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Review Article

A Scientometric and Bibliometric Analysis for Actinomycetes Research - Current Status and Future Trends

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ABSTRACT

Actinomycetes are Gram-positive filamentous bacteria used as biocontrol agents against pathogens. Currently, little research on actinomycetes has been published in Indonesia. This study provides issues related to the most relevant keywords in actinomycetes, the most productive authors and countries on actinomycetes research, current research on actinomycetes, and future topics in actinomycetes research. This paper aims to understand the current status and trend of research on actinomycetes in biological control, especially their acts as biocontrol agents. We used VOSviewer and CiteSpace software to perform a scientometric and bibliometric analysis. Out of 452 Scopus publications published between 1971 and 2022. Research on actinomycetes has increased rapidly since 2000, leading to an exponential trend. The result showed that >50% of papers focus on Agricultural and Biological Sciences and indicate that actinomycetes are mainly applied as biocontrol agents. China is the most documented and powerful country, followed by the United States and Iran. In contrast, Indonesia ranks 19th in the world with nine published papers. Scientometric analysis shows Shahidi Bonjar nominated as the strongest citation burst author (4.01). Their topic is mainly on the biological control of pathogens by Actinomycetes, especially *Streptomyces* sp., while fungi are a dominant pathogen. These findings are related to bibliometric analysis, showing *Streptomyces* spp. and fungi are two primary keywords in the Scopus database, found on 183 and 139 documents. We found actinomycete research focuses on their ability to manage plant diseases naturally. In the future, we predict actinobacterial research is still essential to biological control, particularly those involving *Streptomyces* species. Also, several important topics were associated with their activities in controlling pests (nematode), postharvest disease, and growth promoter ability.

Keywords: bibliometric; biological control; CiteSpace; scientometric; *Streptomyces*

INTRODUCTION

Actinomycetes, a group of prokaryotes, are filamentous bacteria (Shahidi Bonjar *et al.*, 2006a; Barreto *et al.*, 2008; Tedsree & Tanasupawat, 2021; Díaz-Díaz *et al.*, 2022), which have the enormous composition of cytosine and guanine in their DNA (Tedsree & Tanasupawat, 2021). These bacteria, also known as aerobic and able to form mycelium (Barreto *et al.*, 2008), are found in soil and the rhizosphere and colonize the root surface (Shahidi Bonjar *et al.*, 2006b). Actinomycetes could be utilized as a biological control agent against plant pathogens. Actinomycetes are known to be capable of reducing pathogen activities, such as inhibitory activity of mycelial growth of *B. cinerea* on tomatoes by 52.38% to 96.19% (Lahmyed *et al.*, 2021); *in vitro* inhibition up to 85% hyphal desegregation, and antibacterial activity against soilborne-pathogens on *Solanum lycopersicum* and *Daucus carota* (Djebaili *et al.*, 2021); development suppression of *Alternaria brassicicola* on cabbage with increases of ≥80% protection level compared to control (Hassan *et al.*, 2017); reduce damping-off incidence of *Pythium aphanidermatum* in cucumber by up to 71% (Costa *et al.*, 2013); and inhibit mycelial growth of *Fusarium solani* by up to 70% (Torres-Rodriguez *et al.*, 2022). These pathogen suppressing activities are caused by their ability to produce several enzymes, i.e., amylase, protease, cellulase, chitinase, esterases, and lecithinase (Loliama *et al*., 2013; Lahmyed *et al*., 2021; Zulfa *et al*., 2021; Díaz-Díaz *et al*., 2022). In addition, they also produce antibiotics, antifungal substances, plant growth factors (Zulfa *et al*., 2021), siderophores, kaempferol, iso-scutellarin, umbelliferone, and Cichoriin (Jaber & Fayyadh, 2019). As a biological control against plant diseases, actinomycetes may be used as a substitute for pesticides (Djebaili *et al*., 2021).

Streptomyces spp. is the biggest and most common genus among this large Actinomycetes group (Shahidi Bonjar *et al*., 2021). This species has been known to produce famous antibiotics, including blasticidin-S and kasugamycin (Chaiharn *et al*., 2018; Djebaili *et al*., 2021). This genus has been widely used as a biological control of the pathogen. Several studies related to the use of *Streptomyces* as a biocontrol agent include: the use of *Streptomyces* to inhibit *Ganoderma* sp. (Zulfa *et al*., 2021), *Alternaria brassicicola* on cabbage seedlings (Hassan *et al*., 2017), charcoal rot disease on cowpea and mungbean (Jaber & Fayyadh, 2019), damping-off disease in cucumber (Costa *et al*., 2013), *Macrophomina phaseolina* and *Rhizoctonia solani* on *Phaseolus vulgaris* (Díaz-Díaz *et al*., 2022), *Fusarium solani* from tomato (Torres-Rodriguez *et al*., 2022), etc. In contrast, there is currently relatively little research on actinomycetes from Indonesia. There is no literature review related to actinomycetes research. This paper will focus on using actinomycetes as biological control agents to provide a comprehensive overview of numerous topics and current research. This study asked the following research questions: (a) what are the most relevant keywords for actinomycetes, (b) who are the authors and what are the countries producing the most research on actinomycetes, (c) what are the current issue focused on actinomycetes, and (d) what are the upcoming issue in actinomycetes research articles?

