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Unveiling the global reach of African anthrax research: A bibliometric study



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ABSTRACT

Anthrax is a zoonotic bacterial disease caused by *Bacillus anthracis*. It poses significant threat to humans through contact with infected animals or their by-products. Concerns arise from its long-lasting spore viability and lethality, fuelling its biowarfare potential. Recent anthrax outbreaks across multiple African nations prompted this bibliometric study. The aim of the study was to assess the contributions of African countries, institutions, authors, research funding, and collaborations, while identifying research trends and gaps. We conducted an extensive bibliometric analysis of anthrax-related research publications in Africa from 1923 to 2023, utilizing the Scopus database and VOSviewer. The study covered 364 publications from 32 African countries, accumulating 5,636 citations at an average of 15.5 citations per article, with research articles comprising 88.5% of the corpus. The publication growth rate from 1923 to 2023 was modest at 8.3%, indicating gradual advancement. Notably, there was a significant surge in publications between 2011 and 2023, accounting for 73.1% of total publications. The African research contributions, were categorized into five thematic focuses: ecological dynamics and host interactions, human-livestock anthrax interface, molecular insights into bacterial activity and treatment strategies, collaborative approaches for zoonotic disease prevention, and antibody response and vaccination strategies. Leading institutional contributors included the University of Pretoria and the University of KwaZulu-Natal. Collaborations extended globally to 35 non-African countries, with significant involvement from the United States, United Kingdom, and Germany. Strong African partnerships, especially between Kenya, Nigeria, and South Africa, emerged. The top 10 cited papers explored diverse aspects, including disease impact on wildlife and innovative control strategies, underscoring the importance of multidisciplinary approaches. South Africa played a prominent role, contributing 95 publications and securing funding from various sources, including the National Research Foundation. Collaborations with global institutions highlighted its commitment. This study unveils the dynamic landscape of anthrax research in Africa, emphasizing the pivotal role of collaboration, multidisciplinary One Health approaches, and global partnerships in enhancing research outcomes. Ongoing research and practical solutions for human and animal health remain imperative.

1. Background

Anthrax is a highly lethal infectious disease affecting both animals and humans caused by the spore-forming bacterium *Bacillus anthracis*. It is considered one of the most potent biological weapons due to the robustness of its spores [1]. Anthrax can be diagnosed using various

methods including differential diagnosis and laboratory techniques like polymerase chain reaction (PCR). It can manifest in different clinical forms such as cutaneous, gastrointestinal, inhalational, and injective anthrax, with inhalational anthrax being particularly lethal [2]. Worthy of note is that the injective anthrax is a recent clinical variant associated with drug users which causes considerably high fatality rate

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exceeding 33% [3]. Zoonotic diseases, including anthrax, are responsible for about 75% of emerging infectious diseases, with anthrax being highly fatal in both domestic and wild animals [4].

Anthrax is hyper-endemic in West Africa, exerting its impact on wildlife, livestock, and human populations [5]. According to the World Health Organization, the annual incidence of anthrax globally is estimated to be less than 100,000 cases. However, it is important to acknowledge the likelihood of a substantial number of unreported outbreaks [6]. In a 2023 meta-analysis report, it was reported that the consolidated prevalence of anthrax within the African region is approximately 29%, with a 95% confidence interval ranging from 26% to 30%. This implies that roughly 29% of livestock in Africa may be plagued by anthrax [7].

Numerous factors may contribute to the high prevalence of anthrax in the African region, some of which may include the high populations of herbivores such as cattle, sheep, and goats, which serve as the primary hosts for the pathogen. In addition, the warm and arid climate prevalent in various African regions creates ideal conditions for the long-term survival of anthrax spores. A relatively high prevalence of anthrax in some parts of African can also be attributed to factors such as deficient veterinary infrastructure, restricted access to veterinary services, and suboptimal livestock management practices. These circumstances collectively foster the persistence and dissemination of the disease among animal populations [5,7,8].

Anthrax continue to pose serious challenges in Africa, impacting both human and animal populations. The challenges include its endemicity in regions with a history of livestock farming [9], persistent underreporting due to limited healthcare infrastructure and awareness, diagnostic constraints resulting in delayed responses, substantial economic losses stemming from severe livestock outbreaks, health hazards for those handling infected animals or their by-products, restricted availability of vaccines and antibiotics, enduring environmental spores, insufficient healthcare infrastructure, climate-related influences, intricate zoonotic transmission patterns, low public awareness necessitating educational initiatives, shortages of chemicals or their alternatives required for the burial of carcasses [7–10], and the potential for cross-border dissemination. These multifaceted challenges highlights the importance for comprehensive One Health, multidisciplinary strategies to effectively combat anthrax in Africa. Nevertheless, the persistence of underreporting of anthrax cases and non-compliance with public health regulations and surveillance systems in many African nations exacerbate the difficulties in disease control [4,11].

International cooperation and a One Health approach are crucial for addressing the complex and interconnected nature of anthrax and other zoonotic diseases [12]. Collaborative efforts among different disciplines and sectors can enhance knowledge exchange, surveillance, and preventive measures [4].

Bibliometrics is a quantitative method used in information science and research evaluation. It is employed to analyze different facets of academic publications, particularly scholarly literature. It applies statistical and mathematical techniques to bibliographic data, involving citations, publication patterns, authorship, and journal impact, offering insights into the generation, dissemination, and influence of scientific knowledge [13].

This discipline empowers researchers, institutions, and policymakers alike to appraise research output, recognise influential publications and authors, and the tracking of discipline trends. The significance of bibliometrics in research is multifaceted. It encompasses the evaluation of research impact, the determination of emerging research trends, the assessment of author performance within specific fields, the critical examination of research funding, and the scrutiny of research quality. Moreover, it fosters benchmarking and facilitates collaboration while aiding in policy formulation. Additionally, it plays a pivotal role in maintaining publication standards through quality control within the peer-review process [14].

Examples of some zoonotic diseases subjected to bibliometric assessment include and are not limited to tuberculosis, Monkeypox, Ebola virus disease, Marburg virus disease, and Lassa fever [15–17]. However, such analyses may have limitations, including language bias, data source selection, and potential time-effect bias [18–20].

Despite some of the challenges mentioned above, progress has been made in anthrax research, particularly with the development of effective vaccines and antibiotic treatments. Nevertheless, the disease remains a public health concern, necessitating continued efforts in understanding its pathogenesis, transmission dynamics, and strategies for prevention and control [11].

