them to be used in a range of biomedical settings. Researchers have utilized varying types of biological materials for producing green NPs. The range of biological extracts prepared from plants, algae, bacteria, and viruses have shown the presence of bioactive molecules. These biomolecules reduce and cap the metal ions to produce green NPs, exhibiting less metal toxicity, and are more biocompatible. Apart from the low-cost productivity, the green NPs are ecofriendly too and do not need stabilizers. Surfaces of green NPs tend to adsorb biomolecules upon contact with cellular fluids, leading to the corona formation, which provide an additional advantage. The use of marine sources and medicinal plant extracts provide an excellent pharmacological property to the green NPs, which further raises their prospects to be used in biomedical and allied fields.

Hence, in this book, we have gathered up-to-date and state-of-the-art methods used for green synthesis of NPs and their potential applications in different fields. Special attention has also been given to explore the anticancer effects of green NPs. The book has been designed for scientists engaged in NPs research. Nonetheless, it should be of interest to a variety of scientific disciplines including marine biology, environmental science, genetics, pharmacology, medicine, drug and food material sciences, and consumer products. Also, the compilations will be of interest to the environmental watchdogs, federal regulators, risk assessors, and policy makers.

Riyadh, Saudi Arabia Quaiser Saquib
Riyadh, Saudi Arabia Mohammad Faisal
Riyadh, Saudi Arabia Abdulaziz A. Al-Khedhairy
Riyadh, Saudi Arabia Abdulrahman A. Alatar

Acknowledgments

The authors are grateful to the Deanship of Scientific Research, King Saud University for funding through Vice Deanship of Scientific Research Chairs.

Contents

Editors and Contributors

About the Editors

Quaiser Saquib currently works as an Associate Professor of Molecular Toxicology and Coordinator of DNA Research, Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia. He has over 12 years of research experience in cellular and molecular toxicology. He has been conferred with SESR Bioscientist Award-2018, NESA-Scientist of the Year Award-2016, and EMSI-Young Scientist Award-2008. Dr. Saquib published 72 research articles, 4 books, and 4 book chapters and serves as an editor and reviewer of several international journals.

Mohammad Faisal has over 12 years of research experience in Plant Biotechnology and currently works as an Associate Professor in the Department of Botany and Microbiology at King Saud University, Riyadh, Saudi Arabia. He received the Plant Biotechnologist Award from the SESR, India (2017), the Scientist of the Year Award-2015 from NESA (2015), and several national and international fellowships. He is a member of several academic bodies/societies and Fellow of the SESR. He has published over 82 research articles, 7 book chapters, and 6 books and serves on the editorial board of several reputed journals.

Abdulaziz A. Al-Khedhairy is a Professor of Molecular Genetics and Genomics in Zoology Department, College of Sciences, King Saud University, Riyadh, Saudi Arabia. He also serves as Director of DNA Research Chair in King Saud University. He has published over 190 research articles in journals of international repute, 4 books, 9 book chapters, and one US patent. As a PI and CO-I, he has successfully supervised several projects funded by KACST, KSA.

Abdulrahman A. Alatar is a Professor in the Department of Botany and Microbiology at King Saud University, Riyadh, Saudi Arabia. He is a consultant for human resources and management at the Ministry of Higher Education, Saud Arabia. Prof. Alatar has published more than 101 scientific articles in international journals and 4 books.

Contributors

Yahaya Abdulrazaq Department of Pure and Applied Chemistry, University of Fort Hare, Alice, South Africa
Department of Chemistry, Kogi State University, Anyigba, Nigeria

Abdulrahman A. Alatar Department of Botany & Microbiology, College of Science, King Saud University, Riyadh, Saudi Arabia

Khursheed Ali Department of Agricultural Microbiology, Faculty of Agricultural Sciences, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Abdulaziz A. Al-Khedhairy Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia

Azzurra Apriceno Institute for Bioengineering of Catalonia (IBEC), The Barcelona Institute of Science and Technology, Barcelona, Spain

Moronkola Bridget Department of Chemistry, Lagos State University, Ojo, Lagos State, Nigeria

Mariafrancesca Cascione Department of Mathematics and Physics “Ennio De Giorgi”, University of Salento, Lecce, Italy

Tijo Cherian Department of Agricultural Microbiology, Faculty of Agricultural Sciences, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Valeria De Matteis Department of Mathematics and Physics "Ennio De Giorgi", University of Salento, Lecce, Italy

Tiago Alves Jorge de Souza Department of Civil Engineering, Adventist University of São Paulo—UNASP, Engenheiro Coelho, SP, Brazil
Department of Genetics, FMRP-USP, São Paulo University—USP, Ribeirão Preto, SP, Brazil

Elias Emeka Elemike Department of Chemistry, Federal University of Petroleum Resources Effurun, Effurun, Nigeria

Mohammad Faisal Department of Botany & Microbiology, College of Science, King Saud University, Riyadh, Saudi Arabia

Saher Fatima Department of Agricultural Microbiology, Faculty of Agricultural Sciences, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

Ayeni Gideon Chemistry Department, Kogi State University, Anyigba, Nigeria

Oladayo Amed Idris Medicinal Plants and Economic Development (MPED) Research Centre, Department of Botany, University of Fort Hare, Alice, South Africa

Wisdom Ivwurie Department of Chemistry, Federal University of Petroleum Resources Effurun, Effurun, Nigeria

Dianwen Ju Department of Biological Medicine and Shanghai Engineering Research Center of Immunotherapeutics, School of Pharmacy, Fudan University, Shanghai, People's Republic of China

Gun-Do Kim Department of Microbiology, College of Natural Sciences, Pukyong National University, Busan, Republic of Korea

Yubin Li Department of Neurology, Xinqiao Hospital, Third Military Medical University (Army Medical University), Chongqing, People's Republic of China
Department of Dermatology, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA, USA
Corporal Michael J. Crescenz VA Medical Center, Philadelphia, PA, USA

