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Impact on the Study of Symbionts Associated in Lichen Assets with Research Productivity

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ABSTRACT: In forests, mountains, and other aquatic ecosystems, symbiotic microbes and their interactions in lichens are significant. The identification of lichens and isolation of actinobacteria from lichens are the various challenges of the study. A bibliographic analysis of lichens and their associated symbionts is scarcely reported. The biblioanalysis research in microbial communities related to lichen and their symbionts. The present study interconnects the research performance of symbionts associated with lichens from 1989 to 2022, based on parameters including a number of publications, citations, collaborations, type of communication, most preferred journals, papers, authorship pattern and highly productive authors. The study analyses 33 years (1989-2022) of publication data drawn from Web of Science citation database. As per the data collected, 10489 papers were published in 33 years with contributions from 31,939 authors in 1,645 journals. The United States has published the most articles (2367), followed by China (1630). Top most authors such as Bonfante P, Curie CR and Grube M. The best journal is New Phytologist and a total citation index of 24876. Lichens are important ecological indicators, and extensive study is needed to understand the role of symbionts associated with them. This research will provide prospective researchers with knowledge about leading contributors, most cited articles, and relevant journals and nations.

Keywords: Scientometric, lichens, symbionts, word cloud and citation.

INTRODUCTION

Lichens may form on a variety of substrates, since they are most commonly seen on barren rocks, tree trunks, or soil (Fig. 1). Their environment is much harsher than that of normal plants (Walser, 2004; Kershaw, 1985). Despite their diminished yield, lichens may be found in stony deserts and at heights of up to 7400 m. Lichens can also manage and survive in cold and humid environments. In some ecosystems, epiphytic lichen biomass can exceed several hundred kg. per hectare (Kershaw, 1985; Boucher *et al.*,1992; Coxson *et al.*,1995). Lichens are well known as bioindicators of particular environmental conditions, despite the exceptional resistance of many organisms to moisture loss, radiation, and extreme temperature variations. When metabolically active, lichens are extremely vulnerable to environmental conditions, but when dry and metabolically dormant, they may be able to withstand harsh conditions. This overarching thought serves as the foundation for the research, and systematic data collection has been done on the stability of the microbial community in lichens under changing abiotic conditions. The findings explain how a holobiont's bacterial component can survive in the face of adversity, which influences how this fabulous life form is viewed. The finding will provide profiles of uncultivable bacterial communities that show how diverse, similar, and dissimilar they are to this society. (Vishnu Raja *et al.*,2022).

As most academics are interested in data science and the literature accessible to the public is growing, scientists use data analytics to mine the literature. Access to publication metadata is available through several literature databases, including WoS, PubMed, and Scopus (Falagas *et al.*, 2008). R is a famous data analysis programme that has gained popularity over time owing to its efficiency, flexibility, and open source nature (Tippmann 2015).

Although scientometrics would not be a new field, the use of R has undoubtedly given it a modern feel. Many scientists have started using scientometrics to related literature. However, there are currently few publications in the subject of conventional biology. This research involves a thorough scientometric analysis of Web of Science (WoS) publications from 1989 to 2022. This research intends to examine basic statistical reports on year-to-year changes in publication, authors, links,

citations, etc., as well as thematic classification to identify distinct areas using Web of Science (WoS) concepts. The goal of the present study is to collect information on lichens and their symbionts using Web of Science (WoS) data, highlighting gaps in our understanding that need to be explored for the research community.

Lichens are keystone species in many ecosystems. They are economically significant and beneficial to the environment in a variety of ways. Some lichens are associated with the conversion of rocks into soil, aiding in the production of soil, enhancing soil quality, and enriching the soil essential for plant development. Lichens also contribute to the nitrogen cycle by fixing nitrogen from the atmosphere. Lichens are a vital source of food for humans all around the planet. The Iceland moss is an important food source in both northern European and American regions.

Petrologists and geologists can study and determine the age and other characteristics of rocks based on the size of these lichens. These species have long been famous for their various colorful compounds and dyes. They are an excellent source of natural dyes. The litmus test, pH indicator and other colors used in laboratories are derived from several lichen species. Lichens also act as a biodegradation agent, degrading polyester, lead, copper, radionuclides, and other contaminants that pollute the Earth (https://byjus.com/biology/economic-importance-of-lichens/).

Aside from the pharmaceutical industry, lichens are used extensively in the cosmetic industry and as a natural therapy for a variety of skin illnesses and rashes. Some lichen species are used to degrade microorganisms and other environmental reservoirs that cause serious infectious diseases in plants, animals, and humans. They are also an important source of nutrients for many aquatic creatures and are commonly employed as anti-infective agents in pharmaceutical businesses to make antibiotics, anti-mycobacterial, antiviral, and anti-inflammatory drugs.

There are very few works available on biblioanalysis research in microbial communities related to lichen and their symbionts. Thus, the current study reports on the research performance of lichen-associated symbionts from 1989 to 2022, based on a variety of parameters such as journals, bibliography, international and national collaborative partnerships, type of communication, most preferred journals, highly cited papers, authorship pattern, and most productive authors.