In this study, we employed bibliometric methodologies to evaluate the engagement of African nations, specifically focusing on countries and authors affiliated with African institutions. Our objective is to quantitatively assess their participation and impact in anthrax research publications from 1923 to 2023. Considering the recent occurrences of anthrax outbreaks among animal populations in various African countries, including Burkina Faso, Mali, Kenya, Tanzania, Ghana, Niger, Togo and Nigeria, there is a compelling need for a thorough investigation into the distinct contributions, implications, and collaborative initiatives undertaken by African nations concerning the control and mitigation of anthrax within the continent.

2. Materials and methods

2.1. Data source

Relevant documents were retrieved from Scopus database (www.scopus.com) hosted by Elsevier (The Netherlands) on August 10, 2023. The following search strings were employed: "Anthrax" AND ("B. anthracis" OR "Wool sorters' disease" OR "Black Baine" OR "Splenic fever" OR "Cumberland Disease"), with searches conducted within the Title-Abstract-Keyword field. The search included articles retrieved covering the periods 1923–2023 respectively. Our analysis was limited to over a century which we believed is sufficient to give an overview of anthrax-related research output from the African continent. The initial number of publications retrieved from Scopus was 16,904 documents. The selected documents were manually screened to exclude duplications, non-English communications, and topics that do not match the scope of this investigation and limited to contributing African countries. After that, 364 documents relevant to our study were saved as a *.csv file and later exported to VOSviewer for bibliometric analysis, see flow chart (Supplementary Fig. 1).

Qualitative and quantitative analyses of the dataset was performed using the 'analyse function' in the Scopus database to monitor the number of publications per year and the highest contributing authors and countries. Relevant graphs and table were constructed in MS Excel®. Detailed analysis of the documents and networks were generated in VOSviewer (CWTS, Netherlands). VOSviewer, a user-friendly software with a free license, operates on Java and possesses the capability to generate high-resolution visual representations of bibliographic networks. This software provides researchers with a platform to thoroughly scrutinize bibliographic endeavors [21].

2.2. Data analysis

The bibliometric techniques employed by Elisha and Viljoen [22] and further refined in Elisha et al. [23] were adopted with certain adaptations. The documents obtained were scrutinized using Scopus' inherent "data analysis" function. Additionally, VOSviewer was harnessed to assess term co-occurrence within both the title and abstract component, producing term maps and facilitating the examination of bibliographic data for prevalent research themes. While adhering to default configurations, selective adjustments were made to parameters, enabling the creation and examination of network maps and other visual representations.

2.3. The rationale for selecting scopus database

Scopus offers an extensive range of scholarly literature across diverse disciplines such as science, technology, medicine, social sciences, and the arts and humanities, providing researchers with access to a wide array of relevant publications and research outputs [24]. Furthermore, Scopus aggregates content globally from journals, conference proceedings, and patents, enabling researchers to conduct international-scale analyses of trends, collaborations, and research impact [25]. It stays current with regular updates, ensuring access to the latest research findings, which is crucial for staying abreast of recent developments in specific fields [26, 27]. Scopus also facilitates citation analysis, invaluable for tracking article, author, or institutional impact over time and understanding scholarly interactions [28]. Author profiles in Scopus provide comprehensive information on an author's publications, affiliations, citation metrics, and collaborations, aiding in building a holistic view of their research contributions and network [29]. Additionally, its broad coverage of disciplines encourages interdisciplinary research, fostering innovative collaborations and discoveries across seemingly unrelated fields [13].

3. Results and discussion

3.1. Publication summaries, growth patterns and research emphasis in Africa anthrax-related publications: a Scopus database analysis spanning 1923–2023

From 1923 to 2023, anthrax research in Africa experienced noteworthy contributions from thirty-two (32) distinct African nations, leading to the compilation of 364 publications that collectively garnered 5,636 citations, resulting in an average of 15.5 citations per article (Fig. 1A and 1B). These 364 documents are categorized into research articles (88.5%), reviews (7.4%), book chapters (1.9%), notes (1.4%), and conference papers (0.8%), respectively.

A total of 208 journals contributed in these 364 publications. However, only 6.7% of these sources published five or more articles during the review period. *PLoS One* made a substantial contribution with 16 documents and 275 citations, closely followed by *PLoS Neglected Tropical Diseases* with 15 publications and 278 citations. Other sources

of publications included *Onderstepoort Journal of Veterinary Research* (8 publications: 276 citations), *Scientific Reports* (8 publications: 64 citations), *Journal of Applied Microbiology* (6 publications: 264 citations), *BMC Public Health* (6 publications: 133 citations), *Tropical Animal Health and Production* (6 publications: 117 citations), and *Emerging Infectious Diseases* (6 publications: 108 citations), respectively see [Supplementary Table 1](#). Fig. 2 visually represents all top contributing sources, with the size of nodes directly proportional to the number of publications—larger nodes indicating higher publication counts [21].

A total of 1,688 authors contributed to the 364 publications, averaging around five authors per publication. Only 2% of authors had published five or more works (Fig. 3). Among the top 10 contributors with strong affiliations to African institutions are Van Heerden Henriette from the University of Pretoria, South Africa, with 23 publications; Wayne Marcos Gertz from the University of KwaZulu-Natal, South Africa, with 19 publications; Hassim Ayesha from the University of Pretoria, South Africa, with 9 publications; Bernard K. Bett from the International Livestock Research Institute, Kenya, with 8 publications; Gift Matope from the University of Zimbabwe with 8 publications; Okechukwu C. Ndumnego from the African Health Research Institute, South Africa, with 8 publications; Davies Mubika Pfukenyi from the University of Zimbabwe, with 8 publications; John Mwangi Gachohi from Jomo Kenyatta University of Agriculture and Technology, Kenya, with 6 publications; Kgaugelo Edward Lekota from North-West University, South Africa, with 6 publications; and Athman Juma Mwatondo from the Ministry of Health, Kenya, with 6 publications. Among these top authors, 5 are from South Africa, 3 from Kenya, and 2 from Zimbabwe. Fig. 3 provides a visual representation of co-authorship relationships among authors, highlighting their research focus and affiliations or collaborative clusters.