Eva Liatsi-Douvitsa Department of Chemistry, University College London (UCL), London, UK

Adriano Magesky CHU de Québec-Université Laval, Québec-QC/Institut National de Santé Publique du Québec (INSPQ), Québec, QC, Canada

R. V. Meenakshi Department of Biotechnology, Bharathidasan Institute of Technology, Anna University, Tiruchirappalli, Tamil Nadu, India

Javed Musarrat Department of Agricultural Microbiology, Faculty of Agricultural Sciences, Aligarh Muslim University, Aligarh, Uttar Pradesh, India
School of Biosciences and Biotechnology, Baba Ghulam Shah Badshah University, Rajouri, India

Chijioke Olisah Department of Pure and Applied Chemistry, University of Fort Hare, Alice, South Africa

Maheshkumar Prakash Patil Research Institute for Basic Sciences, Pukyong National University, Busan, Republic of Korea

Vandana B. Patravale Department of Pharmaceutical Sciences and Technology, Institute of Chemical Technology, Mumbai, India

Émilien Pelletier Institut des sciences de la mer de Rimouski (ISMER), Université du Québec à Rimouski, Rimouski, QC, Canada

Leonardo Franchi Pereira Department of Genetics, FMRP-USP, São Paulo University—USP, Ribeirão Preto, SP, Brazil

Bui Dai Phat Faculty of Materials Science and Technology, University of Science, VNU-HCM, Ho Chi Minh City, Vietnam

Sreeranjini Pulakkat Department of Pharmaceutical Sciences and Technology, Institute of Chemical Technology, Mumbai, India

K. Rajaram Department of Biochemistry and Biotechnology, CSIR—Central Leather Research Institute, Chennai, Tamil Nadu, India

K. Ravi Shankar Department of Biotechnology, Bharathidasan Institute of Technology, Anna University, Tiruchirappalli, Tamil Nadu, India

Rosaria Rinaldi Department of Mathematics and Physics "Ennio De Giorgi", University of Salento, Lecce, Italy

Loris Rizzello Department of Chemistry, University College London (UCL), London, UK
Institute for Bioengineering of Catalonia (IBEC), The Barcelona Institute of Science and Technology, Barcelona, Spain

Larayetan Rotimi Department of Pure and Applied Chemistry, University of Fort Hare, Alice, South Africa
Department of Chemistry, Kogi State University, Anyigba, Nigeria

Izabella Sant'Ana Storch Department of Structures and Civil Construction, Federal University of São Carlos – UFSCar, São Carlos, SP, Brazil
Department of Civil Engineering, Adventist University of São Paulo-UNASP, Engenheiro Coelho, SP, Brazil

Quaiser Saquib Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia

Lilian Rodrigues Rosa Souza Department of Chemistry, FFCLRP-USP, University of São Paulo—USP, Ribeirão Preto, SP, Brazil

P. Sureshkumar Department of Biotechnology, Bharathidasan Institute of Technology, Anna University, Tiruchirappalli, Tamil Nadu, India

V. Tamil Elakkiya Department of Biotechnology, Bharathidasan Institute of Technology, Anna University, Tiruchirappalli, Tamil Nadu, India

Cao Minh Thi Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Vietnam

Pham Van Viet Faculty of Materials Science and Technology, University of Science, VNU-HCM, Ho Chi Minh City, Vietnam

Tran Hoang The Vinh Faculty of Materials Science and Technology, University of Science, VNU-HCM, Ho Chi Minh City, Vietnam

Shaofei Wang Department of Cellular and Genetic Medicine, School of Basic Medical Sciences, Fudan University, Shanghai, People's Republic of China

Chunlan Xu The Key Laboratory for Space Bioscience and Biotechnology, School of Life Sciences, Northwestern Polytechnical University, Xi'an, Shaanxi, China

Research Progression on Studies Related to Green Synthesis Nanoparticles: A Bibliometric Review

1

Rotimi Larayetan, Chijioke Olisah, and Oladayo Amed Idris

Abstract

The growing application of green synthesis nanoparticles (NPs) in medical and pharmaceutical sciences has made this area of research to be extensively explored by scientists. Here, we conducted a bibliometric investigation to evaluate the trend of research on green synthesis nanoparticle using articles retrieved from the WoS (Web of Science) from 2007 to 2018. A total of 710 articles (article, 699; review, 11) were retrieved from 243 journal sources. These articles were authored by 2473 authors with an article/author and author/article ratio of 0.287 and 3.48, respectively. A steady increase of article production in this area of research was noticed within the survey years with the high number of articles recorded in 2018 with 190 items. Asia countries dominated the top 20 countries on articles related to green synthesis nanoparticle research. India was ranked first with 308 articles, followed by Iran and Korea with 129 and 41 articles, respectively. A Lokta distribution based on a beta coefficient of 2.77 and goodness of fit of 0.92599 suggests that more articles are likely to be produced in this area of research in years to come. Sparse collaboration linkage was noticed between developed countries and developing countries in green synthesis-related research. To this end, more research should be encouraged to foster green synthesis research in

R. Larayetan (✉)
Department of Pure and Applied Chemistry, University of Fort Hare, Alice, South Africa

Department of Chemistry, Kogi State University, Anyigba, Nigeria

C. Olisah
Department of Pure and Applied Chemistry, University of Fort Hare, Alice, South Africa

O. A. Idris
Medicinal Plants and Economic Development (MPED) Research Centre, Department of Botany, University of Fort Hare, Alice, South Africa

Unit for Environmental Sciences and Management (UESM), Faculty of Natural and Agricultural Sciences, North West University, Potchefstroom, North West, South Africa

Q. Saquib et al. (eds.), *Green Synthesis of Nanoparticles: Applications and Prospects*, https://doi.org/10.1007/978-981-15-5179-6_1

regions that depend on herbs as an alternative source of medicine, particularly in Africa.