This study combined scientometrics and bibliometrics methods to answer these research questions. Scientometrics is the numerical investigation of science, science policy, and scientific communication (Ghaleb *et al*., 2022). This study include the analysis of author's and papers' co-citation and co-word (Chen, 2017). Scientometric analysis have been used on many research topics, such as construction project complexity (Ghaleb *et al.,* 2022), health communication in China (Dang *et al*., 2021), visualization of different field of research (Chen & Song, 2019), artificial intelligence and business management (Qiu *et al*., 2019), etc. Meanwhile, bibliometric analysis have been used to topics, such as solid waste in Iran (Mesdaghinia *et al*., 2015), mapping research spotlights for different regions in China (Hu *et al.,* 2017), global research trends in spinal ultrasound (Zhai *et al*., 2017), nanotechnology (Muñoz-Écija *et al*., 2017), remote sensing in human health (Viana *et al*., 2017), Covid-19 research (Hamidah *et al*., 2020), etc. Typically, a science mapping tool requires collecting bibliographic data from a research area. It provides a perspective of the whole area of knowledge, similar to CiteSpace and VOSviewer (Chen & Song, 2019). Finally, this paper aimed to understand the current topics and trends of research on actinomycetes in biological control, especially as biocontrol agents, by examining the Scopus database for actinomycetes-related papers. Results from this study is hoped to support researchers for further research proposals.

METHODS

Collection and Data Extraction

Actinomycetes as biocontrol agents has been studied globally and relevant search on proceedings, articles, publications, and reviews on this topic with no year of publication limits was conducted through the Scopus database (www.scopus.com). Searches was done on titles, abstracts, and keywords for a comprehensive literature review. The research query was carried out on 22 August 2022 with the following final keywords: (TITLE-ABS-KEY ("actinomycetes") AND TITLE-ABS-KEY ("biocontrol agent" OR "biological control)). Titles and abstracts search were done to identify studies that relevant to the issue of this study. After manually filtering, four hundred fifty-two documents remained in the final dataset that consisted of 404 journal articles (89.38%) and 48 papers in the book, book chapter, proceeding, etc. (10.62%). The database was extracted into CSV and RIS format and data was tabulated by Microsoft Excel 2016.

Bibliometric Analysis

A bibliometric search collects necessary academic documents. The bibliometric study was conducted using VOSviewer software version 1.6.18 (Leiden University, Leiden, The Netherlands). This software creates bibliometric maps to detect clusters and their reference relationships (van Eck & Waltman, 2010; van Eck & Waltman, 2014; Perianes-Rodriguez, Waltman, & van Eck, 2016). VOSviewer is a free software that can analyze large amounts of bibliometric data (van Eck & Waltman, 2011) and build networks from databases, including Web of Science and Scopus (Perianes-Rodriguez *et al.*, 2016). It provides a quick summary of each region's widely researched topics (Hu *et al.*, 2017), provides numerous styles of visualization (van Eck & Waltman, 2011), and allows users to choose between full or fractional counting methods (Perianes-Rodriguez *et al.*, 2016). Analysis followed the modified protocol of Dang *et al.* (2021). In this paper, we mostly performed co-occurrence and co-authorship analyses.

Scientometric Evaluation

The scientometric evaluation is the quantification of knowledge advancement research. It is a method for analyzing research impact and examining citation relationships to map a research area with Scopus trends. The scientometric analysis developed a network models that represents actinomycetes as a biocontrol agent. It assist researchers answer research questions and achieve research objectives. Scientometrics were analyzed with open-source software CiteSpace version 6.1.R3, which C.M. Chen devised at Drexel University in 2004 (https://citespace.podia.com). Initially, the Scopus database (in RIS/CSV format) was uploaded into Web of Science (WOS) by CiteSpace software. The following analyses were done to identify the study pattern: author co-citation, keyword co-occurrence, identifying a burst, and document co-citation and clustering analysis. The flowchart of data acquisition and analyses showed in Figure 1.

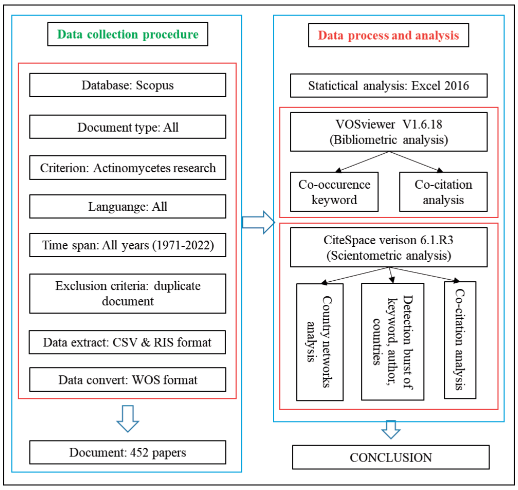

Figure 1. Flowchart of data acquisition and analyses

RESULTS AND DISCUSSION

Data Acquisition

The number of publications on actinomycetes as a biocontrol agent displayed fluctuating patterns (Figure 2). From 2000 upward increasing trends began and most articles were published between 2016 and 2021, with 34 and 31 published documents, respectively. The best model to describe this publication's progress was exponential.