The foremost objective of this study is to investigate the research enactment of lichen and their symbionts research in worldwide perspective, as revealed in its publications productivity during 1989 to 2022. In certain, the study emphases on the following objectives: To study the

— Topographical wise dissemination of Publications and Countries

— Focused on the Significant keywords

— Highly productive authors Contribution to symbionts Research

— Bond of Research Collaboration among the Citations and Country

— Utmost desired journals

— Contribution to the Research on the Highly Cited Papers

MATERIALS AND METHODS

Data collection and processing: The unrefined metadata for lichens and symbionts from Web of Science (WoS) was collected in Plain text format and transformed using HistCite from 1989 to 2022. These entries include author, link, title, abstract, keyword, and citation information. Since only WoS supports downloading a maximum of 500 records at a time, the data is split into a maximum of 500 records. After exporting all the data to the local computer, the Bibliometrics program (Aria *et al.,* 2017) was used to extract it in R and convert it into a row and column format that could be easily manipulated.

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Scientometric analysis: The Web of Science (WoS), produced by Clarivate analysis in the United States, is an online version of the Institute for Scientific Information's Science Citation Index (SCT)-Expanded. The same "bibliometrix" package's "biblioanalysis" function was also utilised for the scientometric analysis. This creates statistics for a range of parameters, such as author, affiliation, and citation, which are subsequently saved in various formats. R scripts were used to calculate the number of authors, which was then saved to a comma separated value (csv) file. The top 20 authors, articles, countries, sources, and keywords from the bibliometric object were also determined using R's summary function. The programme "wordcloud" was used to create a word cloud based on the keywords and their frequency. The Web of Science (WoS) types was defined, and a graphic from the Web of Science (WoS) server were generated. The symbionts associated in lichens were discovered by the screened data.

Data analysis and Interpretation: The present study has enclosed lichens and their symbionts literature which is indexed by Web of Science virtual database. The total of Records: 10489, Authors: 31939, Journals: 1645, Cited References: 317383, Words: 16574 from the year 1989 – 2022 (June 2022). The data were analysed and presented in the form of tables and maps to enable the elucidation in the following sections.

RESULTS

Topographical wise dissemination of Publications and Countries: The year-by-year publication plot exhibits a random growth pattern rather than a regular development trend (Table 1). A reduction in the number of publications between 1989 and 2000 was soon followed by a newly expanded publication in 2001, with high initial and progressive research.

Similarly, the citation numbers were also gathered, and the overall citation counts for each year have been plotted. The data illustrates that the overall number of citations fell in 2000 and then increased dramatically in 2001. This is not surprising since newer papers have fewer citation sources. Moreover, the data revealed that these reports originated in 149 different countries. The most articles have been published (2367) in the United States, followed by China (1630). (Fig. 2). Germany (1096), Spain (693), France (673), the United Kingdom (666), Italy (572), Canada (558), Japan (526), Brazil (473), Australia (421), India (378), Switzerland (323), Austria (293), Denmark (278), Sweden (270), the Netherlands (228), Poland (188), Finland (180), Mexico (175), South Korea (169), Russia (155), Argentina (154) and Belgium published the fewest articles (153). The United States has collaborated with individuals and other nations the most than any other country (Fig. 3).

Focused on the Significant keywords: To extract the keywords from each paper, text mining was used. 16574 keywords were retrieved after cleaning the texts. The number of the keywords was also calculated and processed in order to build a word cloud using an R script. The greater the frequency of the terms, the larger the font size. A few terms were shown to have a significantly greater frequency. The terms "DIVERSITY" and "GROWTH" appear to be the most often used (Fig 4). The term "DIVERSITY" appeared 1432 times and "GROWTH" appeared 991 times in the 10489 recordings. The phrases "IDENTIFICATION," "FUNGI," "SYMBIOSIS," "FUNGUS," "SOIL," "EVOLUTION," "PLANTS," and "COMMUNITIES" were commonly used.

Highly productive authors Contribution to symbionts Research: As per the scientometrics, 31,939 authors have done the research on the symbionts associated in lichens. From that, top 20 authors were taken for further analysis (Fig. 5). Author Bonfante P is the top most scientists with 95 records, who is a Professor of Plant Biology, Department of Life science and System Biology, University of Turin, Italy (Table 2). She has an enormous research experience in the biology of plant – microorganism interactions. She participated in numerous research projects as the coordinator, received numerous awards, and engaged in scientific and editorial work. She is well known for her work in the fields of botany, fungus, and genes. The scientist has contributed considerably in the fields of botany, mycorrhiza, symbiosis, ecology, and fungi. Paola Bonfante's botany research has encompassed topics such as Medicago truncatula, Glomeromycota, and cell biology. She has studied mycorrhiza in a variety of disciplines, including 16S ribosomal RNA, biochemistry, Lotus japonicus, Glomus, and complementation. Her work explores issues like obligate, genome, and colonization, all of which overlap with symbiosis. Her scientific research interests include bacterial physiological phenomena and microbial ecology. Her research focuses on habitat, truffle, mycorrhizosphere, ecology, and molecular ecology, as well as fungi (https://research.com/u/paola-bonfante).