Keywords

Green nanoparticles · Nanoparticles · Nanoresearch · Biogenic nanoparticles

1.1 Introduction

Plants used for traditional remedies contain a broad range of substances that can be used to treat chronic as well as contagious diseases. The plant empire is a virtual gold mine of prospective drug targets and other useful molecules waiting to be discovered. About 10–15% of the 750,000 known species of higher plants have been assessed for biologically active compounds [1]. Majority of consumers all over the globe still depend on therapeutic plants as a way out of the health problems militating against them [2]. Due to the astonishing growth in nanotechnology in recent years, researchers in this area have engaged themselves in the development of reliable routes to generate nanomaterials ranging from 1 to 100 nm, though the traditional technique employed since the time of Michael Faraday to produce metal NPs has still been used, which entails costly chemical and physical procedures involving toxic materials with probable dangers like toxicity to the environment and carcinogenicity [3]. The organic solvents used for the synthesis of these nanoparticles coupled with the stabilizers and reducing agents utilized are the sources of its toxicity, and this toxic factor prevents the application of such synthesized nanoparticles in biomedical and clinical execution; the reasons mentioned above can contestably be managed through biogenic synthetic route [4, 5]. Plant part/living organism-mediated synthesis of metal nanoparticles has been carried out by several natural product scientists as seen in published literature [6, 7] under the area of research tagged 'biogenic synthesis of nanoparticles'. This is usually done to check their antimicrobial, anti-plasmodium and anti-parasitic activities in animal and human cells. This fact and many others had made this area of research to be extensively studied. It is therefore paramount to carry out their bibliometric compilation. The bibliometric tool statistically analysed academic literature (journals, books, abstracts, symposiums and all kinds of documents) of a particular field of interest using various bibliometric indices. Such indices include 'most productive authors', 'top articles per citation', 'most productive country', 'total citation per country', 'most relevant sources' and 'most relevant keywords'. This tool also assists scientist to have a firm idea regarding which article to read and where to publish their findings/outcomes. A software with a bibliometric tool module is installed on computer support to retrieve information of a particular subject from a database based on the above-mentioned indices. To analyse the sequential growth in the field of 'green synthesis nanoparticles', data were retrieved from the databases of the Web of Science (WoS). The WoS database was employed due to the fact that it covers a large scope of scientific literature that spans through art and humanities, life and physical sciences, social sciences and management sciences. Besides, articles related to bibliometric survey have also employed the use of WoS databases in the past [8, 9]. The main aim of this work is to employ bibliometry procedure to retrieve data on 'green synthesis nanoparticles' from publications covering a period of 2007–2015 in order to detect and evaluate the essential literature in this field and also to recognize international research productivity trend on this field through evaluation of articles published and important evolution over the years in this field of interest. To the best of our knowledge, there is paucity of information on the bibliometric data collection on biogenic synthesis of nanoparticles which if embarked upon will add to the cognitive, public and intellectual development of this field and also give researchers future direction in scientific work pertaining to this research area with particular emphasis on information provider to devise policies and strategies for the collection and acquisition of information resources.

1.2 Materials and Methods

Information on green synthesis nanoparticles was retrieved using a method described in Olisah et al. [9, 10]. Briefly, articles indexed on the WoS database were retrieved on September 27, 2019. The term 'green synthesis nanoparticles' was used as a search term for articles published from January 1, 2007, to December 31, 2018. Title-specific search (TSS) was chosen over topic search because in the former, errors related to sensitivity are minimized [8, 11]. Besides TSS has a high rate of recovery. Literature types such as proceeding paper, meeting abstract, correction, book chapters, editorial materials, letters, note, early access, correction addition and retracted publication were excluded from the search documents. Only article and review on green synthesis nanoparticle were used for the survey. These two document types were downloaded in BibTex format in two batches (500 documents in one batch and 210 documents in the second batch). The downloaded files were inputted into an RStudio (v.3.4.1 software) with installed bibliometric R-package. It is worth noting that only articles related to green synthesis nanoparticles were downloaded and articles were scrutinized before downloading by three principal investigators in the field of green synthesis. Command programmes for bibliometric indices were gotten from https://www.bibliometrix.org. Other statistical commands for Lokta and beta coefficient, Kolmogorov-Smirnov *p*-value, bipartite networks, co-citation network, keyword co-occurrence, most productive authors, top citation per article, international collaboration networks and author coupling were retrieved from https://cran.r-project.org/web/packages/bibliometrix/vignettes/bibliometrix-vignette.html.

1.3 Global Progression of Publications on Green Synthesis Nanoparticles

It has been established from a bibliometric analysis that the quantity of publications of a research field determines the overall output and efficiency yield of that field [12]. This current study revealed that a total of 710 publications was related to

Table 1.1 Summary of statistics recovered on green synthesis nanoparticles from WoS (1994–2019)

Representations	Counts
Period	2007–2019
Total number of articles	699
Number of research articles	711
Number of review articles	11
Source (journals, books, etc.)	243
Keyword plus (ID)	1195
Keywords used by author (DE)	1753
Average citations per documents	29.11
Authors	2473
Authors' participation	3199
Documents authored by single author	12
Documents authored by multiple author	2461
Documents per author	0.287
Authors per document	3.48
Co-authors per documents	4.51
Collaboration index	3.53