Most paper cited occurred in 2006, with the number of documents cited being 810. Nineteen articles were published in 2006 with 43 citations per paper on average. As a comparison, in 2022, 11 documents were published with only three citations. In 2006, the most popular paper focussed on non-streptomycete actinomycetes as biocontrol agents of soil-borne fungal plant pathogens and as plant growth promoters. The article was published by El-Tarabily and Sivasithamparam (2006) and cited 179 times. In contrast, the actinomycetes research during the 2022 period focused on using *Streptomyces*.

In the past 50 years, 89.38% of publications related to actinomycetes as biocontrol agents were published in journals, while less than 11% of publications were published as Book chapters, reviews, Conference papers, Books, or Erratum. Most of these paper, about 273 papers (>50%), focus on Agricultural and Biological Sciences. These findings showed that actinomycetes were primarily applied in agricultural settings as a biological control agents. In comparison, actinomycete-related articles were also published in other subjects such as chemistry, engineering, pharmacology, physics, mathematics, etc. (Figure 3).

Co-occurrence Keywords Analysis

VOSviewer counted that 259 keywords were related to research on actinomycetes as biocontrol agents and divided into 7 clusters that consisted of Cluster 1 #*Streptomyces* spp. (●), Cluster 2 #actinomy

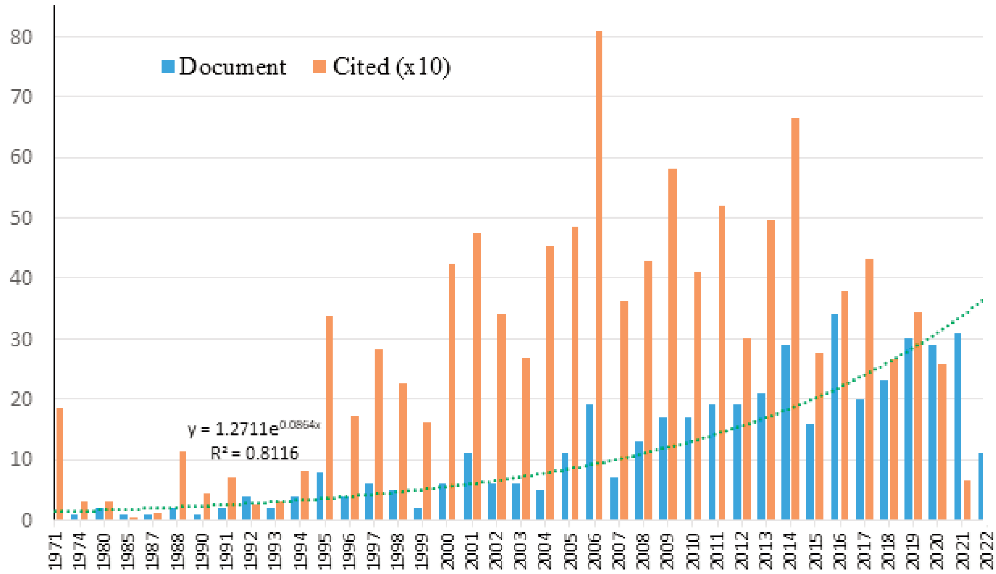

Figure 2. Number of documents and citation by year of publication

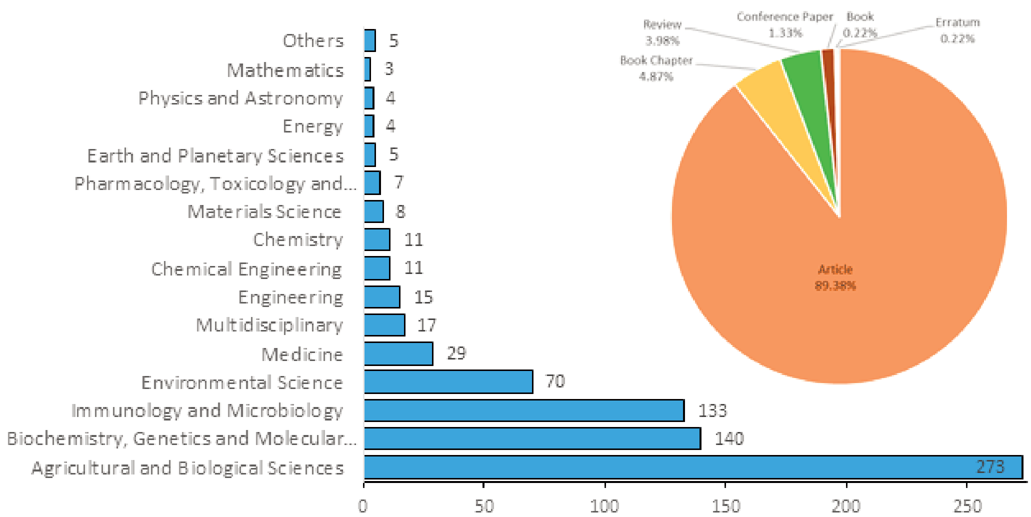

Figure 3. Subject area and type of document on Actinomycetes as a biocontrol agent

cetes (●), Cluster 3 #rhizosphere (●), Cluster 4 #microbiology (●), Cluster 5 #pest control (●), Cluster 6 #disease control (●), and Cluster 7 #sustainable agriculture (●) (Figure 4). The term used most frequently in the study was actinomycetes and found in 287 documents. The result showed that the dominant author keywords were actinomycetes and biological control, which were similar with cluster (Figure 4). Moreover, both actinomycetes and biological controls are related and have high link strength.