A total of 1,368 institutions participated in the 364 publications through collaborations involving 32 African and 35 non-African countries. Noteworthy African institutes include the University of Pretoria, South Africa (34 publications); the University of KwaZulu-Natal, South Africa (21 publications); the University of Zimbabwe (20 publications); the University of Zambia (17 publications); Sokoine University of Agriculture, Tanzania (16 publications); the University of Nairobi (14 publications); Makerere University, Uganda (12 publications); the International Livestock Research Institute, Kenya (10); Muhimbili

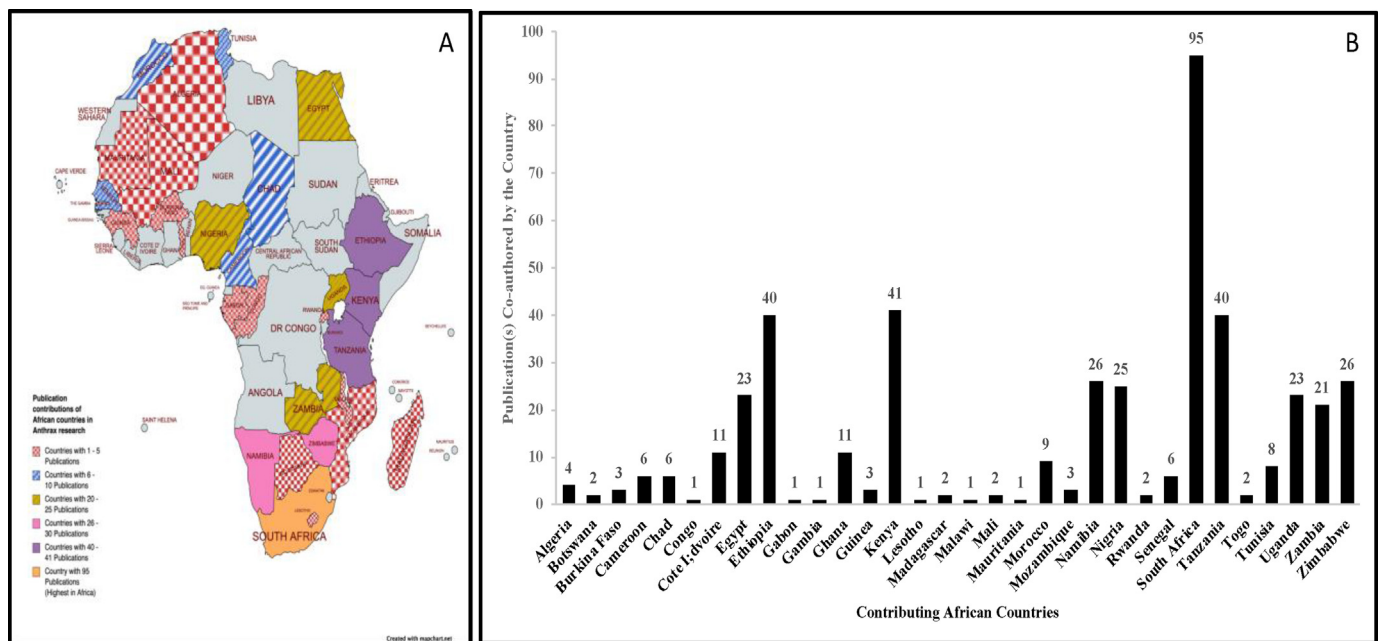


Fig. 1. (A) Contributions of African countries in anthrax research publications from 1923–August 2023, data retrieved from Scopus database (N = 364). (B) Anthrax publication(s) co-authored by contributing African countries, records retrieved from Scopus database, 1923–2023.

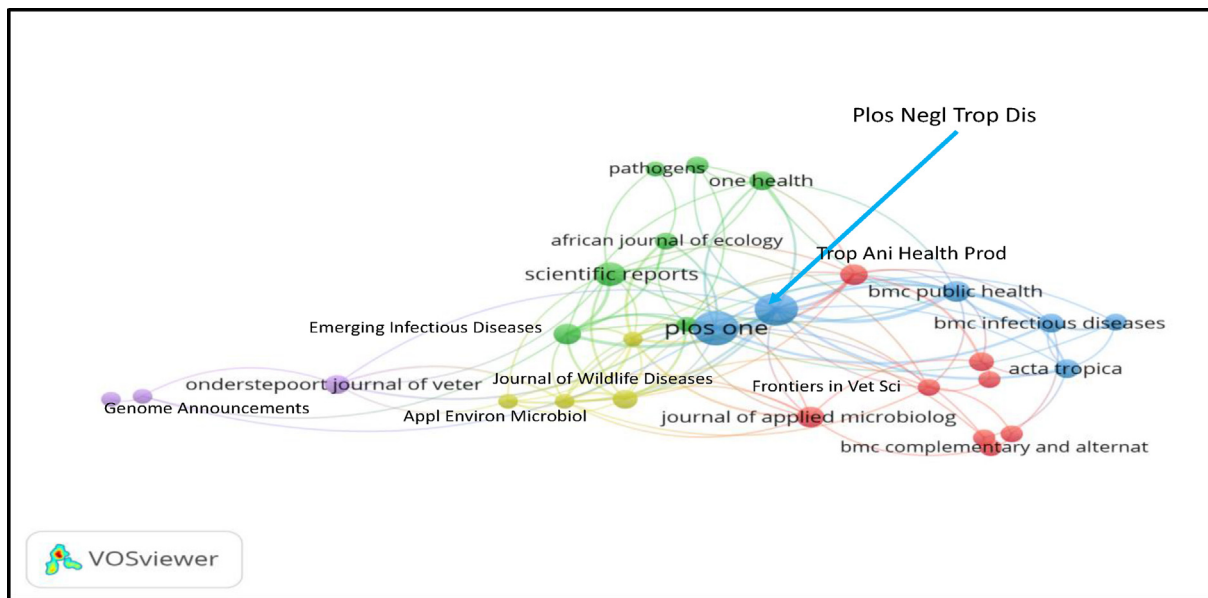


Fig. 2. Network visualization of some of the contributing journals on anthrax-related publications from authors with African affiliations from 1923 to 2023, retrieved from Scopus database.