studies on the biogenic synthesis of nanoparticles. The 710 articles were obtained from 243 sources from WoS during the investigation period (2007–2019) (Table 1.1). The various researches on this field were carried out by 2473 authors, and the analysis confirms that the article/author versus author/article ratio was 0.287 and 3.48 correspondingly. The record shows that 12 authors published singly during the period of investigation and were removed from the total number of authors. Thus this indicates that 2461 authors were engaged in multiple-authored publications. Our analysis showed a collaboration index of 3.53, thus showing high participation of co-authorship for every publication (Table 1.1) [13]. A careful observation of the annual scientific production of articles showed an increase in research publications in the area of green synthesis within a space of 12 years (2007–2019) (Table 1.1). Although some variations were recorded in article production within some years, factors such as standard working laboratory environment and the appearance of new researchers in the field of biogenic synthesis coupled with financial support and improved skills were believed to be responsible for the stable boost and improvement in publications associated with the green synthetic field [14]. The scientific productivity related to research on biogenic synthesis, as shown by Lokta's law, revealed a β coefficient of 2.77 with a constant of 0.56 and the Kolmogorov-Smirnov p-value of 0.09 ($p < 0.05$) and goodness of fit of 0.92 (Fig. 1.1). The equation and R squared value of $y = 16.51x - 33.182$ and $R^2 = 0.880$ obtained from the linear regression plot of the number versus years of publication (2007–2018) confirmed that they were strongly correlated. An annual growth rate of 61.23% was recorded on research pertaining to the biogenic synthesis of nanoparticles. Compared to other research areas like organochlorine pesticides research with an annual growth rate of 5.13% [9] and *Plesiomonas*-related research with an annual growth rate of −0.8% [8] it is quite encouraging that research on biogenic synthesis is likely to keep

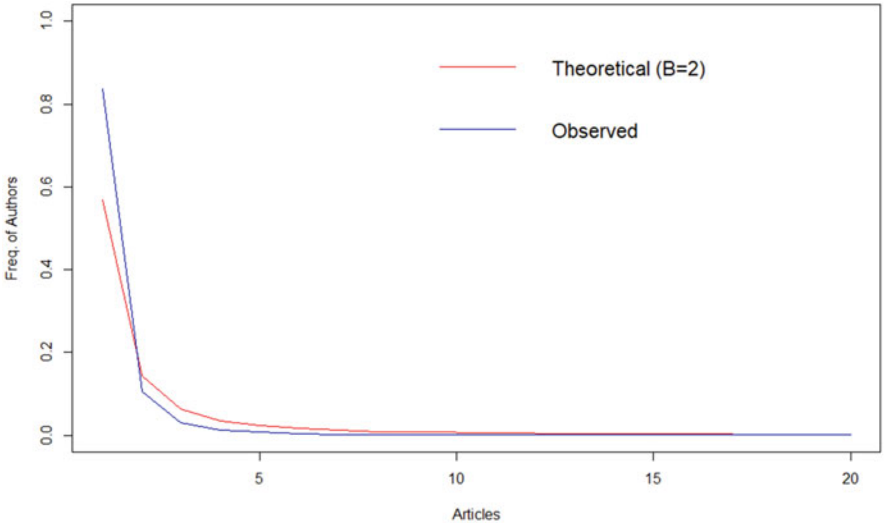

Fig. 1.1 Scientific output of green synthesis research based on Lokta distribution

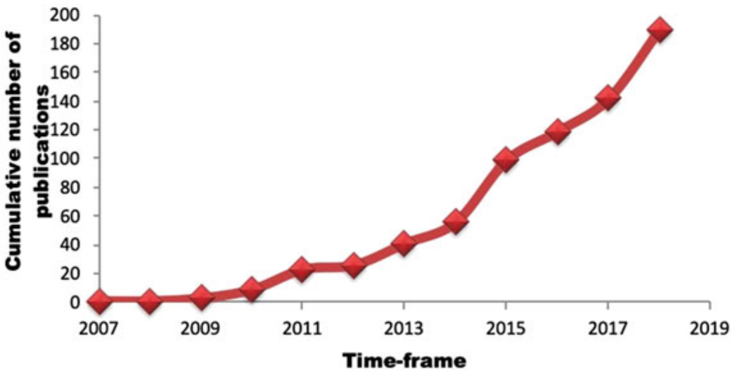

Fig. 1.2 Global trend in green synthesis nanoparticles (1994–2019)

growing each year. The significant difference sandwiched between the theoretical and observed Lokta distributions also signifies that the number of publications on the research of biogenic synthesis is expected to rise in the nearest future [15].

The timeline in Fig. 1.2 was fractionated into a period of 1 year each. Only one article, each on green synthesis nanoparticle, was published between 2007 and 2008 as retrieved from WoS. An erratic trend was noticed concerning the nature of published articles on green synthesis between 2009 and 2010, and amplification of published articles was seen in the year 2009 where a total of 32 publications (amounting to 4.50% of the total publication of 710) were made. Still, sadly a downward trend was observed in the year 2010 where publication of articles plummeted from 32 in 2009 to 9 articles (about 1.26% of the total article of 710)

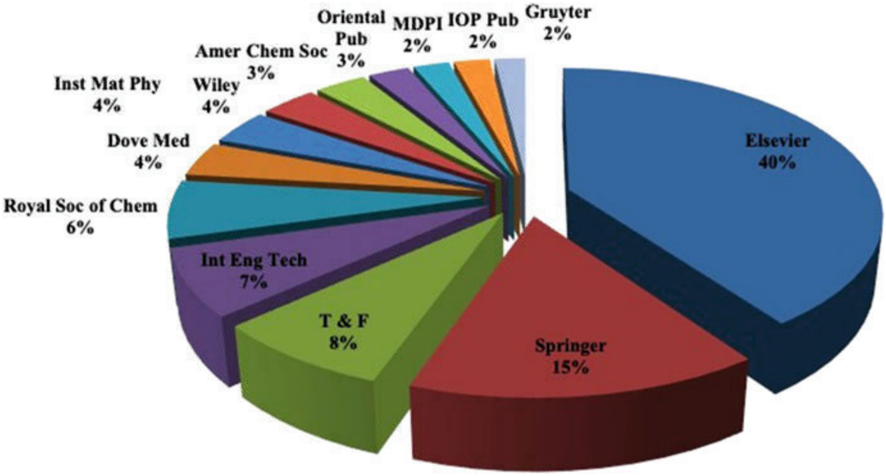

Fig. 1.3 Percentage of distribution of the top 25 publishers on biogenic synthesis (1994–2019)

in 2010, and publications of articles improved again in the year 2011 with a total publication of 23 (3.23% of 710), and this kept increasing till 2018. The sudden upsurge in the number of articles published started in 2015 with a publication record of 99 (13.94% of 710), reaching its climax in 2018 with a published article of 190 (26.76% of 710). Research productivity is believed to continue to rise in as much as the enabling environment is maintained in various countries where research on biogenic synthesis is carried out yearly.