The author Currie C R. affiliated to University of Wisconsin, Madison, USA is the second top most scientist with 92 records. The focus of the researcher is symbiotic relationships between mammals and microorganisms. In this way, the symbiotic relationships that exist between animals and microorganisms thus forms the base of the study. A multidisciplinary approach that includes ecological, evolutionary, genomic, and microbiological methodologies to investigate the bacterial influence on the biological attributes of higher creatures has been ventured through this research. The quadripartite relationship of fungus-growing ants, their fungal cultivars, mutualistic bacteria, and specialist garden pathogens serves as our primary research system (https://bact.wisc.edu/people_profile.php?t=rf&p=ccurrie).

The author Grube M. is third top most scientist with 84 records; affiliated to University of Graz, Austria. His research focuses on determining the variety of microbial communities in different habitats, as well as the biotic and abiotic factors that influence them, as well as activities that could be used in environmental biotechnology. Molecular systematics, phylogenetic reconstruction, and their applications to systematics, biogeography, and evolutionary research are all parts of the field of phylogenetic analysis. Numerous facets of environmental microbiology and microbial ecology are the focus of this research. The purpose of this research is to identify the various microbial communities that exist in various habitats, the biotic and abiotic factors that affect them, and the activities that these communities engage in, that could be useful for environmental biotechnology. As a result, the current research focuses on how the diversity of edaphic bacterial communities is affected by the settlement of Antarctic marine animals, as well as the factors that affect the formation of interspecific associations using cyanolichens as models and functional genes related to nutrient cycling in search of potential applications in environmental biotechnology (Grube *et al.*, 2009).

Bond of Research Collaboration among the Citations and Country: Citation and country collaborations have seven types of clusters, representing different color ranges. Citation and authors have eleven clusters and a total of 995 link strength, of which 296 authors have the highest number of link with red color, different colors such as green, blue, yellow, purple, showing different link strength.

Utmost desired journals: This study describes that the New Phytologist is top most journal from our keywords lichens and symbionts (Table 3). The first top most journal New Phytologist has high documents (330) with impact factor (10.32) and total citation score (24876). New Phytologist offers exceptional, original, rigorous, and timely plant science and its applications research and study. Articles in the four areas Physiology & Development, Environment, Interaction, and Evolution address issues ranging from intracellular processes to global environmental change. Cross-disciplinary approaches are particularly encouraged, although the journal is organized as follows for everyone's

convenience. We acknowledge that methodologies ranging from molecular and cellular biology to functional genetics to modelling and systems-based approaches will be used across the full spectrum of plant research. The following policies on scope apply: fungal papers, fungal and microbial decomposition, plant-relevant soil processes and use of transgenic organisms (https://nph.onlinelibrary.wiley.com/journal/14698137).

The second top most journal is Frontiers in Microbiology and it has 279 documents with an impact factor of 6.06 and total citation score of 4691. Frontiers in Microbiology is a peer-reviewed publication that publishes thoroughly peer-reviewed research throughout the whole range of microbiology. An exceptional Editorial Board of foreign experts supports field chief editors Martin G. Klotz at Washington State University and Paul D. Cotter at Teagasc Food Research Centre. This interdisciplinary open access journal strives to disseminate and provide scientific knowledge and exciting discoveries to academics, universities, clinicians and the general public worldwide. As scientists gain a better understanding of the unknown majority of organisms and the abiotic factors that support microbes, making Earth suitable for all kinds of organisms, they can identify the rules by which microbes interact with co-existing pathogens and microorganisms throughout health and sickness. It is also clear that scientists are developing better and better approaches to reduce the adverse effects of human activities on the richness, diversity and distribution of life(https://www.frontiersin.org/journals/microbiology).

The third top most journal is Mycorrhiza and it has 199 documents with an impact factor of 3.85 and a total citation score of 7942. Mycorrhiza is an international magazine dedicated to study on mycorrhizas, which are the most diverse symbioses in nature, including plants and a variety of soil fungi from all over the world. Mycorrhiza research is covered in the journal, covering molecular biology of plants and fungus, fungal systematics, mycorrhiza growth and structure, and impacts on plant physiology, productivity, reproduction, and disease resistance. Coverage includes interactions between mycorrhizal fungus and other soil organisms, as well as mycorrhizal fungi's influence on plant biodiversity and ecosystem structure. Mycorrhiza publishes original papers, brief notes, review articles, opinions, and news items. It provides a place for fresh ideas and conversations, as well as the foundation for a global community of mycorrhizologists(https://www.springer.com/journal/572).

Contribution to the Research on the Highly Cited Papers: The details of highly cited 20 papers were given in the Table 4. The first highly cited paper is "The role of root exudates in rhizosphere interations with plants and other organisms" written by HP Bais, affiliated to Department of Biological Sciences, University of Delaware, Newark, DE, United States. His area of research focuses on Molecular biology, Botany and Microbiology. This paper was published in the journal "Annual review of Plant Biology".