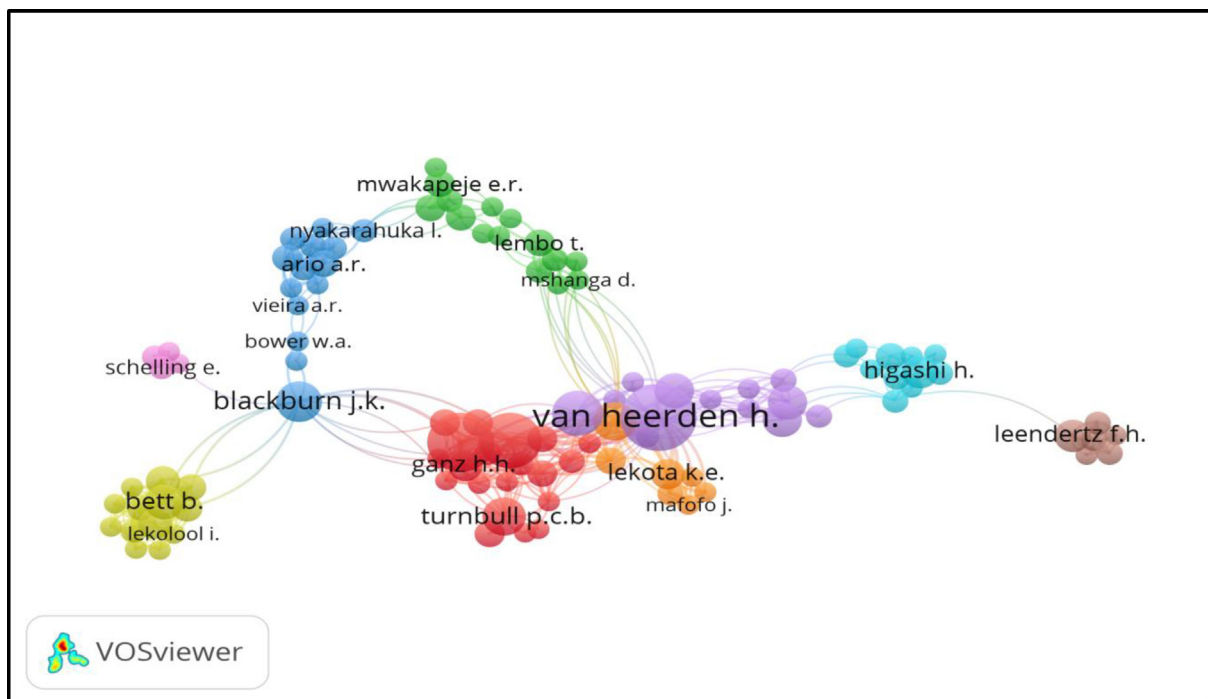


Fig. 3. Network visualization of authors contribution to anthrax publication showing the different research clusters.

University of Health and Allied Sciences, Tanzania (10 publications); and the University of South Africa (9 publications).

3.1.1. A drill-down of subject areas covered by Africa's anthrax publications from 1923 to 2023

The subject areas covered by the 364 publications related to anthrax research in Africa from Scopus database in a descending order include medicine (42.6%), agricultural and biological sciences (25.3%), immunology and microbiology (16.8%), veterinary research (15.7%), biochemistry, genetics and molecular biology (15.4%), environmental science (12.4%), multidisciplinary research (8.2%), pharmacology, toxicology and pharmaceutics (6.6%) respectively (Supplementary Fig. 2). The subject areas comprises diverse domains, each characterized

by its distinct strengths, weaknesses, opportunities, and challenges. The notable emphasis on medicine underscores a dedicated commitment to comprehending anthrax's ramifications for human health. This focus is well-aligned with public health concerns and the imperative to devise effective diagnostics and treatment methodologies. The substantial representation within agricultural and biological sciences highlights the acknowledgment of anthrax's influence on livestock and agriculture. This contribution can foster improved animal health practices and bolster economic stability within the agricultural sector.

A relatively low attention to environmental aspects may potentially curtail a comprehensive understanding of anthrax's ecological dynamics, thereby impeding the formulation of all-encompassing control strategies. Limited coverage in the field of pharmacology, toxicology,

and pharmaceuticals suggests a potential gap in the exploration of anthrax-associated pharmaceutical and toxicological facets. These aspects are critical for drug development and safety evaluations. The emphasis on immunology and microbiology presents an avenue to delve deeply into the intricacies of anthrax's infection mechanisms, virulence factors, and immune responses. This knowledge can facilitate the development of novel therapeutic interventions. The concentration on veterinary aspects opens doors for enhancing animal health practices, devising effective vaccination strategies, and mitigating the economic losses linked to anthrax outbreaks. A relatively limited focus on biochemistry and genetics may impede a comprehensive exploration of anthrax's genetic composition and molecular mechanisms, which could potentially limit insights into its pathogenicity. While multidisciplinary approaches are present, the moderate coverage might restrict the synergistic advantages that arise from collaborative efforts across diverse disciplines. This could result in missed opportunities for innovative breakthroughs. By addressing these elements, a comprehensive understanding of anthrax and its implications in Africa can be enriched.

3.1.2. Publication growth pattern in Africa's annual anthrax record from 1923 to 2023

The publication growth rate for the articles published in Scopus database during 1923–2023 is a modest 8.3%, reflecting a comparatively gradual advancement. A significant upswing in publications was observed between 2011 and 2023, amounting to 266 papers, constituting 73.1% of the total publications (N = 364). The publication growth rate between 2011 and 2023 stands at 10.7% (Fig. 4). During the years 2011 to 2023, African anthrax research underwent significant transformation, as evidenced by a comprehensive collection of publications from the Scopus database. These papers covered diverse fields such as microbiology, veterinary medicine, and disease surveillance, offering a broad perspective on the advancement in comprehending anthrax and its complex implications.

3.1.3. Evolutionary content trajectory from inaugural appearance of anthrax publications in 1923 and 1945 and the quiescent era

The inaugural appearance of anthrax-related content in Scopus database traces back to the efforts of Taylor JA, a senior medical officer stationed within the Ugandan protectorate. Taylor's work involved

documenting instances of anthrax occurring in Ankole, Uganda. This consequential report, which found publication in the *Transactions of the Royal Society of Tropical Medicine and Hygiene* (volume 17, issue 1–2, pages 51–54), offers a meticulous delineation of anthrax cases that were previously documented by Dr. Spearman in Kampala in 1917, followed by Duke and Peacock in 1921. The *British Medical Journal* and *Lancet* were the respective platforms for disseminating these case records [30]. This report bears immense significance in the field of anthrax research as it presents a comprehensive record of anthrax cases, effectively building upon prior research contributions and contributing to a deeper understanding of the disease's prevalence and impact.

The second publication found within Scopus database, originating from authors primarily affiliated with Africa, comes in the form of a report authored by Dr. Stott H. This report, emerging from the colonial medical service and emanating from the native civil hospital situated in Kerugoya, Kirinyaga county, Kenya, holds notable significance. Dr. Stott's account underscores a remarkable case where the successful application of penicillin effectively treated cutaneous anthrax in an elderly individual. This particular case carries significant weight due to the limited availability of reports detailing the use of penicillin, especially considering that its production and clinical application had only recently commenced in 1943. It is noteworthy that despite Dr. Stott's British origins, his association with the medical services of Kenya highlights the global impact of this pioneering effort. The documentation of utilizing penicillin to address cutaneous anthrax was meticulously chronicled in the *British Medical Journal*, volume 2, issue 4412, on page 120, aptly titled "Treatment of human cutaneous anthrax with penicillin." This report stands as a noteworthy milestone in anthrax research, showcasing the early and effective application of penicillin within a novel context [31].