Some other bibliometric indices examined were the type and numbers of publisher engaged in the production of articles on researches carried out in the area of biogenic synthesis of nanoparticle. Forty per cent of the publications on this area of research were published by Elsevier with *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* ($n = 29$) and *Materials Letters* ($n = 28$) occupying the first and second in the pecking order of the top 25 publishers with 29 and 28 articles, respectively (Fig. 1.3), while Springer with 15% ranked second in the order of publishers with *Journal of Cluster Science* ($n = 21$) and *Applied Nanoscience* ($n = 20$) topping the lead in Springer publisher category. The presence of Taylor and Francis was also noticed as shown in Fig. 1.3 with 8% of published articles of the top 25 publishers; taking the lead in this category is *Artificial Cells, Nanomedicine and Biotechnology* ($n = 18$) with a total of 18 publications. Some notable publishers in the top 25 categories are the International Engineering Technology (7%), Royal Society of Chemistry (6%), Wiley (4%), Dove Medical (4%) and Oriental publisher (3%) (Fig. 1.3).

1.4 Keywords Utilized in Biogenic Synthesis Research

Keywords used by authors in a publication symbolize the core information that the author is trying to articulate; in addition to this, they also capture, in summary, the idea expressed by the author. It is often a common practice for most journals to demand keywords ranging from three to eight depending on the journal type from authors before submission of their draft manuscripts can be considered for publications; this is usually required to facilitate online searches. In this report, the research trend of biogenic synthesis was carefully analysed using both keywords and keyword plus; the former predicts the progression trend of a precise subject matter obtained through WoS [16], while the latter is an effective and very useful means in capturing ideas and contents used in the investigation of this kind of green synthetic category [17].

Twenty most pertinent keywords comprising of both keyword plus and keywords obtained from the WoS database (journal list) on green synthesis nanoparticles are displayed in Table 1.2. Based on frequency of use it was established from Table 1.3 that keywords such as green synthesis silver nanoparticles nanoparticles and gold nanoparticles are often used by authors. These keywords were ranked first, second, third and fifth in author's keyword ($n = 286$, 210, 93 and 68; 40.28%, 29.57%, 13.09% and 9.57%) respectively. These terms are usually employed when carrying out research on the biological synthesis of various metal nanoparticles while other terms like TEM (transmission electron microscopy), XRD (X-ray diffraction), FTIR (Fourier transform infrared) and SEM (scanning electron microscopy) ($n = 36$, 35, 31 and 23; 5.07%, 4.92%, 4.36% and 3.23%) are characterization techniques used to ascertain the compositionstructure and morphology of the biogenic synthesized nanomaterials [7, 18, 19].

The keyword plus commonly used by authors are also displayed in Table 1.2. Keyword plus such as antioxidant, antibacterial and antibacterial activity ($n = 41$, 50 and 51; 5.77%, 7.04% and 7.18%) are often used to depict the biological activities performed on the biosynthesized nanomaterials [7].

Both keywords and keyword plus have seven keywords in common. These are biosynthesis, AgNPs, AuNPs, antimicrobial, antioxidant, antibacterial and antibacterial activity ($n = 25$, 45; 133, 210; 118, 68; 35, 35; 41, 25; 51, 33; 50, 90). Figure 1.4 presents the co-occurrence and interconnection of the highest 20 keywords used by authors in the area of biogenic synthesis of nanoparticles with every circled coloured node depicting a term; among the terms depicted by the coloured circle loop in Fig. 1.4 are biosynthesis, gold nanoparticles, metal nanoparticles, silver nanoparticles and leaf extract.

Table 1.2 Twenty most relevant keywords used for biogenic synthesis retrieved from WoS 2007–2018

Order	Keywords used by author	Publications (% of 710)	Order	Keyword plus	Publications (% of 714)
1	Green synthesis	286 (40.28)	1	Biosynthesis	258 (36.33)
2	Silver nanoparticles	210 (29.57)	2	Leaf extract	140 (19.71)
3	Nanoparticles	93 (13.09)	3	Silver nanoparticles	133 (18.73)
4	Antibacterial activity	90 (12.67)	4	Gold nanoparticles	118 (16.61)
5	Gold nanoparticles	68 (9.57)	5	Metal nanoparticles	81 (11.40)
6	Biosynthesis	45 (6.33)	6	Extract	63 (8.87)
7	TEM	36 (5.07)	7	Reduction	61 (8.59)
8	Antimicrobial activity	35 (4.92)	8	Au	60 (8.45)
9	XRD	35 (4.92)	9	Gold	60 (8.45)
10	Antibacterial	33 (4.64)	10	Biological synthesis	58 (8.16)
11	FTIR	31 (4.36)	11	Particles	55 (7.75)
12	X-ray diffraction	30 (4.22)	12	Ag	53 (7.46)
13	Silver	28 (3.94)	13	Antibacterial	51 (7.18)
14	Transmission electron microscopy	26 (3.66)	14	Antibacterial activity	50 (7.04)
15	Antioxidant	25 (3.52)	15	Size	46 (6.47)
16	SEM	23 (3.23)	16	Antioxidant	41 (5.77)
17	Electron microscopy	22 (3.09)	17	Antimicrobial activity	35 (4.92)
18	Green chemistry	22 (3.09)	18	Degradation	34 (4.78)
19	Antimicrobial	20 (2.81)	19	Aqueous extract	32 (4.50)
20	AgNPs	19 (2.67)	20	Mediated synthesis	32 (4.50)

