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Original article

Antimicrobial Activity of Rhizospheric Actionobacteria: Bibliometric and Research Trend Studies

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Abstract

Rhizospheric Actinobacteria is Gram-positive bacteria that are known for antimicrobial activity. Currently, there is little bibliometric review on antimicrobial properties of soil Actinobacteria. This study provides relevant information about the most productive country, author, journal, and institution as well as the most relevant keywords and future topic about this topic. The data was collected from Scopus database and examined bibliometrically via VOSViewer software. Two hundred and three documents including noticeable contributions in Frontiers in Microbiology are obtained in this study. Publication trends have shown consistent growth since 2000, culminating in 2022. China appeared as the most prolific contributor, subsequent to Sathyabama Institute of Science and Technology as the leading institution. Popular research keywords include *Streptomyces*, nonhuman, microbial diversity, soil microflora, and enzyme productivity. Insights captured from this study contribute to more understanding of the rhizospheric Actinobacteria research field, guiding further research priorities and collaborations in antimicrobial activity studies.

Keywords: Global perspective, Soil Actinomycetes, *Streptomyce,* Antimicrobial agent, VOSViewer
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Introduction

Antimicrobial resistance (AMR) is becoming a critical worldwide medicine and public health concern (Rodrigues *et al.*, 2024a). The substantial frequency of resistant microbes has led to increased morbidity and mortality numbers due to the extensive usage of antibiotics globally (Helmi 2025; Tfaily & Borjac, 2025a). The World Health Organization (WHO) projected AMR could surpass to 10 million deaths yearly by 2050. Additionally, AMR does not belong solely to human, it also affects to plant agriculture. The indiscriminate use of pesticide could lead to global crop production lost between 20 and 40%. Opportunistic resistant microbes may infect both human and plant which cause public health and agricultural problems (Miller et al., 2022). To address this, researchers and other stakeholders are actively organizing action plans to develop novel antimicrobial agents for overcoming this pressing issue (Helmi 2025). They have looked into new bioactive substances and defined possible targets through Actinobacteria taxa (Rodrigues *et al.*, 2024b).

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Actinobacteria is one of the Gram-positive bacteria characterized by its sporigenous, high guanine-cytosine content (%GC), saprophytic, and primarily filamentous (Tfaily & Borjac, 2025a; Smati *et al.*, 2025; Wongsariya *et al.*, 2024). Streptomyces is a large genus that produces over three-fourth of antibiotics globally including streptomycin, gentamycin, and chloramphenicol (Rodrigues *et al.*, 2024b; Tfaily & Borjac, 2025b; Jangra *et al.*, 2025). This class of bacteria can be found in diverse ecosystems worldwide. This strain is mostly found in nutrient-rich rhizosphere soils with high percentages of microbial communities and secondary metabolite properties (Smati *et al.*, 2025; Sami *et al.*, 2025). That habitat is considered ideal for Actinobacteria due to their roles in plant material decomposition (Ardiono *et al.*, 2025). Besides, this group is still discovered in extreme and underdeveloped environments with particular geographical challenges and ecological niches (Helmi, 2025; Smati *et al.*, 2025; Ye *et al.*, 2023; Lu *et al.*, 2025). Those conditions impose selective natural selection of unique biosynthetic gene clusters (BGCs) such as non-ribosomal peptide synthase (NRPS), polyketide synthase (PKS), and amicetin (Zakalyukina *et al.*, 2024; Mohaptra *et al.*, 2025) 13,14. Those BGCs encode multiple secondary metabolites may promise as antimicrobial discovery sources (Helmi, 2025; Smati *et al.*, 2025; Lu *et al.*, 2025).

Actinobacteria has ability to compete coexisting microorganisms through inhibition depends on environmental factors (Wongsariya *et al.*, 2024). Numerous techniques have been applied such as cross-streak, agar diffusion, and broth dilution (Smati *et al.*, 2025; Tfaily & Borjac, 2025b; Bano *et al.*, 2022; Virués-Segovia *et al.*, 2022; Alazemi *et al.*, 2025). *Streptomyces* spp. isolate WP and

OP isolated from *Origanum majorana* rhizosphere revealed inhibition against *Staphylococcus aureus*, methicillin-resistant *S. aureus* (MRSA), *Escherichia coli*, and extended-spectrum beta-lactamases (ESBLs) *E. coli* (Tfaily & Borjac, 2025b). Additionally, 3 native *Streptomyces* isolates demonstrated fluconazole-resistant Candida spp. strains with 20-100% inhibitions (Arango-Gil *et al*., 2025). *Streptomyces* sp. SGI16 obtained from date palm rhizosphere illustrated suppression against wide Gram-positive and negative bacteria as well as fungal species through agar diffusion assays (Smati *et al*., 2025). Novel species *Kitasatospora hibisci* also exhibited wide antimicrobial activity against Gram-negative and plant pathogenic fungi (Xiao *et al*., 2025).