Co-occurrence between keyword showed in Figure 4B. Keywords that appears together more frequent will be red. Vice versa, light blue to blue colours indicate less frequent occurrences.

Highest keyword co-occurrence was dominantly in Cluster 2 (Table 1). It illustrated the role of actinomycetes as a bacterial group that is used as a biocontrol agent against fungi. The links display the proportion of connections between a specific nodes, whereas the total link strength indicates the size and strength of the links connected to a specific nodes (Ghaleb *et al.*, 2022). *Streptomyces*, a species of Actinomycetes, was the most common biological control agent. The entire link strength of this keyword was 2531, which was the third most frequent keyword that

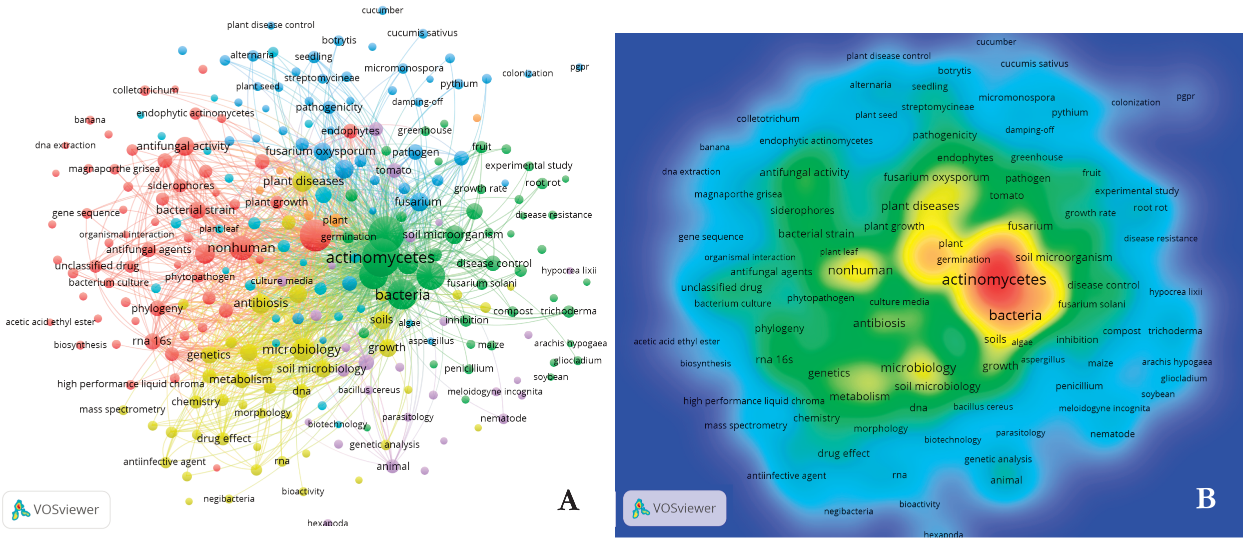

Figure 4. Network of keywords co-occurrence (A) and density of keywords co-occurrence (B)

Table 1. Most dominant keyword co-occurrence on research on Actinomycetes as a biocontrol agent in the Scopus database

Keywords	Cluster	Link	Total Link Strength (TLS)	Occurrence
Actinomycetes	2	258	3422	287
Biological controls	2	257	2803	251
Streptomyces spp.	1	257	2531	183
Biocontrol agents	2	253	2290	140
Bacteria	2	254	2276	158
Fungi	2	248	1997	139
Microbiology	4	241	1657	78

occurred. These findings demonstrated that actinomycetes was also used to control other diseases caused by nematodes, bacteria, and viruses, even though at relatively small numbers.

Similar results were drawn from the scientometric study by CiteSpace. Actinomycetes was the keyword with the strongest citation bursts (Table 2). Actinomycetes was most popular at the beginning of the 1990s. During this period, research on actinomycetes focussed on their taxonomic group of bacteria and capability as a biocontrol agent. However, current trending topics on actinomycetes were more specific, such as their antifungal activities of actinomycetes, role as growth promoters and bio-agents, and the biological properties of actinomycetes.

Author and Co-Author Analysis

According to the Scopus database, we selected the top 15 most productive authors based their number of publication. Based on the Scopus database, the most productive authors were authors who have published the most articles. This criterion ignored other variables and considered the number of papers they written either as the primary, second, or corresponding author. The highest number of documents were published by Shahidi Bonjar (15 articles), followed by El-Tarabily, who published 11 articles. While other author only published less than ten papers in Scopus. However, when considering author's position as the corresponding author, four writers were regarded as highly productive: Shahidi Bonjar, Wang W, Gopalakrishnan, and Ponmurugan. The four authors have each published five publications as corresponding authors (Figure 5).