1.5 Progression of Publications on Biogenic Nanoparticle Synthesis by Countries

Research outputs that correlate to the number of publications are articulated in Table 1.3 for the 25 most productive countries on green synthesis retrieved from WoS (2007–2018). To study this variable in this present bibliometric analysis, countries were categorized according to the number of publications from 2007 to 2018. Republic of India ($n = 133$; 18.92%) in South Asia ranked first among the top 25 most productive countries of the world carrying out active research on green synthesis nanoparticles (Table 1.3) with a total number of 133 publications amounting to 18.62% of the overall publications within the investigation period. It

Table 1.3 Twenty-five most productive countries on green synthesis retrieved from WoS (2007–2018)

Most productive countries								Summation of citations per country			
Order	Country	Publications	(% of 714)	Freq	SCP	MCP	MCP ratio	Order	Country	Total citations	Average publication citations
1	Indian	133	18.62	0.187	125	8	0.06	1	India	1039	7.81
2	Iran	81	11.34	0.11	77	4	0.04	2	Korea	941	18.45
3	Korea	65	9.10	0.09	57	8	0.12	3	Nigeria	881	10.87
4	China	52	7.28	0.07	41	11	0.21	4	Brazil	710	10.92
5	Pakistan	51	7.14	0.07	41	10	0.19	5	Japan	668	26.72
6	Saudi Arabia	33	4.62	0.04	30	3	0.09	6	Malaysia	654	12.57
7	Malaysia	25	3.50	0.03	20	5	0.20	7	China	503	15.24
8	South Africa	25	3.50	0.03	22	3	0.12	8	Taiwan	455	32.50
9	Egypt	20	2.80	0.02	14	6	0.30	9	Iran	331	18.38
10	Mexico	18	2.52	0.02	18	0	0.00	10	South Africa	213	10.65
11	Turkey	14	1.96	0.01	13	1	0.07	11	Italy	193	19.30
12	USA	14	1.96	0.01	5	9	0.64	12	USA	172	34.40
13	Brazil	14	1.96	0.01	12	2	0.14	13	Egypt	162	13.50
14	Nigeria	12	1.68	0.01	7	5	0.41	14	Thailand	123	4.92
15	Japan	12	1.68	0.01	6	6	0.50	15	Tunisia	113	9.41
16	Romania	10	1.40	0.01	6	4	0.40	16	Spain	99	49.50
17	Iraq	9	1.26	0.01	7	2	0.22	17	Hungary	96	48.00
18	Russia	9	1.26	0.01	9	0	0.00	18	Cameroon	94	10.44
19	Ecuador	9	1.26	0.01	8	1	0.11	19	Germany	92	15.33
20	Indonesia	7	0.98	0.00	6	1	0.14	20	Finland	67	67.00
21	Australia	7	0.98	0.00	5	2	0.28	21	Saudi Arabia	67	4.78
22	Czech Republic	6	0.84	0.00	2	4	0.66	22	Australia	57	11.40

(continued)

Table 1.3 (continued)

Most productive countries								Summation of citations per country			
Order	Country	Publications	(% of 714)	Freq	SCP	MCP	MCP ratio	Order	Country	Total citations	Average publication citations
23	Taiwan	6	0.84	0.00	5	1	0.16	23	Singapore	54	54.00
24	Thailand	5	0.70	0.00	2	3	0.60	24	New Zealand	51	25.50
25	Singapore	5	0.70	0.00	3	2	0.40	25	Czech Republic	49	24.50

SCP single country publications, *MCP* multiple country publications

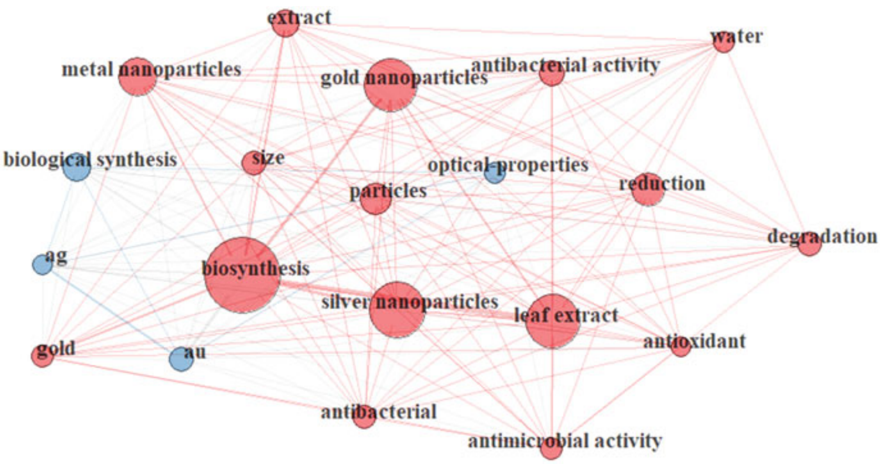

Fig. 1.4 Co-occurrence network of the top 20 terms on biogenic synthesis research. The sphere of the terms depicts the frequency of occurrences in studies. The line thickness between terms shows the degree of cooperation