This paper is about rhizosphere that is the millimeters of soil around a plant root where diverse ecological and biological processes take place. This work deals with the latest developments in understanding the function of root exudates with regard to interaction between the roots of the pants and other microbes, plants, and nematodes that are available in the rhizosphere. There is additional evidence that root exudates may be involved in the signaling processes that trigger the implementation of these interactions. From the molecular to the ecological scale, several beneficial and harmful plant-plant and plant-microbe relationships are emphasized and described. Moreover, techniques for addressing these interrelations in the laboratory are described (Bais *et al.,* 2006). This is the most cited paper (2259) published in the year 2006.

The second highly cited paper is "Natural products: A continuing source of novel drug leads" contributed by Cragg, G.M and Newman D.J, affiliated to Division of Cancer Treatment and Diagnosis, Frederick National Laboratory for Cancer Research, Frederick, MD 21702-1201, USA. This review paper was published in the journal "Biochimica et BiophysicaActa - General Subjects". The overview of the research covers the development of natural product medications, highlighting major pharmaceuticals naturally derived that have transformed the treatment of critical disorders. As a perennial source of vital substance for human ailments, nature continues to supply human beings and interdisciplinary knowledge stands as the way forward. The surge of genetic information resulted not only in fresh knowledge, but also in the application of combinatorial biosynthetic technologies and genome mining. The knowledge gathered has enabled the identification of previously undiscovered compounds. Computational chemistry may be used to optimize these source of bioactive structures, resulting in new therapeutic aspirants for a variety of ailments (Cragg *et al.*,2013). This paper is the second most highly cited (1496) and it is published in the year 2013.

The third highly cited paper is "Bacterial diversity and community along the succession of biological soil crusts in the Gurbantung gut Desert, Northern China" by Zhang, B.C, affiliated to Xiamen University, People's R China. This paper was published in the journal "Journal of Basic Microbiology". Bacteria are a significant component of semi-arid and arid environments. Proteobacteria, particularly *Microcoleus vaginatus*, dominates the algae, lichen crusts, and were the primary C-fixing bacteria is in biological soil crusts (BSCs). *Sphingomonas* sp., *Niastella* sp., *Pedobacterium*, *Candidatus solobacter*, and *Streptophyta* populations increased as desert soil evolved. Different bacterial OTU compositions were shown to have high connections with mineral elements, salinity, and enzymes. Furthermore, it brings out the fact that differences in microbial populations resulted in diverse ecological processes (Zhang *et al.,* 2016). This paper is the third most cited (1424) article published in the year 2016.

DISCUSSION

Although it was difficult to go through many reports manually and get significant data, always literature data presented a big data challenge (Sivarajah *et al.,* 2017). These, like other types of big data, are unevenly and irregularly distributed. The most challenging aspect of mining this data is that it is composed entirely of sentences and is multidimensional in nature (Oda *et al.,* 2008; Manconi *et al.,* 2012). Though scientometrics is still in its early stages, it has the potential to produce a plethora of information when applied to our chosen raw bibliometric data. In this study, we looked at WoS publications that were relevant to lichens and symbionts. R has attracted the interest of scientists because to its effectiveness in a wide range of data analytics fields, including biological data analysis, social network analysis, text mining, language processing, and many more (Tippmann 2015). The use of scientometrics in research has expanded during the last era (Gupta *et al.,* 2013; Djalalinia *et al.,*2017; Ouyang *et al.,* 2018).

Nevertheless, because to a lack of awareness about these approaches, the majority of them do not use any data analytics application, such as R, and instead do it manually. This research may help people adapt their lives to communicate between data professionals and conduct these inquiries. R also has a reproducible bibliometric analysis profile, and information from the R console can be readily transferred to external packages for statistical analysis and data representation. WoS is the most extensively used indexing method and offers trustworthy reporting (Falagas *et al.,* 2008). There are other databases such as PubMed and Scopus, and it is always possible to find reports in them that are not accessible in WoS. However, since most academics and researchers in the scientific stream adhere to WoS, we limited our investigation to WoS data.

The few studies that have used molecular fingerprinting techniques to delineate bacterial populations of lichens have had poor phylogenetic resolution and yielded conflicting results. Grube *et al.,* (2009) observed species-specific patterns in the community makeup of various lichen-associated microbial communities, and they advanced the concept that bacteria are important in the symbionts associated in the lichens. Cardinale *et al.* (2006) on the other hand, demonstrated that the structure of bacterial communities in lichens is unrelated to host species and that some lichen-associated bacteria may be opportunistic, mutualistic partners but may act as modifiers of nearby geographic soil ecosystems. Bacterial populations linked with lichens differ physically from those found in neighbouring soils. In close geographic location, various lichen species have different microbial communities, and the lichen group seems to be the predictive of community structure. Our findings support the concept that symbionts associated in lichen communities are organised, most likely as a result of their functional involvement in the lichen symbiosis, and they also imply that some microbial taxa are found in a wide range of lichen species. Although Alphaproteobacteria appears to be the most prevalent bacterial group associated within lichens, lichen species include a diverse range of bacteria from higher-order taxa, some of which are undiscovered. Finally, our findings imply that communities of microbes from different lineages may give N to lichens; however, the functional characteristics of lichen-associated bacteria remain mostly undiscovered. Taken together, the findings of this study add to previous evidence that bacteria are an important component of the lichen symbiosis (Bates *et al.,* 2011).