In addition to being the most productive authors, some belonged to the most potent group of citation bursts. The scientometric analysis also resulted in Shahidi Bonjar being nominated as the most robust

Table 2. Top 25 Keywords with the strongest citation bursts

Keywords	Strength	Begin	End	1971 – 2022*)
Actinomycete	12.82	1995	2004	
Actinobacteria	10.07	2006	2011	
Growth	9.05	2015	2019	
Bacteria (microorganisms)	6.53	1997	2007	
Actinobacteria (class)	6.39	2006	2011	
Genetics	6.36	2013	2018	
Antifungal activity	6.03	2020	2022	
Isolation and purification	5.92	2014	2017	
Classification	5.84	2014	2019	
RNA 16	5.77	2014	2022	

*) Blue lines illustrates the interval time in citation bursts, while the red lines illustrates the time interval with the most robust citation bursts.

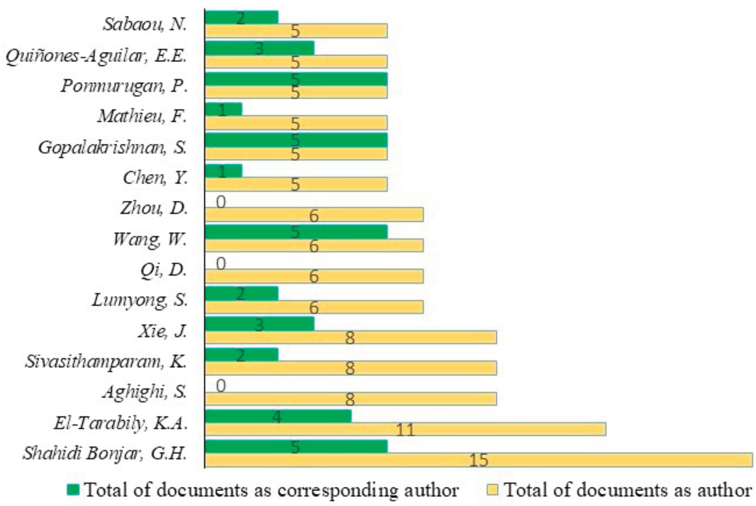

Figure 5. Top 15 authors with the most publication on Actinomycetes as a biocontrol agent

citation burst author. Citation burst describes the author whose publications were cited by others in a short period. For example, from 2005 to 2009, Shahidi Bonjar had the highest citation burst, 4.01 followed by Aghighi (Table 3). Shahidi Bonjar publishes the most topics, and Aghighi focused on the biological control of pathogens by using Actinomycetes (*Streptomyces* sp.) (Shahidi Bonjar & Aghighi, 2005; Shahidi Bonjar *et al.*, 2006a; Shahidi Bonjar *et al.*, 2006b). Fungi were a dominant pathogen used in their research. At the same time, Chen Y published only on *Streptomyces* sp. It suggested that the likelihood of the paper being cited by other authors increases with the number of publications published.

VOSviewer was used to identify the number of cited documents for each author. In VOSviewer, we set type analysis as citation documents, and the minimum number of document citations is 5. Out of 308 documents and 25 clusters found, authors such as Shahidi Bonjar, Adhghi, Chen Y, Wang X, and Pathom-Aree were not dominant. On the contrary, VOSviewer showed that Cao L, Yuan WM, Gopalkrishnan S and El-Tarabily KA, Castillo UF, and Broadbent P became the author with the most papers cited (Figure 6).

Size of a node represents how many citations each paper author has published (Figure 6A). A similar statement was also showed by the yellow to red colors in the density map (Figure 6B). In contrast, lines connecting the node illustrate who cited the document or are defined as connectivity between authors.

Several publication topics with large number of citations were presented in Table 4. Results showed that before the 20th century, popular research topics that were widely cited were related to actinomycetes and their characteristics. In the 2000s, research continued using actinomycetes to control plant diseases, especially diseases caused by fungi. Meanwhile, in the 21st century, research has developed, especially concerning Actinomycetes' beneficial effect on soil and plant health.

Most Productive Countries

Two analysis methods on the number of publications and citation impact of the published articles were used to determine most productive nations in terms of publications on Scopus database. The co-occurrence map analyzed the citation impact of papers published by each country in Scopus. In CiteSpace, results were obtained by using the following parameters "Period: 1971 to 2022 (slice length=1); Term Source: abstract, author keywords, title (DE), keywords plus (ID); Node type: Country; Selection criteria: g-index (k)=9; Pruning: pathfinder." Node size indicates the quantity of literature for that country (Figure 7). The outer circle of the node's

Table 3. Author with strongest citation burst

Authors	Strength	Begin	End	1965 – 2022*)
Shahidi Bonjar G.	4.01	2005	2009	
Aghighi S.	3.93	2005	2009	
Chen Y.	3.54	2017	2022	
Wang X.	3.28	2015	2022	
Pathom-Aree W.	2.97	2019	2020	
Cao L.	2.75	2004	2007	
El-TarabilY.K.	2.56	1997	2010	
Saadoun I.	2.40	2005	2006	
Lumyong S.	2.37	2019	2020	
Crawford D.	2.34	1995	2000	
Gopalakrishnan S.	2.28	2011	2014	
Sivasithamparam K.	2.21	1997	2009	
Li Y.	2.13	2017	2020	
Xue Q.	2.07	2019	2020	
Chen J.	2.03	2018	2022	

*)Blue lines illustrates the interval time in citation bursts, while the red lines illustrates the time interval with the most robust citation bursts.