has been documented in the scientific impact of developing nations of the world by Gonzalez-Brambila et al. [20] that the most used tool to evaluate a nation's scientific feet is international comparison with peer countries [21–23]. The scientific input based on publications and citations of each country was compared to their relative impact; it was concluded that India which was among the other eight developing countries of the world is reducing her science gap with research and development (R&D) investment and the velocity of their scientific impact is rising at more than double the rate of the developed world [20], and this may be the reason why India a newly industrialized country (NIC) would have the largest number of publications than Australia ($n = 7$; 0.98%) which is among the developed nations of the world. Secondly, it could be that in the last few years, an increasing number of developing countries like India, China and South Africa ($n = 133$, 52, 25; 18.63%, 7.28%, 3.50%) ranking 1st, 4th and 8th position, respectively, have declared publicly their dedication to science and technology as a primary pillar to their economic development making them to rank as one of the top most prolific countries [20]. Nigeria ($n = 14$; 1.68%) ranked 14th position, while Brazil ($n = 13$; 1.96%) ranked 13th position among the top 25 most prolific countries in terms of biogenic research output obtained from the WoS (Table 1.3). The encouraging research output for Nigeria might be as a result of the recent input on the part of the Federal Ministry of Science and Technology with the 2012 inauguration of Science, Technology and Innovation (ST&I) revised policy which was centred at building a virile Science, Technology and Innovation competence and potentials necessary to generate a modern economy; a number of specific objectives were highlighted by this agency. These objectives include facts acquisition, sustaining the Nigeria institutions through adequate funding, innovation, sustaining the diffusion of local technology, improvement of ST&I database, producing and sustaining reliable mechanisms for funding and commencing and strategizing on bilateral and multilateral collaboration in ST&I, among others. Also, the National Agency for Science and Engineering Infrastructure (NASENI) regarded nanotechnology as an essential upcoming area that the country is deficient and not making too much progress in expertise and skills. It was recommended by NASENI that the field of nanotechnology should be given more priority [24].

The stimulating research output by Brazil of 14 publications accounting for about 1.96% of the entire article published placed this country as number 13th in the area of biogenic nanoparticle synthesis. This outcome could be attributed to the fact that Brazil has declared her commitment to science and technology, knowing that it serves as a strong pillar to any country's economic growth [20].

Citation share is the number of cites that a given country received in comparison to the overall number of citations that were produced around the world in a given period [20]. The categorized order of these countries was slightly altered when productivity was calculated based on the number of citations per country. India still maintained itself in the list of top 25 prolific countries in terms of citations with a total citation of 1039 and an average publication citation of 7.81%, while Korea and Nigeria had 941 and 881 amounting to 18.45% and 10.87% of the total citation and were both 2nd and 3rd positions on the list of top 25 most productive countries based on the number of citations obtained per country. The efficient output of scientific research of a country is extensively based on the innovation in technology, population size, economic development and availability of fund for scientific research, existence of tranquil environment and excellent policies enacted by the government of that country, in addition to the existence of modern analytical instruments, and all these factors are exhibited by Korea [25].

The top 10 as regards average publication citations are India (7.81%), Korea (18.45%), Nigeria (10.87%), Brazil (10.92%), Japan (26.72%), Malaysia (12.57%), China (15.24%), Taiwan (32.50%), Iran (18.38%) and South Africa (10.65%), respectively. South Africa occupying the tenth position and number two position in Africa ranking behind Nigeria could be seen in their strong research and development initiatives in biology and agricultural sciences; they are at the same time bridging the gap with more research output in clinical medicine and biomedical research [20].

Figure 1.5 depicts the top countries' partnership network on green synthesis research. The bigger the coloured circle, the better the number of collaboration/teamwork among countries. In addition to this, a line having a thicker diameter in between two circles demonstrates the teamwork strength between the two countries. It is interesting to see that India, Iran, Saudi Arabia and Korea correspondingly exhibit the most collaborative partnership between 9 and 15 teamwork alliances with other countries. The generated cluster set-up discloses that India, Iran, Saudi Arabia and Korea top the list with a collaborative strength of 15, 10, 10 and 8, respectively, with the four countries going into partnership with each other and commonly entering into collaboration with Italy, Russia, South Africa, the USA and Taiwan as seen in Fig. 1.5. These four countries are the 1st, 2nd, 6th and 3rd on the list of most productive countries (Table 1.4), and their efficiency and productivity can be

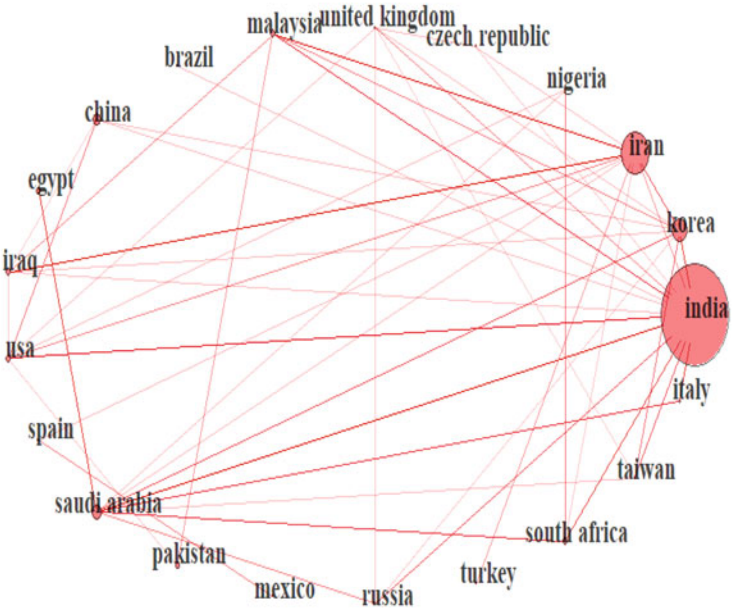

Fig. 1.5 Country collaboration network on green synthesis research. Each sphere depicts a country. The line thickness between shows the collaboration strength between different countries

attributed to a high level of participation in international and probably multinational collaboration with other countries, which is capable of impacting research visibility and citation rate [26–28].

India and Iraq showed a greater teamwork alliance with Saudi Arabia, the USA, Iraq and Malaysia, as seen in the high degree of the coloured lines between these countries. Malaysia teamwork alliance with five countries of the world, viz. Pakistan, Iraq, India, Iran and Korea, is quite noticeable (Fig. 1.5). Although China is not top on the list of collaboration networks, their teamwork with about 4 countries from the top 20 nations might be due to some of their government policies like funding researchers and scientists to pursue career abroad and framework programme co-sponsored by China and European Union (https://www.enago.com). Nigeria collaborative linkage with three countries, viz. the USA, Saudi Arabia and South Africa, can be attributed to the good work of Tertiary Education Trust Fund (TETFund) which is intended to afford opportunity to lecturers in Nigeria University, Polytechnic and College of Educations to be trained abroad, thereby enabling them to interact with other researchers worldwide and benefit from such exposures and interaction to the advantage of research output in Nigeria educational system.