Several secondary metabolites and enzymes are identified as antimicrobial properties. These compounds have unique features compared to synthetic ones for structural complexity and vast scaffold diversity to complement synthetic and semisynthetic antimicrobials (Rodrigues *et al*., 2024a). New isolate *Microbacterium proteolyticum* LA2(R) from *Rauwolfia serpentine* rhizosphere had antibacterial activity that inhibited *S. aureus*, *Klebsiella pneumonia*, and *Salmonella abony* individually and through biofilm formation. This strain revealed n-hexadecanoic acid as major antibacterial compounds (Bano *et al*., 2022). Aside, novel kribbellichelin A and B from *Kribbella* sp. CA-293567 illustrated consequential results against *Candida albicans* with half inhibitory concentration (IC_{50}) of 1.7 and 3.2 µg/mL. However, those constituents proposed weak suppression against *Acinetobacter baumanii*, *Pseudomonas aeruginosa*, and *Aspergillus fumigatus* (Virués-Segovia *et al*., 2022). In addition, *Solanum tuberosum* rhizosphere *Nocardiopsis* sp. ICDN5 strain exhibited 33 volatile bioactive compounds that showed strong antifungal activity against multiple phytopathogens (Alazemi *et al*., 2025).

The aim of this study is to investigate trend of rhizopheric Actinobacteria related research regarding antimicrobial activity. Bibliometric analysis has been widely used in various researches globally, such as environmental microbiome, antimicrobial biosurfactants, and multidrug resistance in human urinary tract infections (UTI) (Putri *et al*., 2024; Alfian *et al*., 2025; Putri *et al*., 2025). According to the current studies, there is no bibliometric related to antimicrobial activity of rhizospheric Actinobacteria. Previous studies addressing the importance of bibliometrics in antimicrobial resistance (AMR) supressing actions that linear to the health and infected diseases. However, no bibliometric conducted in antimicrobial properties of soil Actinobacteria so that this study may be underline its importance in Sustainability Development Goal in discovery of land microorganism for human health. As a result, comprehensive profile literatures require several methods that can compromise core aspects. First aspect is about mapping collaboration worldwide as well as evaluating the institution and author performances. This aspect may help authors to connect, collaborate, and participate in related fields from different institutions and countries. Secondly, investigating the credible journal outputs, analyzing the citation, and highlighting most arising keywords are addressed in most bibliometric review. They help identify potential areas for further investigation and recommend scientists to develop the topic in research articles. These current report findings may present a visual summary and assess future research implications.

Methods

Data source and search strategy

Rhizospheric Actinobacteria antimicrobial activity publication trends were collected from the Scopus database from last 30 years (1995-2025). However, first document was published in 1996 so this year is considered as starting point. Scopus was chosen for its broad journal coverage including other databases that supports keyword searches and citation analysis (Falagas *et al*., 2008). Data collection was conducted on August 25, 2025. A bibliometric filter was generated using key terms TITLE-ABS-KEY "rhizosphere" AND "actinobacteria" OR "actinomycetes" AND "antimicrobial activity" OR "antimicrobial" OR "antimicrobe" in the title and abstract parts. Those keywords were chosen according to the topic relevance and inclusivity of each keywords synonyms.

Data collection and screening

Article terms especially author, year, subject area, document type, source type and title, keyword, affiliation, territory, and language were filtered manually from selected bibliometric from Scopus database.

Bibliometric analysis

In the meantime, co-authorship regarding country, author, and country as well as keyword co-occurrence were assessed by VOSViewer software. Those methods aimed to evaluate global profile, author collaboration, and map prevalent keywords over past the two decades (McAllister *et al*., 2022).

Results

Publication year to year

Since 2012, the number of publications on rhizospheric Actinobacteria as antimicrobial has been reliably rising. This is likely due to the growing research on drug discovery from undiscovered environments to inhibit different microbial activities. Maximum productivity was documented on 2024 with 33 articles produced. Publication numbers for 2025 may be increasing as stated on Figure 1.