The period 1923 to 1973 is generally described as the period of publication quiescence (Fig. 4). Several factors may have contributed to the limited research and publication on anthrax in Africa. One significant factor was the historical context of colonialism, which affected the ability of African countries to engage in independent scientific research and disseminate findings. Colonial powers often exerted control over scientific resources and institutions, impeding the autonomy of African researchers. Additionally, the inadequate academic and research infrastructure prevalent during that era hindered the establishment of

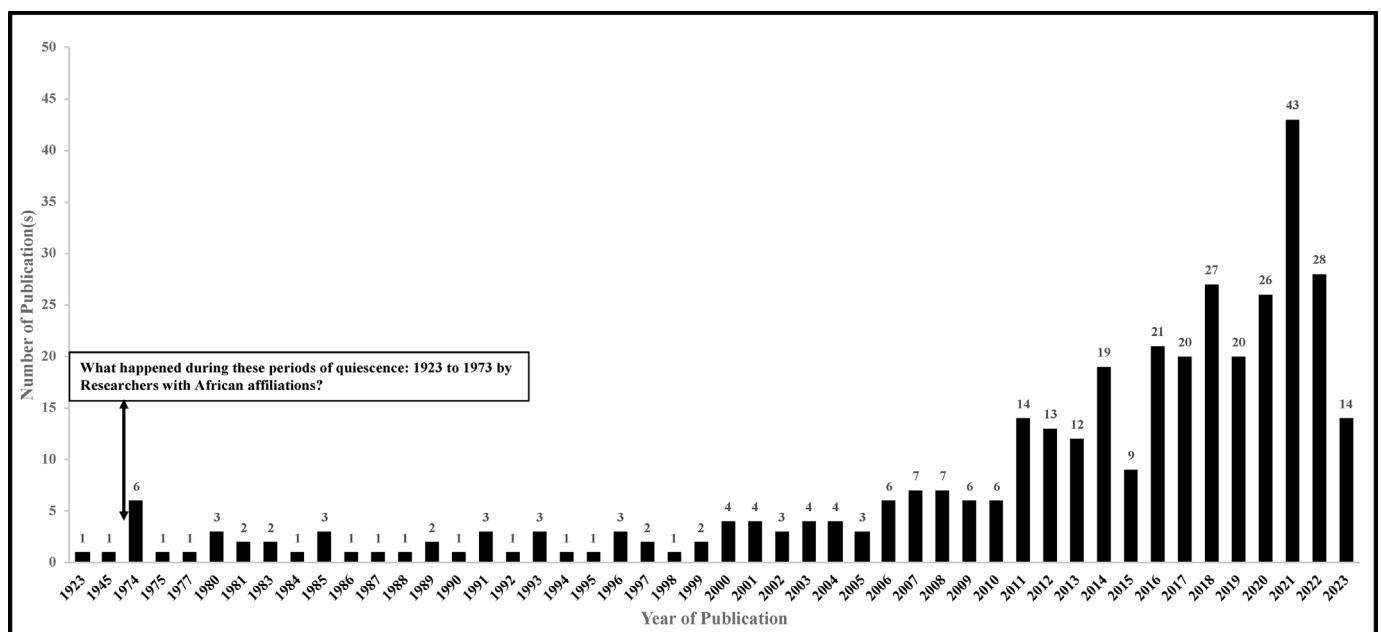


Fig. 4. Annual publications on anthrax and *Bacillus anthracis* related researches from 32 African countries with 35 other non-African affiliates starting from 1923 to August 2023, documents retrieved from Scopus database.

universities and research institutions, limiting the training of local scientists [27,33,38,39].

Furthermore, African researchers faced challenges in accessing international scientific literature and journals, which hindered their ability to stay informed about advancements in anthrax research and share their own findings. These factors collectively contributed to the scarcity of research and publication on anthrax in Africa during the specified time frame. It is important that we acknowledge these historical, socio-political, and economic factors [27,33,38,39]. Subsequent to 1973, changes in these factors likely played a role in stimulating increased research and publication on anthrax in Africa.

3.1.4. Content narrative of flourishing publication period (2011–2023)

The publications in this timeframe encompassed an in-depth exploration of complex microbial aspects of anthrax, unraveling its genetic composition and shedding light on its virulence factors. Microbiologists delved into innovative methods for the isolation and purification of *B. anthracis*, the causative agent of anthrax, holding the potential to refine diagnostic and treatment approaches.

As time progressed, the narrative took a darker turn with documented anthrax epidemics and outbreaks, underscoring the enduring menace of this age-old disease. In areas where livestock farming was a central economic activity, anthrax outbreaks reverberated through agricultural communities. Veterinary medicine emerged as a pivotal player, with researchers diligently enhancing vaccination strategies to safeguard livestock and alleviate the economic impact of these outbreaks.

The spotlight then shifted to the dynamics of disease transmission, as researchers strived to unravel the intricate interplay among anthrax, its animal hosts, and the environment. Noteworthy insights emerged, shedding light on the influence of environmental factors on the persistence and dispersal of anthrax spores. This knowledge formed the basis for innovative disease surveillance methods, fusing genetic analysis and ecological modeling to predict and pre-empt potential outbreaks.

Publications during this period highlighted significant strides in anthrax vaccination, a vital aspect of public health and livestock protection. Researchers achieved substantial progress in developing advanced vaccines with enhanced efficacy and broader coverage. These breakthroughs injected renewed vigour into disease control

strategies, establishing a foundation for more proactive management techniques.

Amid these scientific achievements, collaboration and knowledge exchange emerged as recurring themes. Multidisciplinary teams united to confront the complex challenges posed by anthrax, showcasing the power of collective expertise.

The information documented in anthrax-related publications from the Scopus database between 2011 and 2023 depicted a captivating story of microbiological exploration, epidemiological vigilance, and collaborative endeavors. This narrative not only highlighted progress but also illuminated the ongoing mission to safeguard both animal and human populations from the persistent danger of anthrax.