Table 1.4 Bibliometric assessment on the 20 most prolific authors on green synthesis nanoparticles (1994–2019)

Order	Author	Affiliation	Nation	Publications	*h*-index	*g*-index	TC
1	Nasrollahzadeh M	Department of Chemistry, Faculty of Science, University of Qom, Qom	Iran	20	17	20	953
2	Sajadi SM	Department of Petroleum Geoscience, Faculty of Science, Soran University, PO Box 624, Soran, Kurdistan Regional Government	Iraq	14	12	14	712
3	Veisi H	Department of Chemistry, Payame Noor University, Tehran	Iran	12	9	12	368
4	Bora U	Medicinal Chemistry Division, Regional Research Laboratory, Jorhat	India	9	6	9	241
4	Hemmati S	Department of Organic Chemistry, Faculty of Chemistry, Bu-Ali Sina University, Hamedan	Iran	9	6	9	220
4	Maaza M	School of Physics, University of Witwatersrand, Johannesburg, South Africa	South Africa	9	6	9	433
4	Rostami-Vartooni A	Department of Chemistry, Faculty of Science, University of Qom, Qom	Iran	9	8	9	463
5	Fardood ST	Department of Chemistry, University of Zanjan	Iran	8	6	8	125
5	Govindarajan M	Division of Phytochemistry and Vector Biology, Department of Zoology, Annamalai University, Annamalai Nagar	India	8	7	8	239
5	Khan M	King Abdullah Institute for Nanotechnology, King Saud University	Saudi Arabia	8	4	8	134
5	Ramazani A	Department of Chemistry, University of Zanjan	Iran	8	6	8	125
5	Shameli K	University Technology Malaysia (UTM)	Malaysia	8	7	8	307
6	Nagabhushana H	Department of Studies and Research in Physics, University of Tumkur	India	7	6	7	225
7	Benelli G	Department of Agriculture, Food and Environment, University of Pisa	Italy	6	5	6	94
7	Jafarizadeh-Malmiri H	Department of Chemical Engineering, Sahand University of Technology	Iran	6	5	6	62
7	Kim YJ	Department of Oriental Medicine Biotechnology, College of Life Sciences, Kyung Hee University, Yongin, Korea	Korea	6	6	6	154

7	Philip D	Department of Physics, Mar Ivanios College, Thiruvananthapuram	India	6	6	6	697
7	Singh P	Department of Oriental Medicine Biotechnology, College of Life Sciences, Kyung Hee University, Yongin	Korea	6	6	6	278
7	Suresh D	Department of Studies and Research in Chemistry, Tumkur University, Tumkur	India	6	6	6	208
7	Wang C	Department of Oriental Medicine Biotechnology, College of Life Sciences, Kyung Hee University, Yongin	Korea	6	6	6	147

TC total citations

1.6 Most Prolific Authors Engaged in Green Synthesis Nanoparticle Research Retrieved from WoS (2007–2018)

Table 1.4 depicts the list of 20 most proactive authors on green synthesis nanoparticle research (2007–2018). These 20 most proactive authors contributed 171 research items of the total 710 publications, with an average of 8.55 articles per author. The total number of papers published by an author can be used to quantify his/her overall impact, although it may be overblown by an undersized number of a big hit that may not necessarily reflect the researcher's output if he or she is a co-author on a paper with many more authors. Seven of these authors published articles with a higher number than the group average (8.55). The authors are Nasrollahzadeh M (20 publications), Sajadi SM (14 publications), Veisi H (12 publications), Bora U (9 publications), Hemmati S (9 publications), Maaza M (9 publications) and Rostami-Vartooni A (9 publications) (Table 1.4). It is interesting to see that five out of these seven authors are from Iran; this could be as a result of the unwavering economy of Iran, which ranks second in the world on natural gas reserve and fourth in crude oil reserve. It has been opined that the economy potency of a country has an effect on the research productivity of that country [26, 28–30]. In addition, citation analysis (a procedure that measures the quality of an article by quantifying the number of times other researchers cited it in their published work) was obtained from WoS (2007–2018) and used for this bibliometric investigation. Citation per paper enables a comparison of researches irrespective of age. As regards citation, these 20 top prolific authors have an overall cumulative citation of 6185 as depicted by Table 1.3, and the 7 authors mentioned above have a citation of 953, 713, 368, 241, 220, 443 and 463, respectively (Table 1.4). The *h*-index summation of the top 20 proactive researchers was computed to be 140, with an average *h*-index value of 7. *h*-index is usually employed to compute the scientific research productivity of researchers [31]. Only three authors, as seen in Table 1.3, exhibited higher *h*-index value than the group average. These are Nasrollahzadeh M with *h*-index of 17, Sajadi SM with an *h*-index of 12 and Veisi H with an *h*-index of 9; other authors fell below the average group *h*-index.

1.7 Most Cited Journal on Green Synthesis Nanoparticle Research

The 710 articles considered under this bibliometric investigation were published in 243 journals from different scientific fields. The most cited journal in terms of green synthesis research during this survey period (2007–2018) is *Green Chemistry* published by Royal Society of Chemistry with total citations of 1715 of the overall citation of the 25 most cited articles gotten from WoS. The number of citations recorded for *Green Chemistry* above exceeds the average citations (232) of the most referenced publication, followed by *Colloids and Surfaces A: Physicochemical and Engineering Aspects* published by Elsevier Science BV with an overall citations of 763; this also surpasses the average citations 232 of the most cited article, while the