Symbionts associated in lichens are algae - fungi that grows on trees, rocks, and soil. Several populations of bacteria, actinobacteria, and cyanobacteria influence the symbiotic relationship of lichen formation in tree, rock, and soil. The species-specific microbial community in lichens growing on wood, rock, and soil is diverse and varied across geographic regions and substrate chemical composition. Nonetheless, there has been little study on corticolous symbionts associated in lichen community studies on *Roccella montagnei* in Tamil Nadu, India. Keeping the above-mentioned points in mind, and in order to solve the research problem, Vishnu Raja *et al.* (2022) are interested in using Illumina's next-generation sequencing approach to investigate bacterial population characterization of *Roccella montagnei* in corticolous lichens diverse agro - climatic and same tree substrate in distinct geographic regions. The geographical origin, biotic and abiotic components surrounding the environment, the substrate in which they form, and the microclimate environment that surrounds the lichen sample all contribute to the variation in bacterial communities in lichen. Because of chemical and physiological variations, lichen-associated bacteria colonise different thallus portions in varying abundances and patterns. This research and data examination has followed the existing research on the bacterial population stability in lichens under changing abiotic environments. The systematic research developments can be traced on this fascinating lifeform by demonstrating how the holobiont's microbial element preserves its viability in the face of adversity. Finally, the findings of this study will provide this society with uncultivable microbiome profiles, with their variety, similarity, and dissimilarity exposed by Vishnu Raja *et al.* (2022). Most importantly the sequence of the development in the field along with the details of the major research contributors can be figured out by narrowing down the data on the research as exemplified through this work.

Fig. 1. Various types of lichens are present in tree bark and twigs. (a) *Parmotrema* sp., (b) *Roccella montagnei*, (c) *Roccella montagnei*, (d) *Evernia* sp., (e) *Diriniria* sp., and (f) *Diriniria* sp.

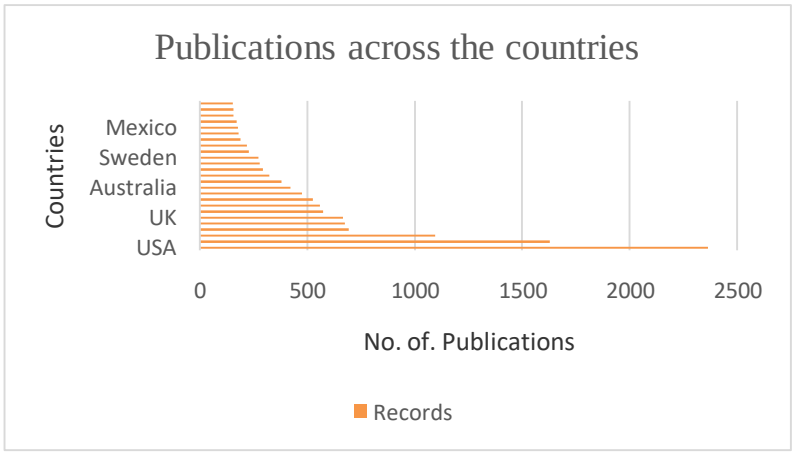

Fig. 2. Publications across the countries of symbionts associated in lichens.

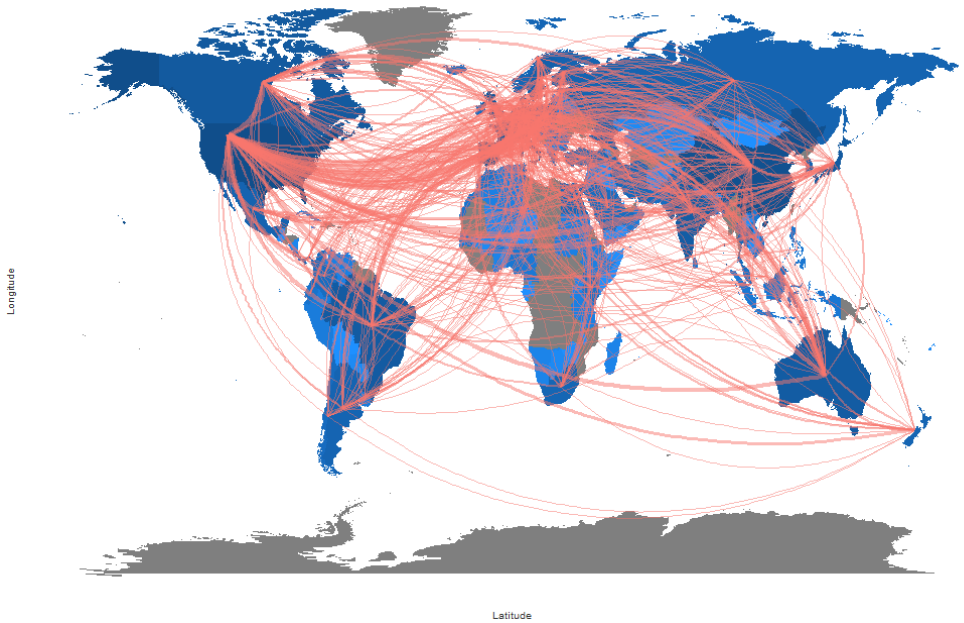

Fig. 3. Network overlay diagram shows the country collaboration of symbionts associated in lichens.