3.2. Exploring key contributors from African nations and international involvement in anthrax publications: a glimpse into Scopus database records (1923–2023)

The country co-authorship map (Fig. 5A) revealed that 32 African countries had collaborative research/publication association with 35 non-African countries in anthrax research during the period under review. The United States of America led the pack by contributing to 26.6% of all publications. The United Kingdom came next with 10.4%, followed by Germany with 8%, Norway with 5.5%, France with 4.4%, and Italy with 3.6% respectively. The research on anthrax exhibited diverse contributions from a wide range of African and non-African nations, highlighting the importance of international cooperation in addressing this critical issue. Such collaborative efforts are essential for enhancing knowledge exchange and fostering advancements in anthrax prevention and treatment (Fig. 5). Bah et al. [32] in a similar research reported a heavy reliance of African countries on foreign and international collaboration, particularly with the United Kingdom and United States of America respectively.

Among the additional African nations making substantial contributions within the African network, Kenya has developed partnerships with both Nigeria and Malaysia. Meanwhile, Morocco and France showcased notable collaborative endeavors. Likewise, Nigeria continues to foster a robust research alliance with both Malaysia and Kenya, as previously noted. In contrast, Tanzania has established strong affiliations with the United Kingdom and the United States. Remarkably, the network mapping unveiled a noteworthy connection between Namibia and various

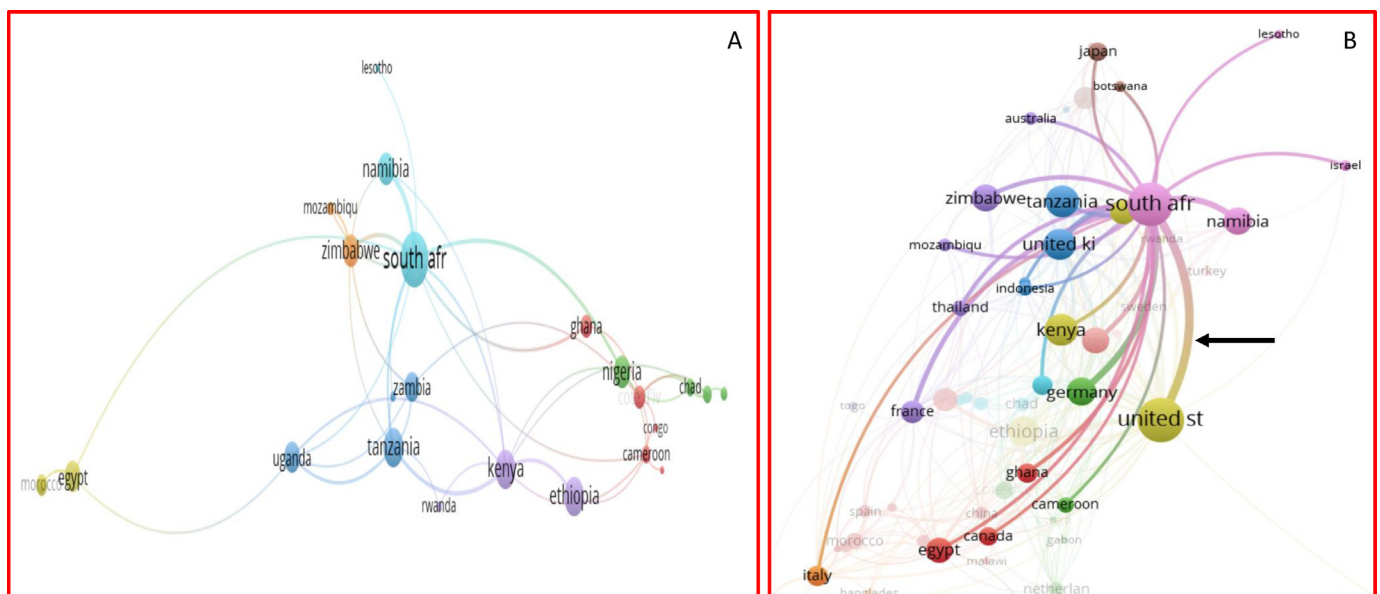


Fig. 5. (A) Network visualization of the Co-authorship relationship between the linked 32 African countries on anthrax research and publications from 1923 to 2023. (B) Co-authorship network visualization of South Africa with other countries on anthrax research and publications. The arrow is indicative of the thick curved line that suggest very strong research collaboration between South Africa and the United States, South Africa also has a strong research collaboration with Namibia and Germany. south afr = South Africa; united st = United States; united ki = United Kingdom; mozambique = Mozambique.

countries, including South Africa, the USA, the UK, Germany, and Turkey (Fig. 5A).

Some barriers to collaborative research in Africa include the lack of skilled research teams, limited resources, unreliable and weak internet access, and regulatory challenges. However, creating a research culture, employing simple data collection tools, and promoting collaboration with other research teams were identified as beneficial factors for advancing collaborative research efforts [33].

Therefore, it can be safely alluded that the progress of African institutions in research still lags significantly behind their European and American counterparts, as evidenced by their publication output. To bridge this gap, African countries need to foster a culture of scientific research and collaboration among national and continental institutions. Prioritizing the use of English as a common language can play a crucial role in enhancing global visibility and engagement in African research endeavors [34].

3.3. The top 10 most cited anthrax-related publications from Africa and African affiliates

A total of 18 nations participated in the highest-ranking 10 publications centered on anthrax, as outlined in [Supplementary Table 2](#). Citations for the top 10 most influential anthrax papers originating from both African institutions and their global counterparts ranged from 70 to 150 citations respectively. These papers collectively accounted for 14.8% of the overall citation count. The United States was engaged in 5 out of the ten studies, followed by South Africa with 4, while Namibia and the United Kingdom each contributed to 3 publications. Additionally, two of these papers were featured in Nature. These eminent publications traversed various subject domains: agricultural and biological sciences (30%), biochemistry, genetics, and molecular biology (30%), environmental science (30%), immunology and microbiology (20%), medicine (20%), and veterinary (10%), respectively.

3.3.1. Content narrative from the 10 most cited papers retrieved from Scopus database

A noteworthy observation is the entirety of the extensively cited anthrax papers being full-fledged research articles ([Supplementary Table 2](#)). This underscored their thoroughness and influence in anthrax research. These articles carefully explore multifaceted aspects of anthrax, offering comprehensive analyses, methodologies, outcomes, and discussions pertinent to the subject matter. The conspicuous prevalence of citations is indicative of their significant impact and influence on the field, given their reference by fellow scholars. This reinforces the significance of these papers in advancing the comprehension of anthrax and its intricate dimensions.