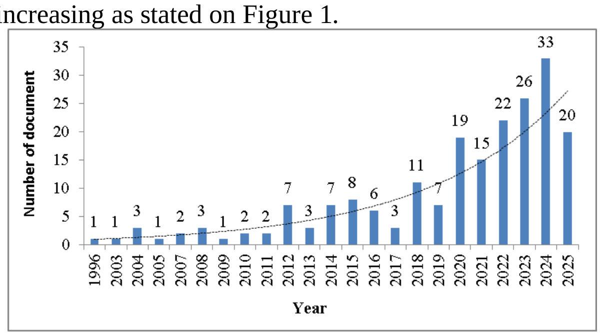

Fig. 1. The global trend of antimicrobial activity of rhizospheric Actinobacteria publications. A steady increase since 2017 was observed, reaching a peak in 2024.

A total of 203 documents were turned up by our analysis consist of 198 (97.54%) journals as dominant source. According to the Figure 2, articles topped the list followed by reviews by 181 (89.16%), among totals. Furthermore, English was written in majority of the documents with 198 (97.54%) of totals.

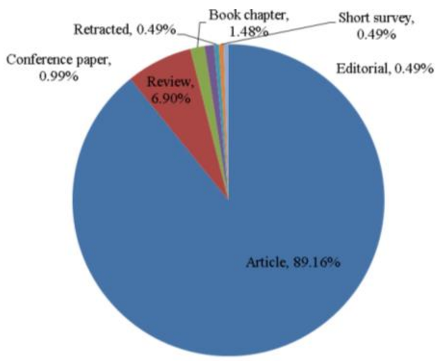

Fig. 2. Type of publications in antimicrobial rhizospheric Actinobacteria research.

Collaboration and contribution

The top 10 countries that conducting research on antimicrobial rhizospheric Actinobacteria research is listed in Table 1. China had the most publications of any nation with 56 documents and collaborating with 9 countries. China leads other countries due to research and development (R&D) policies in health and agriculture fields, massive publication funding, and talent return programs (Jonkers *et al*., 2020; Appelbaum *et al*., 2018).

Within the top ten lists, South Korea had the fewest number of publications and collaborated with a country. Indonesia was ranked on the 7th position together with Egypt. Nevertheless, no working countries found for the articles written. Figure 3a revealed the formation of 6 separate clusters visualized using VOSviewer, each represented by a different color: red (United States, Egypt, and Malaysia), green (Thailand and Portugal), dark blue (Germany, Brazil, and Ukraine), yellow (Italy and Tunisia), purple (China and South Korea), and blue (India).

Table 1. The top ten countries in the publication of antimicrobial activity of rhizospheric Actinobacteria research

Country	Number of document	%	Collaboration countries
China	56	27.59	9
India	48	23.65	5
United States	14	6.90	10
Saudi Arabia	14	6.90	9
Thailand	11	5.42	4
Germany	11	5.42	10
Indonesia	9	4.43	0
Brazil	8	3.94	2
South Korea	7	3.45	1

In 2018, countries such as India, the United States, and Egypt were the main contributors to this research. However, more recent studies have been mostly carried out in Italy, the United Kingdom, and Malaysia. Notably, China has emerged as the second-largest node after India, with a green hue in the figure, signifying a shift in research dominance toward this country in early 2020. Additionally, Malaysia appeared prominently in the latest movement which featured the brightest yellow color (Figure 3b).

Journal

Table 2 displayed the highest 12 journals with the most articles globally. Frontiers in Microbiology held on the first position (25, 12.32%) publications. This journal stand