Fig. 4. The materials chosen for the study were used to create a word cloud of symbionts associated in lichens.

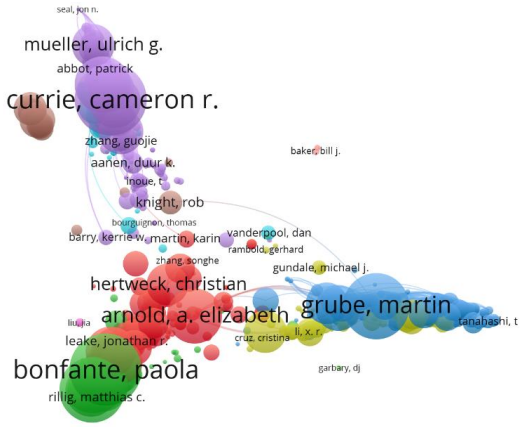

Fig. 5. Network overlay diagram shows the collaboration in citation and author of symbionts associated in lichens.

Table 1: Year wise publication documents and citation score of symbionts associated in lichens.

Sr. No.	Publication Year	Documents	Total Citation	CPP*
1.	1989	5	200	40
2.	1990	11	226	20.55
3.	1991	82	3581	43.67
4.	1992	62	4490	72.42
5.	1993	109	6724	61.69
6.	1994	120	6946	57.88
7.	1995	108	5011	46.4
8.	1996	111	5045	45.45
9.	1997	115	5393	46.9
10.	1998	141	7652	54.27
11.	1999	149	7557	50.72
12.	2000	159	1354	8.52
13.	2001	175	11117	63.53
14.	2002	199	11316	56.86
15.	2003	184	9967	54.17
16.	2004	217	11747	54.13
17.	2005	244	14711	60.29
18.	2006	231	14925	64.61
19.	2007	260	15502	59.62
20.	2008	294	17221	58.57
21.	2009	313	16553	52.88
22.	2010	366	17101	46.72
23.	2011	382	16996	44.49
24.	2012	406	15821	38.97
25.	2013	484	20223	41.78
26.	2014	463	14929	32.24
27.	2015	542	14523	26.8
28.	2016	567	15772	27.82
29.	2017	658	13353	20.29
30.	2018	698	11651	16.69
31.	2019	764	7709	10.09
32.	2020	867	4427	5.11
33.	2021	970	1129	1.16
34	2022	33	3	0.09
	Total	**10489**	**330875**	**1385.38**

*CPP – Citation Per Paper

Table 2: Author wise distribution with their affiliation of symbionts associated in lichens.

Sr. No.	Author	Documents	Total Citation	H-Index	Institution	Country
1.	Bonfante P	95	5555	4	University of Turin, Dept Life Sci & Syst Biol, Turin	Italy
2.	Currie CR	92	5881	59	University of Wisconsin System, Dept Energy, Madison, WI	USA
3.	Grube M	84	3596	52	University of Graz, Inst Biol, Graz	Austria
4.	Boomsma JJ	72	3379	63	University of Copenhagen, Dept Biol, Copenhagen	Denmark
5.	Martin F	66	5099	0	Inst Murciano Invest & Desarrollo Agr & Medioambie, C-Mayor S-N, Murcia	Spain
6.	Mueller UG	62	3946	48	University of Texas Austin, Dept Integrat Biol, Austin, Tx	USA
7.	Poulsen M	55	2233	5	Museum Sonderskov, Brorup	Denmark
8.	Wang Y	55	665	23	Beijing Institute of Petrochemical Technology, Beijing	People's R China
9.	Lutzoni F	45	3961	54	Duke University, Dept Biol, Durham, Nc	USA
10.	Kohler A	43	3232	2	Uit the Arctic University of Tromso, Dept Geosci, Tromso	Norway
11.	Li Y	43	536	2	South China Normal University, Sch Environm, Guangzhou	People's R China
12.	Muggia L	42	1001	26	University of Trieste, Dept Life Sci,Trieste	Italy
13.	de los Rios A	41	1072	2	University of Buenos Aires, Fac Ciencias Exactas & Nat, Buenos Aires, DF	Argentina
14.	Smith SE	40	2971	0	Univ Hosp Sussex Nhs Fdn Trust, Worthing Hosp, Worthing	England
15.	Wingfield MJ	37	1148	42	University of Pretoria, Forestry & Agr Biotechnol Inst, Pretoria	South Africa
16.	Balestrini R	36	1865	5	Consiglio Nazionale Delle Ricerche (CNR), Inst Sustainable Plant Protect, Turin	Italy
17.	Liu Y	36	740	5	Beijing Normal University, Sch Environm, Beijing	People's R China
18.	Berg G	35	1810	4	Def Pow Mia Accounting Agcy, Dpaa Lab, Joint Base Pearl Harbor Hickam, Honolulu, Hi	USA
19.	Hamada N	35	730	32	Central Research Institute of Electric Power Industry, Japan,Biol& Environm Chem Div, Komae	Japan
20.	Ott S	35	953	0	Technical University of Munich,Chair Timber Struct & Bldg Construct, Munich	Germany
	Total	**1049**	**50373**	-	-	-

(https://www.webofscience.com/wos/woscc/basic-search)

Table 3: Journal with records and Citation of symbionts associated in lichens.