These prominent articles extensively investigated various facets of anthrax, leading to a profound comprehension of its complex repercussions. One study explored fatal infections in wild chimpanzees in Ivory Coast, pinpointing *B. anthracis* as a potential menace that jeopardizes both non-human primates and human health when consuming bushmeat. Furthermore, the drop in the roan antelope population in Kruger national park in South Africa exposed intricate interactions among contributing elements. Additionally, the unexpected identification of anthrax in tropical rainforests highlighted its capacity to imperil a wide array of wildlife, including chimpanzees, carrying significant implications for conservation endeavors. Among the research papers, one emphasized Ethiopia's susceptibility to zoonotic hazards and emphasized the need to prioritize diseases like anthrax, rabies, and brucellosis. Creative approaches, such as establishing a unified One Health zoonotic disease unit and collaborative tactics for handling emerging diseases, were scrutinized. Moreover, certain papers among the top 10 highlighted the ongoing requirement for research to comprehensively grasp the intricate ecological dynamics of anthrax, aiding in the allocation of resources and management approaches. Insights garnered from enzyme immunoassays and wildlife investigations offered valuable viewpoints on

the mechanisms of anthrax transmission, thereby enriching our overall comprehension of this zoonotic disease.

3.4. Analysis of the performance of South Africa as the top contributor in anthrax-related research and publication in the African landscape

From the 95 publications attributed to South Africa, 83 were full research papers, 10 reviews, 1 book chapter, and 1 conference paper. South African publications in anthrax research cover various subject areas, with medicine leading at 30.1%, followed by agricultural and biological sciences (26.3%), environmental science (22.1%), biochemistry, genetics, and molecular biology (18.9%), immunology and microbiology (17.9%), and veterinary sciences (15.8%) respectively. Funding for these publications came from 75 identified and 40 unidentified funding agencies according to Scopus, with the national research foundation (NRF) of South Africa sponsoring 14.7% of the publications during the review period.

The NRF's prominent role in funding anthrax research in South Africa can be understood considering the endemicity of the disease, especially in areas like the Kruger national park, where sporadic outbreaks are reported, and disease surveillance is actively performed by researchers within and outside the country through collaborations and networking [35,36]. The NRF South Africa has remained steadfast in its mission of providing affordable and balanced human resources and expertise in science, engineering, and technology through supporting research and education for the economic growth and social advancement of the nation (www.nrf.ac.za).

In addition, co-authorship analysis of publications from South African researchers and institutions revealed strong research associations with researchers affiliated with institutions in the United States (32.6%), Germany (16.8%), the United Kingdom (14.7%), and Namibia (13.7%) see [Fig. 5B](#). The thickness of the connecting curve lines and the closeness of the nodes or bubbles in the network map between South Africa and the mentioned countries further indicate robust research associations and collaborations [37].

Among the leading institutions actively engaged in anthrax research in South Africa, notable contributors include the department of veterinary tropical diseases at the University of Pretoria, accounting for 35.8% of research output, and the University of KwaZulu-Natal, making a substantial contribution of 22.1%. Collaborative ties between the University of California, Berkeley, in the United States of America and select South African institutions have proven robust, fostering a noteworthy 21.1% share of South African research publications. Eminent and prolific authors from South Africa have significantly enriched the field, including Henriette van Heerden from the University of Pretoria, who has contributed 24.2% of the country's publication outputs. Likewise, Wayne Gertz from the University of KwaZulu-Natal has made a noteworthy contribution of 20%, while Ayesha Hassim from the University of Pretoria has offered valuable input amounting to 9.5%. Additionally, Okechukwu Chinazo Ndumnego from the Africa Health Research Institute, Durban, has made a commendable contribution of 8.4%, and Kgaugelo Lekota from North-West University, Potchefstroom, has enriched the discourse with a contribution of 6.3%.

3.5. Term map analysis from anthrax-related publications retrieved from Scopus database

The calculation of terms from the 364 documents was based on the title and abstract fields, utilizing a full counting method. This technique tallies all instances of a term present in each individual document. A total of 9,985 terms were identified, and only a small portion of these, equivalent to 2.9% or 287 terms, met the threshold of appearing 10 times or more. Subsequently, a relevance assessment was conducted for these 287 terms using VOSviewer, selecting only those terms that achieved a 60% relevance score. Out of these, 112 terms after manual screening

were chosen for the purpose of network mapping and visualization. The resulting visualization displayed 5 clusters, each distinguished by a different color (Fig. 6). These clusters signify varying research or publication focuses over the span of more than a century of anthrax-related publications and research originating from African nations.

3.5.1. Cluster 1 (red colour)

This group constitutes 31.3% of the relevant selected terms and is best characterized as a collection of terms representing ecological dynamics and host interactions. Within the intricate landscape of African anthrax research, this cluster exposes ecological dynamics and interactions among hosts. The narrative brings forth significant terms including “anthrax infection,” “anthrax motility,” “spore,” and “host.” Landscapes like “Etosha National Park” and “Kruger National Park” contextualize anthrax’s existence, while the concept of “evidence” signifies underlying patterns (Fig. 6). This group unveils anthrax’s trajectory within African ecosystems, interwoven with the rhythm of nature.

3.5.2. Cluster 2 (green colour)

Comprising 21.4 % of the pertinent terms, this cluster is aptly titled the “human–livestock anthrax interface.” Key terms such as “attitude”, “cattle owners”, “perception”, and “practice” underscore its essence. It unravels stakeholders’ intricacies, with “cattle owners” illuminating transmission dynamics, “questionnaires” probing “attitudes” and “awareness”, while “knowledge” and “diagnosis” involving “health workers”. This narrative delves into “livestock disease”, “herd”, “consumption” and “household”, touching upon “zoonosis” and “human anthrax”. “Respondents” and “farmers” voices enrich the narrative, aiming to bridge “awareness” and “practice”, fostering coexistence and health synergy (Fig. 6).

3.5.3. Cluster 3 (blue colour)

Similar to the Green cluster, this group comprises 21.4% of essential terms. The cluster is best captioned ‘bacterial activity and treatment strategies: molecular insights’. The cluster underscores bacterial dynamics and interventions. Utilizing keywords such as “activity”, “antibacterial”, and “treatment”, it uncovers the molecular intricacies of anthrax. Emphasizing “*B. anthracis*”, “antibiotic”, and “inhibition”, the

collection of terms under this group uncovers approaches against anthrax's harm (Fig. 6). This narrative resonates with Africa's research commitment to enhancing health.

3.5.4. Cluster 4 (olive colour)

The assemblage comprises 17.9% of chosen terms, aptly titled “collaborative approaches for zoonotic disease prevention”. This cluster interlaces keywords including “collaboration”, “disease control”, and “prevention”. It reveals combined endeavors with a focus on “zoonotic disease”. “Human case” underscores urgency, while “laboratory” and “implementation” highlight essential tools. “Prioritization” and “risk factors” guide focused measures. “Village”, “animal population”, and “prevention” align, portraying comprehensive health safeguards.