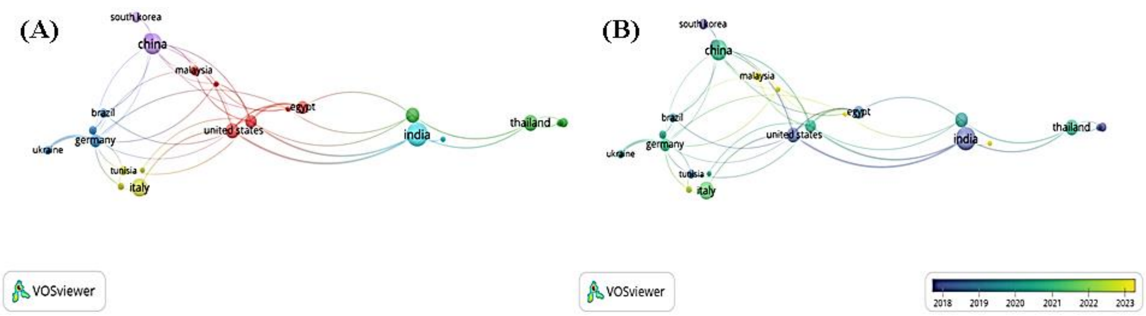

Fig. 3. Mapping the countries' collaboration. Size circle represents the number of collaborations with other countries. Visualizations in (a) network and (b) overlay. The size of the circles stipulates to the frequency of appearances. The degree of relationship is indicated by the length of the links. The distinct colors reveal different clusters. The color grade, from purple to yellow, shows the period from older to more recent publications.

Table 2. The top ten journals of antimicrobial activity of rhizospheric Actinobacteria research.

Source title	Documents	%	SCImago Journal Rank (SJR)	H-index
Frontiers in Microbiology	25	12.32	1.172	259
Microorganisms	5	2.46	1.009	112
International Journal of Systematic and Evolutionary Microbiology	5	2.46	0.749	205
Science of the Total Environment	4	1.97	2.137	399
Antonie Van Leeuwenhoek International Journal of General and Molecular Microbiology	4	1.97	0.485	124
Microbiological Research	3	1.48	1.62	126
Journal of Applied Pharmaceutical Science	3	1.48	0.277	60
Current Microbiology	3	1.48	0.621	114
Chinese Pharmacological Bulletin	3	1.48	0.153	19
Biocontrol Science and Technology	3	1.48	0.386	71
Asian Journal of Microbiology Biotechnology and Environmental Sciences	3	1.48	0	20
Archives of Microbiology	3	1.48	0.637	122

as the main platform due to the broad scopes in microbiology topics as well as has high journal impact factor (3.5) and cite score (5.1). Meanwhile, seven journals like Microbiological Research and Archives of Biology situated the lowest ranking.

Cited article

The top 8 cited articles displayed publications that are widely referenced in antimicrobial activity from rhizospheric Actinobacteria studies. The article with the highest number of citations is "Plant growth promoting and biocontrol activity of *Streptomyces* spp. as endophytes" with 486 citations published by International Journal of Molecular Sciences. This paper emphasizes comprehensive review about endophytic *Streptomyces* roles to combat resistant pytopathogens as a result of overuse pesticides (Vurukonda *et al*., 2018). "*Nocardiopsis* species: Incidence, ecological roles and adaptations" is the oldest one among others (Kumar *et al*., 2020). "Taxonomy and broad-spectrum antifungal activity of *Streptomyces* sp. SCA3-4 isolated from rhizosphere soil of *Opuntia stricta*" from Frontiers in Microbiology contains several top contributed and cited authors like Xie J, Qi D, and Wang W (Qi *et al*., 2019) (Table 3). It is because this research provides brief methodological reports in combining traditional cultivation and assay with omic studies so that the results are significant in ecological isolation and clinical relevance against a varied of phytopathogenic fungi.

Productive institution

Table 4 exhibited the top affiliations with the most publications worldwide. The Sathyabama Institute of Science and Technology (India) is the institution with the massive number of publications with 33 quotations. Additionally, Chiang Mai University (Thailand) contributed 5 documents from this period with 384 cited references. However, citation data Ministry of Education of the People's Republic of China and King Saud University did not appear after data deposit to VOSViewer.

Top author

According to Scopus and VOSViewer data, they revealed that Radhakrishnan M, Gromyko O, and Fedorenko V contributed 7 works each. Nevertheless, Chinese authors such as Wang W, Qi D, Zhou D, and Xie J were the most cited scientists in this field with 156-221 citations, separately (Table 5).

Subject area

With 44.34% research articles, Immunology and Microbiology was illustrated as the most popular subject area. It was succeeded by Biochemistry, Genetics, and Molecular Biology with lesser numbers. Besides, Earth and Planetary Sciences published only 4 (1.97%) papers in total (Table 6).