Sr. No.	Journal	Impact Factor	Documents	Total Citation	CPP*	Subject category
1.	New Phytologist	10.32	330	20429	61.91	Plant Sciences
2.	Frontiers in Microbiology	6.06	279	4691	16.81	Microbiology
3.	Mycorrhiza	3.85	199	6918	34.76	Mycology & plant science
4.	Plos One	3.75	197	5817	29.53	Multidisciplinary Sciences
5.	Symbiosis	3.1	187	3036	16.24	Microbiology
6.	Microbial Ecology	4.19	136	4403	32.38	Ecology, Marine Freshwater biology & Micobiology
7.	Scientific Reports	4.99	134	2374	17.72	Multidisciplinary Sciences
8.	Plant and Soil	4.99	133	6711	50.46	Agronomy, Plant Sciences & Soil Science
9.	Applied and Environmental Microbiology	5	129	8594	66.62	Biotechnology Applied Microbiology
10.	Lichenologist	1.65	112	2143	19.13	Mycology & plant science
11.	Soil Biology & Biochemistry	8.54	112	5840	52.14	Soil Science
12.	FEMS Microbiology Ecology	4.51	99	4033	40.74	Microbiology
13.	Molecular Ecology	6.62	97	4839	49.89	Biochemistry Molecular Biology, Ecology & Evolutionary Biology
14.	Fungal Ecology	4.2	95	1636	17.22	Ecology &Mycology
15.	Science of the Total Environment	10.75	90	1993	22.14	Environment Science
16.	Frontiers in Plant Science	6.62	89	2015	22.64	Plant Sciences
17.	Mycologia	2.95	86	3031	35.24	Mycology
18.	Applied Soil Ecology	5.5	78	2271	29.12	Soil Science
19.	Proceedings of the National Academy of Sciences of the United States of America	12.77	70	8272	118.17	Multidisciplinary Sciences
20.	Environmental Microbiology	5.47	68	2736	40.24	Microbiology
	Total		**2720**	**101782**	-	-

*CPP – Citation Per Paper (Reference: https://www.webofscience.com/wos/woscc/basic-search)

Table 4: Top 20 papers with highly citation on symbionts associated in lichens. (Reference: https://www.webofscience.com/wos/woscc/basic-search)

Sr. No.	Title	Year	Author	No. of Authors	DOI	Source Title	Document Type	Highly Cited	Research Areas	Year Average
1.	The role of root exudates in rhizosphere interations with plants and other organisms	2006	Bais *et al.* (2006) University of Delaware, USA	5	10.1146/annurev.arplant.57.032905.105159	Annual Review of Plant Biology	Review; Book Chapter	2259	Biochemistry, Molecular Biology & Plant Sciences	133.88
2.	Natural products: A continuing source of novel drug leads	2013	Cragg *et al*. NIH National Cancer Institute, USA	2	10.1016/j.bbagen.2013.02.008	Biochimica et Biophysica Acta - General Subjects	Review	1496	Biochemistry, Molecular Biology & Biophysics	149.6
3.	Bacterial diversity and community along the succession of biological soil crusts in the Gurbantung gut Desert, Northern China	2016	Zhang *et al.* Xiamen University, Peoples R China	4	10.1002/jobm.201500751	Journal of Basic Microbiology	Article	1424	Microbiology	203.43
4.	Arbuscular mycorrhiza: the mother of plant root endosymbioses	2008	Parniske, University of Munich, Germany	1	10.1038/nrmicro1987	Nature Reviews Microbiology	Review	1064	Microbiology	70.93
5.	Latitudinal gradients in species-diversity - the search for the primary cause	1992	Rohde, Queensland Govt, Australia	1	10.2307/3545569	Oikos	Review	1054	Environmental Sciences & Ecology	34
6.	Biosynthesis of nanoparticles: technological concepts and future applications	2008	Mohanpuria *et al.* Punjab Agricultural University, India	3	10.1007/s11051-007-9275-x	Journal of Nanoparticle Research	Article	1009	Chemistry Science & Technology	67.27
7.	Bacterial endophytes in agricultural crops	1997	Hallmann *et al.* Julius Kuhn-Institute, Germany	4	10.1139/m97-131	Canadian Journal Of Microbiology	Review	997	Biochemistry & Molecular Biology Biotechnology & Applied Microbiology Immunology Microbiology	38.35
8.	Living in a fungal world: impact of fungi on soil bacterial niche development	2005	de Boer *et al.* Netherlands Institute of Ecology, Netherlands	4	10.1016/j.femsre.2004.11.005	FEMS Microbiology Reviews	Review	966	Microbiology	53.67
9.	Biological synthesis of metal nanoparticles by microbes	2010	Narayanan *et al.* Yeungnam University, South Korea	2	10.1016/j.cis.2010.02.001	Advances In Colloid And Interface Science	Article	962	Chemistry	74
10.	Mycorrhizas and nutrient cycling in ecosystems - a journey towards relevance?	2003	Read *et al.* University of Sheffield, UK	2	10.10046/j.1469-8137.2003.00704.x	New Phytologist	Review	932	Plant Sciences	46.6
11.	*Candida albicans* pathogenicity mechanisms	2013	Mayer *et al.* Hans Knoll	3	10.4161/viru.22913	Virulence	Review	840	Immunology Infectious Diseases Microbiology	84