3.5.5. Cluster 5 (purple colour)

The cluster constitutes 8.0% of selected relevant terms. It signifies “antibody response and vaccination strategies” within African anthrax research. It reveals investigations intertwining keywords such as “antibody”, “cheetah”, “protection” and “vaccination”. The narrative emphasizes safeguarding cheetahs from anthrax, unveiling immunity dynamics and strategies. “Combination” suggests efficacy, “goat” cross-species insights, “sera” studies. “Vaccine” embodies hope against anthrax, uniting science and conservation for wildlife protection.

4. Conclusion and future perspectives

The bibliometric analysis of anthrax-related African publications (1923–2023) reveals a diverse landscape. Contributions from 32 nations resulted in 364 publications with 5,636 citations. Subjects spanned medicine, agriculture, immunology, veterinary sciences, genetics, environmental science, and multidisciplinary research. Collaboration thrived with 1,688 authors and 1,368 institutions, fostering microbiology, disease dynamics, veterinary medicine, and public health advancements. Prolific institutions like the University of Pretoria played a key role. Authors like Henriette van Heerden contributed significantly. Notably, 2011–2023 saw remarkable growth, delving into microbial aspects, transmission, and control strategies. Collaboration and knowledge exchange drove multidisciplinary approaches and international cooperation in tackling anthrax challenges.

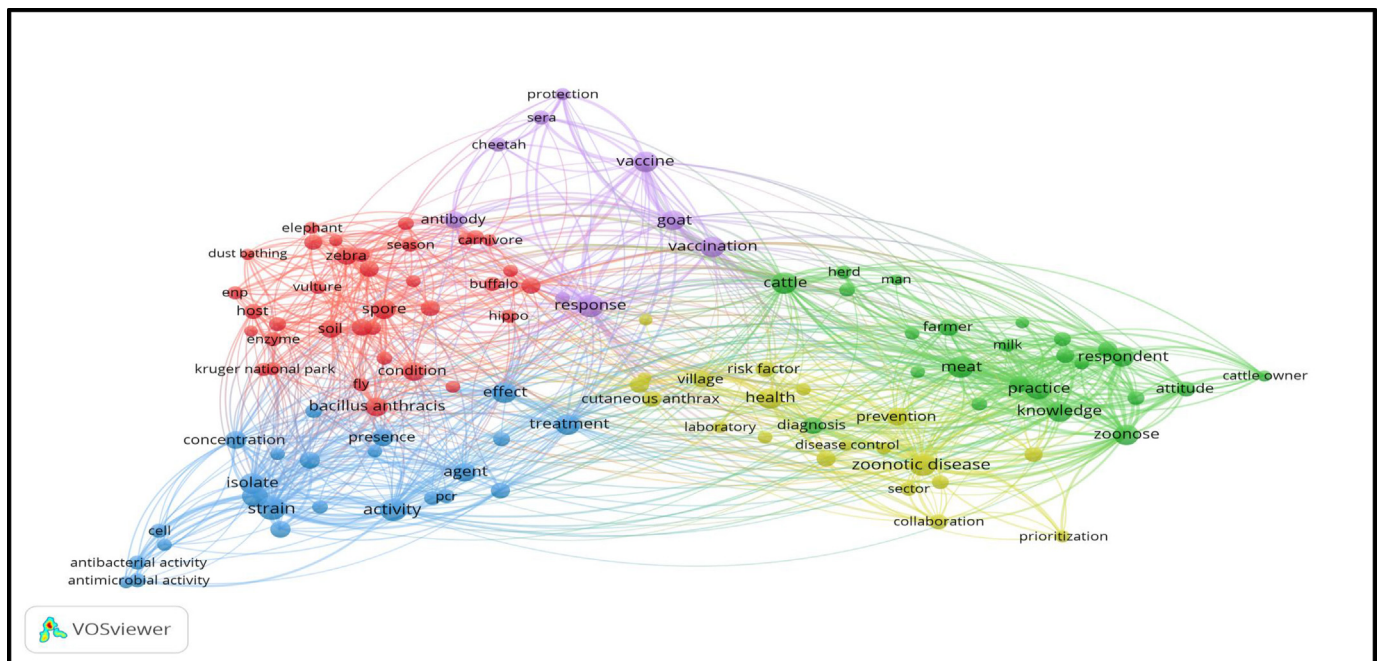


Fig. 6. Visualization map of terms in the 364 documents retrieved from Scopus database on anthrax with 10 or more occurrences during 1923–2023.

Looking ahead, the future of anthrax research in Africa holds promising prospects. Key aspects for enrichment include interdisciplinary collaborations, bridging gaps in knowledge, and accelerating interventions. Capacity building empowers researchers in resource-limited institutions. Global partnerships offer advanced resources. Deeper ecological insights aid transmission understanding. Translating research into practice, improved diagnostics, vaccines, and control measures are vital. Public health and agriculture synergy ensures holistic strategies, promoting stability. Data accessibility promotes knowledge exchange. Funding and infrastructure support quality research. Surveillance, genetic analysis, and modeling predict and prevent epidemics. The analysis of African anthrax research highlights directions for the critical field. Fostering collaboration, addressing gaps, and aligning efforts contribute to global anthrax understanding and management.

In this study, we exclusively use English-language articles, potentially overlooking valuable research in other languages, which could exclude vital contributions from non-English-speaking African researchers. This bias may distort the genuine impact of anthrax research in Africa. Concentrating on a single database and language can perpetuate regional and cultural biases, neglecting studies in African languages or local journals, thereby reducing diversity in perspectives. Relying entirely on Scopus as the exclusive data source may offer an incomplete view of anthrax research, possibly omitting relevant studies in untracked databases and vital research outcomes.

Noteworthy is that while employing VOSviewer to generate network maps, certain challenges emerge. A key challenge revolves around larger nodes obscuring smaller ones and their associated labels, appearance of terms (countries, names of authors, institutions so on) starting with lower cases and abbreviations, thereby impeding the comprehensive and detailed examination of the network. Consequently, this constraint may hinder the reader's capacity to grasp the intricacies of the data's relationships and connections.

Authors contributions

ILE was responsible for the conceptualization and research design. Data collection and analysis were performed by all Authors. The initial manuscript draft was carried out by ILE.

AO, GJS, BLJ, SHJ, RA, HH, SAA, PDL, SM, NSS and MM contributed to thorough review and editing of the final manuscript. All authors participated in final approval and made substantial contributions to the manuscript's publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.soh.2023.100052>.

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