Table 3. The most cited articles on rhizospheric Actinobacteria as antimicrobial properties study

Authors	Title	Journal	Year	Cited by
Vurukonda *et al*. 2018	Plant growth promoting and biocontrol activity of *Streptomyces* spp. As endophytes	International Journal of Molecular Sciences	2018; 19(4): 952	486
Kumar *et al*. 2020	Plant growth-promoting bacteria: Biological tools for the mitigation of salinity stress in plants	Frontiers in Microbiology	2020; 11: 01216	452
Bennur *et al*. 2015	*Nocardiopsis* species: Incidence, ecological roles and adaptations	Microbiological Research	2015; 174: 33-47	130
Qi *et al*. 2019	Taxonomy and broad-spectrum antifungal activity of *Streptomyces* sp. SCA3-4 isolated from rhizosphere soil of *Opuntia stricta*	Frontiers in Microbiology	2019; 10: 01390	103
Abdelgawad *et al*. 2020	Actinomycetes enrich soil rhizosphere and improve seed quality as well as productivity of legumes by boosting nitrogen availability and metabolism	Biomolecules	2020; 10(12): 1675	92
Aralappanavar *et al*. 2024	Effects of microplastics on soil microorganisms and microbial functions in nutrients and carbon cycling – A review	Science of the Total Environment	2024; 924: 171435	90
Chaudhary *et al*. 2021	Illumina based high throughput analysis of microbial diversity of maize rhizosphere treated with nanocompounds and *Bacillus* sp.	Applied Soil Ecology	2021; 159: 103836	82
Feng *et al*. 2021	Complete genome sequence data of rare actinomycetes strain *Saccharothrix texasensis* 6-C, a biological control agent for potato late blight	Molecular Plant-Microbe Interactions	2021; 34(5):571-574	71

Table 4. The institutions with the most publications

Institution	Country	Document	%	Citation
Sathyabama Institute of Science and Technology, Chennai	India	9	4.43	33
Ministry of Education of the People's Republic of China, Beijing	People's Republic of China	6	2.96	-
King Saud University, Riyadh	Saudi Arabia	6	2.96	-
Universität des Saarlandes, Saarbrucken	Germany	6	2.96	63
Ivan Franko National University of Lviv, Lviv	Ukraine	6	2.96	63
Chiang Mai University, Chiang Mai	Thailand	5	2.46	384
Sichuan Agricultural University, Ya'an	People's Republic of China	5	2.46	108
Chinese Academy of Tropical Agricultural Sciences, Haikou	People's Republic of China	5	2.46	221

Table 5. The top authors contributed to antimicrobial activity of rhizospheric Actinobacteria

Author	Document	Citation	Strength	Scopus ID	H-index
Fedorenko VA	7	64	7	7103033524	23
Gromyko OM	7	64	7	6507657157	12
Radhakrishnan M	7	25	5	56232084300	21
Tistechok S	6	40	6	55735889800	8
Luzhetskyy AN	6	63	5	57204143369	41
Manigundan K	4	8	4	57189456294	11
Xie J	4	221	4	7402994627	35
Ye J	4	20	2	57211972275	5
Pathom-aree W	4	52	0	13905116500	32
Qi D	3	184	3	58075717600	19
Wang W	3	156	3	57192615447	24
Zhou D	3	184	3	55915763600	22
Zhao K	3	77	0	57696208300	3
de Araujo JM	3	34	3	35892018600	12
de Souza Lima GM	3	34	3	57217356610	11
Gopikrishnan V	3	3	3	55353242600	15
Huang D	3	3	2	57198262952	6

Table 6. The subject area with the most publications

Subject area	Document	%
Immunology and Microbiology	90	44.34
Biochemistry, Genetics and Molecular Biology	68	33.50
Medicine	58	28.57
Agricultural and Biological Sciences	53	26.11
Pharmacology, Toxicology and Pharmaceutics	31	15.27
Environmental Science	30	14.78
Chemistry	12	5.91
Chemical Engineering	10	4.93
Multidisciplinary	8	3.94
Earth and Planetary Sciences	4	1.97

Keyword

Based on the Scopus database, "Actinobacteria" stood for the first place occurance next to the "rhizosphere" and "antimicrobial activity" with 145, 135, and 133 keywords. Moreover, VOSViewer finding demonstrated more comprehensive keyword information. The first 3 keywords had 38 links and clustered in the first cluster. In this cluster, "Actinomycetes" had the oldest range of publication while the "phylogenetic tree" had the most recent one. "Nonhuman", "*Streptomyces*", and "rhizosphere" were the most often cited keywords with 29.53, 29.31, and 26.68, respectively (Figure 4a).