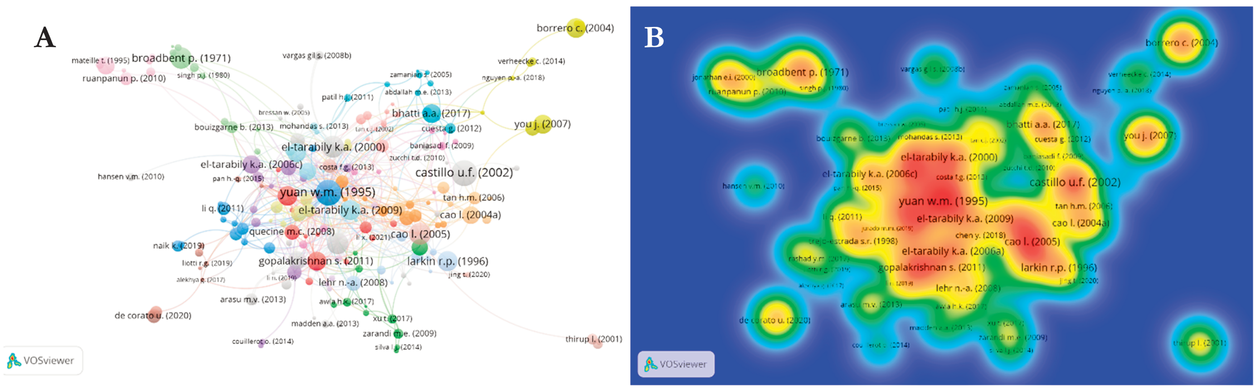

Figure 6. Document citation mapping cluster (A) and density map of author citation (B)

Table 4. Important study areas with citations

Author	Year	Research Topics	Cited by	Number of the document link	Sources
Broadbent *et al.* (1971)	1971	Bacteria and actinomycetes antagonistic to fungal root pathogens in Australian soils	176	9	Australian Journal of Biological Sciences
Yuan & Crawford (1995)	1995	Characterization of *Streptomyces lydicus* WYEC108 as a potential biocontrol agent against fungal root and seed rots	255	41	Applied and Environmental Microbiology
El-Tarabily *et al.* (2000)	2000	Biological control of *Sclerotinia* minor using a chitinolytic bacterium and actinomycetes	189	33	Plant Pathology
Castillo *et al.* (2002)	2002	Munumbicins, wide-spectrum antibiotics produced by *Streptomyces* NRRL 30562, endophytic on *Kennedia nigriscans*	254	9	Microbiology
Gopalakrishnan *et al.* (2011)	2011	Evaluation of actinomycete isolates obtained from herbal vermicompost for the biological control of *Fusarium* wilt of chickpea	142	14	Crop Protection
Bhatti *et al.* (2017)	2017	Actinomycetes benefaction role in soil and plant health	136	3	Microbial Pathogenesis

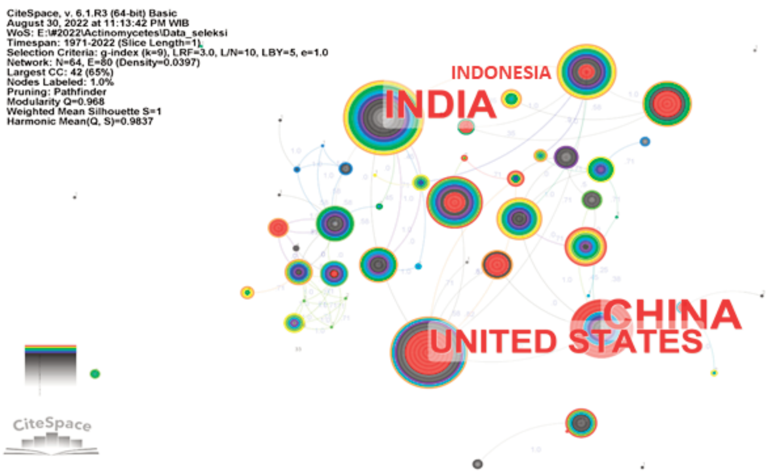

Figure 7. Country co-occurrence map of research on Actinomycetes as a biocontrol agent

color indicated country's literary influence; a thicker line in the outer circle means more influence. The gradient hue within each node showed the publication's premiere date in that country, with warmer colors representing more recent publications and cooler colors representing older ones. The line between nodes indicated when two countries are simultaneously mentioned in an article, with thicker lines indicating stronger part-nerships (Wu *et al.*, 2022).