			Institute, Germany							
12.	Natural products from endophytic microorganisms	2004	Strobel *et al.* Montana State University System, USA	4	10.1021/np030397v	Journal of Natural Products	Review	840	Plant Sciences Pharmacology & Pharmacy	44.21
13.	Nutrient-uptake in mycorrhizal symbiosis	1994	Marschner *et al.* University Hohenheim, Germany	2	10.1007/BF00000098	Plant And Soil	Article	816	Agriculture Plant Sciences	28.14
14.	The rhizosphere: a playground and battlefield for soil borne pathogens and beneficial microorganisms	2009	Raaijmakers *et al.* Institute of Biology Leiden, Netherlands	4	10.1007/s11104-008-9568-6	Plant And Soil	Review	759	Agriculture Plant Sciences	54.21
15.	The endophytic fungus *Piriformospora indica* reprograms barley to salt-stress tolerance, disease resistance, and higher yield	2005	Waller *et al.* University of Wuerzburg, Germany	12	10.1073/pnas.0504423102	Proceedings of The National Academy of Sciences of The United States of America	Article	687	Science & Technology	38.17
16.	The genome of *Laccariabicolor* provides insights into mycorrhizal symbiosis	2008	Martin *et al.* Universite de Lorraine, France	39	10.1038/nature06556	Nature	Article	675	Science & Technology	45
17.	Evolutionary origins and ecological consequences of endophyte symbiosis with grasses	2002	Clay *et al.* Indiana University Bloomington, USA	2	10.1086/342161	American Naturalist	Review	670	Environmental Sciences & Ecology Evolutionary Biology	31.9
18.	Endophytic fungi: a source of novel biologically active secondary metabolites	2002	Schulz *et al.* Novartis Pharma AG Immunol Hepatol & Dermato, Switzerland	5	10.1017/S0953756202006342	Mycological Research	Article; Proceedings Paper	667	Mycology	31.76
19.	454 Pyrosequencing analyses of forest soils reveal an unexpectedly high fungal diversity	2009	Buee *et al.* Universite de Lorraine, France	7	10.1111/j.1469-8137.2009.03003.x	New Phytologist	Article	644	Plant Sciences	46
20.	Molecular evidence for the early colonization of land by fungi and plants	2001	Heckman *et al.* St Lukes Hosp & Hlth Network, USA	6	10.1126/science.1061457	Science	Article	643	Science & Technology	29.23

CONCLUSIONS

It is the conviction of the researchers that this study stands as the most comprehensive scientometric and bibliometric analysis on symbionts associated in lichens. Study on researchers, institutions and nations on a particular field of study can better be done with the citation data based research, which helps to track the course of the research comprehensively by narrowing down the large amount of data. As this study has brought out the facts regarding the countries with the highest number of distributions, it implies the need for explorations from countries such as the United States, People's Republic of China, Germany, and citation based countries such as Brazil, Panama, Colombia, Costa Rica, and Uruguay. The most papers (330) were published in the journal 'New Phytologist,' with 31939 authors and 317383 citations. The first three writers published over 271 records, with the author Bonfante P having the most with 95 records and 6775 citations. Citations and the paper's H-index are used to assess its quality. In the scientometric study, 10489 documents were recorded. The Chinese Academy of Sciences, People's Republic of China, issued highly regarded works. The first highly cited paper is "The role of root exudates in rhizosphere interations with plants and other organisms" by HP Bais, affiliated to Department of Biological Sciences, University of Delaware, Newark, DE, United States. This paper has a very high citation (2259) and was published in the year 2006. Lichens are important ecological indicators. Understand the role of symbionts associated in lichens, extensive study in this field is necessary, including publications, records, authors, citation index, language, nation, and institutions. This research will facilitate prospective researchers to have the required knowledge regarding the leading contributors, most cited articles, most relevant journals and nations that offer maximum focus on this particular field of study.

FUTURE SCOPE

1. Conservation of lichens in various forest, terrestrial ecosystem of Kodiyakarai, Nagapattinam (Dt) and Pollachi, Coimbatore (Dt), Tamil Nadu, India.
2. Exploring the relationship between lichen population dynamics and climatic conditions.

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Conflict of Interest. None.

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