Otherwise, cluster 2 and 3 had lesser occurrences and links overall. "Microbiology", "genetics", and "soil microbiology" as well as "microbial community", "enzyme productivity", and "DNA extraction" led the nodes in the clusters between 37 and 38 links. Nonetheless, "soil microflora" showed the newest trend keyword with mean year of 2022.11 as well as the highest reference with 32.89 (Figure 4b).

Discussion

Current status

This study provided a total of 203 documents related to the emergence of antimicrobial activity of rhizospheric Actinobacteria as a guide for further investigations. The results revealed that there is a gradual increase in this topic publication in 2012.

Regarding to our findings, China is the most prevalent country in this topic. This research is gradually rising altogether with exceptional human and agricultural health in

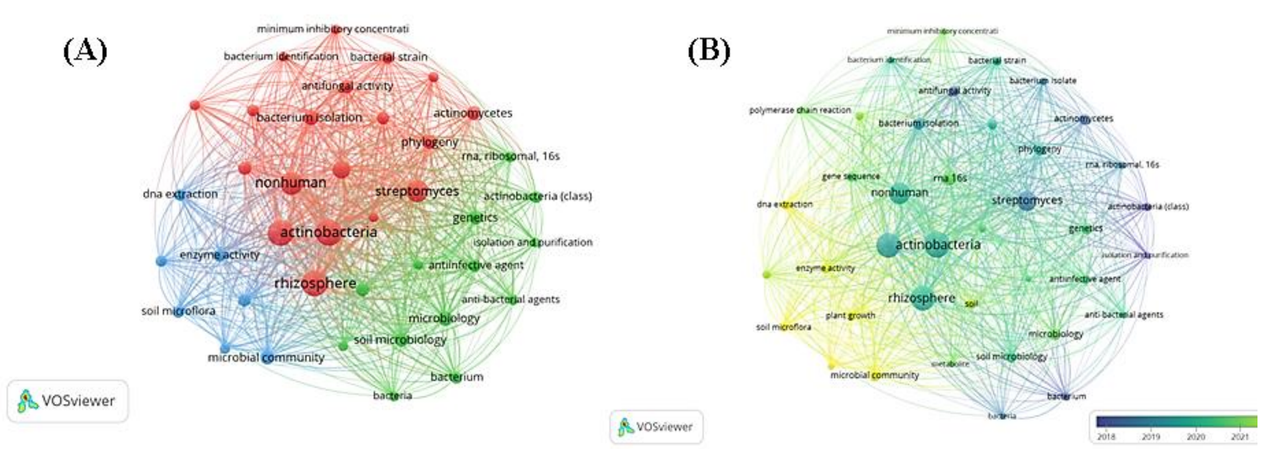

Fig. 4. Mapping of occurrence terms retrieved from titles and abstracts in rhizospheric Actinobacteria as antimicrobial-related research articles conducted by VOSviewer. Size circle represents the number of collaborations with other countries. Visualizations in (a) network and (b) overlay. The size of the circles stipulates to the frequency of appearances. The degree of relationship is indicated by the length of the links. The distinct colors reveal different clusters. The color grade, from purple to yellow, shows the period from older to more recent publications.

China. Starting in 2012, the published documents notably inclined and indicated this field had high research productivity in current periods. This output is mainly contributed by Ministry of Education of the People's Republic of China; Chinese Academy of Tropical Agricultural Sciences, Haikou; and Sichuan Agricultural University, Ya'an. China has this reliable outcomes due to its significant investments in research funding and its rapidly growing scientific output, the global hub for rhizospheric Actinobacteria research is about to move from India. China contributed 19% of all Scopus-indexed papers by 2017, a considerable increase from 10% in 2005, placing it second in the world for research output. This growth is driven by substantial government funding with research and development (R&D) investment reaching 2.12% of gross domestic product (GDP) but still trailing behind the United States (2.74%) (Jonkers *et al.*, 2020). Furthermore, China's increasing international co-publications, particularly with East and Southeast Asian countries, have enhanced the global influence of its research. Talent return programs have also helped the nation by drawing in scientists with foreign training to bolster domestic research networks (Appelbaum *et al.*, 2018). Scholars from various Chinese research institutions collaborate extensively, with the most prolific authors being Xie J and Ye J.