Based on the Scopus database, the top 10 productive countries were China (97 papers), India (71 papers), the United States (33 papers), Brazil (25 papers), Egypt (25 papers), Thailand (22 papers), Iran (19 papers), France (17 papers), Australia (16 papers), and Japan (16 papers). In contrast, Indonesia ranked 19th worldwide with nine publications in the Scopus database. However, a large number of publications were not always followed by a large number of citations. China, India, and United States dominated countries that published on this topic (Figure 7). Based on CiteSpace analysis, India is not included in the countries with the most robust citation bursts (Table 5).

The United States and Iran were the most documented and influential nations after China. It is

Table 5. Top 10 countries with the most citation bursts

Countries	Document	Year	Strength	Begin	End	1971 – 2022*)
China	97	1971	12.66	2017	2022	
United States	33	1971	10.4	1971	2003	
Iran	19	1971	4.31	2005	2009	
Argentina	8	1971	4.08	2008	2010	
Brazil	25	1971	3.76	2003	2008	
Canada	10	1971	3.34	2000	2009	
Australia	16	1971	3.34	1971	2006	
UAE	10	1971	3.15	2000	2006	
Egypt	25	1971	3.12	1995	2004	
Morocco	8	1971	2.79	2009	2014	

*)Blue lines illustrates the interval time in citation bursts, while the red lines illustrates the time interval with the most robust citation bursts.

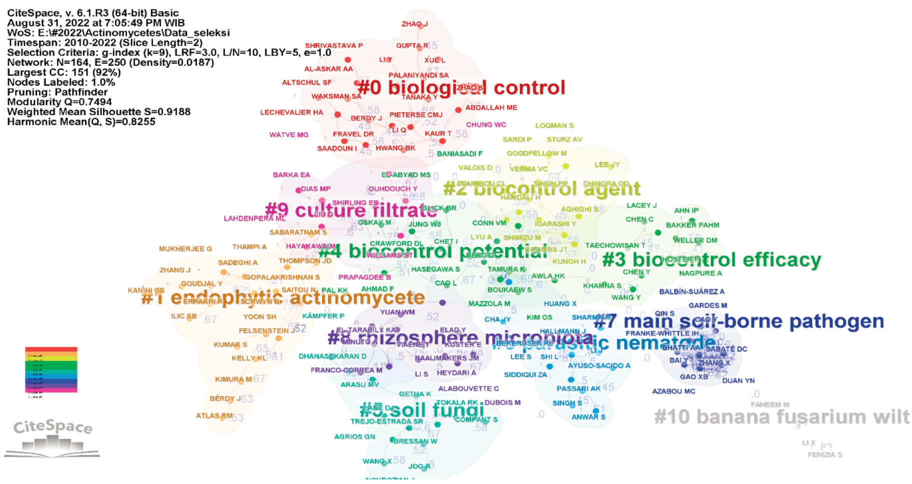

Figure 8. Cluster view of co-citation of research on Actinomycetes as a biocontrol agent ween in 2010-2022

important to note that the China node has a warmer hue, indicating that their articles were released earlier than average. This difference was due to countries with the most citation burst was not only determined by the number of publications but also by other factors, including the number of citations, centrality, degree, and frequency of citations, etc.

Author Co-Citation Analysis

Co-citation network generated by CiteSpace showed co-citation connections between publications and weight of them (Figure 8). Parameters used to generate this visualization were: (1) years span between 2010 to 2022; (2) term source = title/abstract/author/keywords/keywords plus; (3) node type = co-citation; (4) pruning = pathfinder/pruning the merged networks; (5) selection criteria was g-index factor k=9. The threshold was set to 20 to improve readability. After CiteSpace analysis, we found 164 nodes and 250 links. After finding the clusters, the maps were divided into 11 clusters at the modularity (Q), mean of silhouette (S), and harmonic mean (Q,S) of 0.7494, 0.9188, and 0.8255, respectively (Table 6). Modularity Q and mean silhouette scores vary from zero to one. The greater the degree of modularity Q, the networks were more organized. The greater the mean silhouette value, the greater the classification's credibility (Pasko *et al.,* 2021).

Biological control is the leading term in actinomycete research (Table 6). It was then followed by endophytic actinomycete and biocontrol agent. However, in 2021, research on biocontrol potential of actinomycetes against soil-borne pathogens became a hotspot.

Table 6. Summary of the largest 11 clusters

ClusterID	Size	Silhouette	Label Top Terms (Latent Semantic Indexing) LSI	Top Terms (Log-likelihood Ration) LLR	Average Year	The most cited document
0	21	0.89	Biological control	sustainable manner (58.4, 1.0E-4)	2015	(Jacob *et al.*, 2016)
1	20	0.973	Endophytic actinomycete	antifungal mechanism (29.41, 1.0E-4)	2015	(Tedsree & Tanasupawat, 2021)
2	17	0.928	Biocontrol agent	arab emirate (34.23, 1.0E-4)	2013	(de Oliveira *et al.,* 2010)
3	15	1.000	Biocontrol efficacy	biocontrol efficacy (45.2, 1.0E-4)	2015	(Jacob & Sudini, 2016)
4	14	0.926	Biocontrol potential	organic fertilizer (17.25, 1.0E-4)	2013	(Jacob & Sudini, 2016)
5	13	0.891	Soil fungi	soil fungi (40.45, 1.0E-4)	2013	(Goudjal *et al.*, 2014)
6	13	0.823	Parasitic nematode	novel strategy (34.59, 1.0E-4)	2018	(Ahmad *et al.,* 2021)
7	12	0.994	Main soil-borne pathogen	microbial environment (34.11, 1.0E-4)	2021	(Duan *et al.,* 2022)
8	12	0.881	Rhizosphere microbia	biocontrol agent (44.24, 1.0E-4)	2015	(de Oliveira *et al.,* 2010)
9	11	0.847	Culture filtrate	magnaporthe oryzae (26.34, 1.0E-4)	2014	(Toumatia *et al.,* 2015)
10	3	0.917	Banana fusarium wilt	biocontrol potential (27.41, 1.0E-4)	2021	(Zhang *et al.*, 2022)

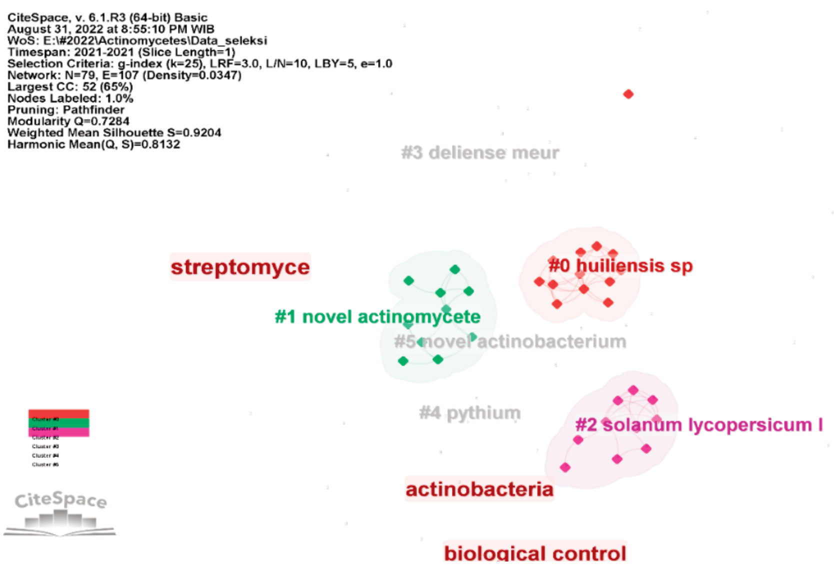

Figure 9. Research keyword clusters of research on Actinomycetes as a biocontrol agent in 2021

Future Research Trends in Actinomycetes

Future research trends of Actinomycetes as a biocontrol agent was predicted by scientometrics based on the Pasko method (Pasko *et al.*, 2021). We believe that a study focused on historical data could be considered thorough without looking into the future. In this study, we analyzed last year's articles (2021) to find novel research opportunities for potential research topics. We created a cluster map based on a keyword co-occurrence map created using the keywords of publications. After CiteSpace analysis, 79 nodes and 107 links were found. Moreover, the software grouped keywords in six clusters with modularity (Q) 0.7284 and silhouette (S) 0.9204 (Figure 9).

Table 7. Predictions for future research topics

Rank	Keyword	Frequency
1	*Streptomyces*	11
2	Biological control	9
3	Actinobacteria	9
4	Non-human	8
5	Actinomycete	8
6	Antifungal activity	7
7	Article	6
8	Controlled study	5
9	Rhizosphere	5
10	Biological pest control	5

Table 7 showed 10 most frequent keywords to appear. The cluster numbers were showed in decreasing occurrence. According to the bibliometric study, we hypothesized that the terms were the ten most frequent among 2021 publications. Soon, these will probably also be the main study areas. We predict that actinobacterial research will still be essential for biological control, particularly those involving *Streptomyces* species. In addition, several aspects will become essential topics associated with using actinomycetes—for example, their activities in the biological control of pests, antifungal activity, and within rhizospheres. In 2022, the results corresponded to the Scopus database, which showed the two most cited articles were on the biological control of Phytonematodes (Ahmad *et al.*, 2021) and postharvest pathogen by actinomy-cetes (Li *et al.*, 2021).

CONCLUSION

We concluded that the most keyword co-occurrence was dominantly about actinomycetes as fungi biocontrol. In addition, *Streptomyces* was the most common genus applied as a biocontrol agents. We found that the application of actinomycetes to control nematodes, bacteria, and viruses were still low. On the other hand, actinomycetes were dominantly applied to control fungi.

China published the most publication and was the most influential country in actinomycetes research, followed by the United States and Iran. Meanwhile, Indonesia ranked 19th in the world with nine publications in Scopus. However, in the last 50 years, Shahidi Bonjar from Iran had the highest citation burst, 4.01, and became the author who published the most paper in Scopus. Finally, in the future, we predict actinobacterial research will still be essential to biological control, particularly those involving *Streptomyces* species. Additionally, some issues connected to the application of actinomycetes will gain importance. These include their roles in natural pest control, antifungal activity, and rhizosphere.

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