"Plant growth promoting and biocontrol activity of *Streptomyces* spp. As endophytes" from International Journal of Molecular Sciences is enlisted as the most cited article (486 citations) (Vurukonda *et al.*, 2018). Interestingly, it was not from the top 10 most published journal. International Journal of Molecular Sciences is open access, peer-reviewed journal that providing forum for broad ranges of molecular sciences in cell biology, biophysics, olecular medicine, and molecular chemistry. Furthermore, this journal may publish antimicrobial Actinobacteria topic less frequent than listed journals. Meanwhile, Frontiers in Microbiology held on the first position (25 documents, 12.32%). Immunology and Microbiology was illustrated as the dominant subject area with 90 articles published.

Additionally, "Actinobacteria" is clustered alongside with "rhizosphere", "bacterium identification","antifungal activity", "phylogeny", and "minimum inhibitory concentration" (Bano *et al.*, 2022; Smati *et al.*, 2025). It illustrated the common workflow on retrieved documents on this bibliometric review. In addition, other clusters focused regarding "soil microbiology", "enzyme activity:, anti-bacterial agents, and "genetics" that showed mostly linear parts with previous group. Meanwhile, research methods from isolation to molecular identification appeared earlier in 2018. It means molecular approach using polymerase chain reaction (PCR) was massively implemented after Actinobacteria isolation, morphology characterization, and antimicrobial assays (Qi *et al.*, 2019; Nonthakaew *et al.*, 2022; Ye *et al.*, 2023). Additionally, microbial community and plant growth depicted in 2022 due to whole genome sequencing (WGS) utilization (Chaudhary *et al.*, 2021; Zakalyukina *et al.*, 2024).

Actinobacteria are unicellular, branched Gram positive and mostly filamentous bacteria that occur in a variety of environments particularly in rhizosphere soil (Malisorn *et al.*, 2020; El-Tarabily *et al.*, 2020; Kumara *et al.*, 2020). *Streptomyces* is dominant group that can produce abundant secondary metabolites and enzymes, which can inhibit and kill pathogenic microbes (Li *et al.*, 2020; Sujarit *et al.*, 2020). Secondary metabolites are commonly extracellular that require purity of culture media, different solvents, the application of a variety chromatographic techniques and analytical systems like thin layer chromatography (TLC), gas chromatography-mass spectrometry (GC-MS), nuclear magnitude resonance (NMR), and the liquid chromatography-high resolution mass spectrometry (LC-HRMS) (Kumara *et al.*, 2020; Saadouli *et al.*, 2020; Ma *et al.*, 2020; Qi *et al.*, 2022; Tistechok *et al.*, 2022; Jatiningrum *et al.*, 2024; El-Hawary *et al.*, 2024). Enzymatic activity generally analyzed is linking about hydrolytic groups and incorporating both physiological and biochemical approaches (Ma *et al.*, 2020; Wei *et al.*, 2020, Elshafie & Camele, 2022).

Studies of secondary metabolites from rhizospheric Actinobacteria are increasing gradually. Furquinocins K and L, novel naphthoquinone-based meroterpenoids were successfully elucidated from *Streptomyces* sp. Je 1-369 of *Juniperus excelsa* rhizospher with NMR approach. However, only furaquinocin L exhibited antagonistic properties against *Bacillus subtilis* DSM 10 and *S. aureus* Newman (minimum inhibitory concentration (MIC) 64 and 2 μg/mL) (Tistechok *et al.*, 2022). Additionally, Rauwolfia serpentia rhizospeher's *Microbacterium proteolyticum* (LA2(R)) illustrated 70-80% anti-biofilm potential targeting mostly to *Klebsiella pneumoniae* stood for threefold reduction (IC_{50} 66.28 μg/mL). The extract of this bacteria found compose primarily with n-hexadecanoic acid which have antimicrobial and antioxidant properties (Bano *et al.*, 2022). Additionally, *Streptomyces sichuanensis* had 12 potential antifungal metabolites including terpenoids. Erucamide was the major compounds after analyzed using GC-MS with antibacterial and antifungal properties (Qi *et al.*, 2022).

Aside of secondary metabolite production, rhizospheric Actinobacteria also secrete hydrolytic enzymes against tested pathogens. Three species *Streptomyces* from different altitude in alpine area of Qinghai-Tibetan plateau demonstrated various hydrolytic results alongside with antimicrobial properties against pathogens. Additionally, *Streptomyces* sp. SNN289 illustrated extracellular cellulose, xylanase, and chitinase as anti-oomycetes activity against *Phytophthora palmivora* CbP03 (Nonthakaew *et al.*, 2022). Enzymatic activities of *Streptomyces* were linear with broad spectrum inhibition targeting different Gram-positive, Gram-negative, yeast, and mold pathogens (Smati *et al.*, 2025). *Streptomyces leeuwenhoekii* C34 known for expressing Baeyer-Villiger monooxygenases (BVMOs) as biocatalyst for organic substance production (Gran-Scheuch *et al.*, 2018; Salwan & Sharma, 2020).

WGS and gene targeting using PCR could be using indirectly to predict putative gene products alongside protein and metabolomics based. *Streptomyces* sp. BP-8T genome contains several types of BGCs producing amicetin and α-naphtocyclinoic acid (Zakalyukina *et al.*, 2024). Additionally, toyocamycin, terpen, and ectoine gene clusters found in *Streptomyces* BITDG-11 with full in similarity (Zhang *et al.*, 2021). *Streptomyces* sp. BTU6 showed absence of NRP genes after determined by PCR approach. Contrary, WGS proved otherwise (Ye *et al*., 2023). On the other hand, PCR-detected BGCs screening may prove the antimicrobial antagonistic assays with different presence of genes (Wang *et al*., 2021).

Future trends

Future research will concentrate more on rhizospheric Actinobacteria for antimicrobial activities in health and agriculture fields. Emerging innovations include WGS that adaptive with Actinobacteria genomes, transcriptomic analysis to determine the effect of pathogens after treating with Actinobacteria extract, metabolomic approaches with high sensitivity utilizing LC-HRMS (Zakalyukina *et al*., 2024; El-Hawary *et al*., 2024; Hsiao *et al*., 2021). Furthermore, molecular methods will continue to evolve with techniques such as PCR for absolute quantification of keystone taxa and target genes and LC-HRMS for high sensitivity detecting secondary metabolites (El-Hawary *et al*., 2024; Ye *et al*., 2023). These advancements will be further accelerated by artificial intelligent (AI)-driven bioinformatics pipelines that integrate multi-omics data with remote sensing and environmental models for deeper ecological insights (Raja & Subathra, 2025).

Antimicrobial resistances have been world health burden with an annual case increase (Rodrigues *et al*., 2024a; Helmi, 2025; Tfaily & Borjac, 2025a). Subsequently, new bioactive substances definitely required combating this case and Actinobacteria taxa provides vast reservoir for that (Rodrigues *et al*., 2024a). Streptomycin, is the example of Actinobacteria secondary metabolites that use widely used to treat bacterial resinstance (Rodrigues *et al*., 2024b; Tfaily & Borjac, 2025b; Jangra *et al*., 2025). Furaquinocins are several examples of new antimicrobial agents derived from rhizospheric Actinobacteria (Qi *et al*., 2022; Tistechok *et al*., 2022).

Rhizospheric Actinobacteria research does not always end up successful for many reasons. Most of isolated Actinobacteria is *Streptomyces* and make others under shadow due to unharvesting. Isolation technique from pretreatment of collected sample, different inoculation techniques, and media selection ensure the isolation of rare Actinobacteria more harvested. High-throughput microbial culturomics, in situ methods, flow cell sorting method, and co-culture are such example of cultivation strategies. The selection of nutrient sources also vitally influences the secondary metabolism. Chemical, biological, and molecular elicitations could produce secondary metabolites from silent and cryptic BGCs that are responsible for the unexpressed metabolite syntheses (Koech *et al*., 2025). In addition, resistance mechanisms of target microbes, production costs, and innovative strategies should be acknowledged to be resolved (Kavin & Subathra, 2025).

Conclusion

Over two decades, 203 documents have been issued, with an average of seven publications annually. The majority of publications were published in 2024. Sathyabama Institute of Science and Technology was the top institution, and China was the country with the most publications. Xie J was the most cited author, while Fedorenko VA and Gromyko OM were found to be the most prolific authors. Streptomyces, nonhuman, microbial diversity, soil microflora, and enzyme productivity are important terms in this study. In conclusion, the information presented in this study shows the progress made in the field of rhizospheric Actinobacteria research from 1996 to 2025 with an emphasis on their antimicrobial qualities, and it may offer guidance for further investigations.

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