Bibliometric analysis of scientific research on *Sclerocarya birrea* (A. Rich.) Hochst.

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Abstract:
Sclerocarya birrea (A. Rich.) Hochst. is an African wild tree found in many countries across the continent. Its leaves, bark, root, and fruits are used in food, cosmetics, and traditional medicine. However, no systematic bibliometric review on *S. birrea* have been performed so far.

This study covered publications made in 1986–2022 and investigated such bibliometric indicators as knowledge dynamics, links and structure, relevant journals, productive organizations, renowned authors, authoring patterns, national and international collaboration levels, etc. The bibliometric data on a total of 369 publications were downloaded from Scopus database and analyzed using the MS-Excel and VOSViewer software.

The Scopus publications on *S. birrea* showed a versatile range in the interdisciplinary areas of research, with agricultural and biological sciences predominating. The Republic of South Africa was responsible for the largest number of citations. All in all, 63 countries published research on *S. birrea* in the specified time period, and the share of African countries was 65.43% of the total global research. Co-authorship and international collaboration were registered for six clusters. A total of 1114 researchers and 160 institutions actively contributed to *S. birrea* studies, with 37 having a minimum of five publications. Mapping of knowledge structure using the keyword co-occurrence revealed the related research areas. The Journal of Ethnopharmacology took the lead in terms of average citation.

The co-citation analysis revealed some remarkable dynamics in *S. birrea* research. This bibliometric study provides a complete insight into *S. birrea* research development and publication patterns over the last 36 years.

Keywords: Bibliometric analysis, citation analysis, research-based data, *Sclerocarya birrea*, marula, Scopus, VOSViewer

INTRODUCTION

Sclerocarya birrea (A. Rich.) Hochst. is a savannah tree from the family of *Anacardiaceae*. Its English name is marula. The tree requires sandy or alluvial soils; propagation is carried out with seeds or cuttings. It grows in a wide variety of soils but prefers well-drained soil. The marula survives at altitudes varying from sea level to 1800 m and at an annual rainfall range of 200–1500 mm [1–3]. The fruits are pale yellow and plum-like, with a plain tough skin and juicy, mucilaginous flesh [4].

Glew *et al*. reported that *S. birrea* seed contained relatively large amounts of copper (24.8 mg/g dry weiht), magnesium (4210 mg/g dry weight), and zinc (62.4 mg/g dry weight) [5]. The protein content of the pit was high (36.4% of dry weight); however, the protein fraction was low in leucine, phenylalanine, lysine, and threonine. The potential benefits of marula oil are due to its high content of antioxidants and some important nutrients. In addition, marula oil also contains monounsaturated and polyunsaturated fats, which are good for health [6].

Marula oil can enhance hair health by moisturizing and fighting dryness without leaving any greasy impact, especially when used in moderate amounts [6]. Marula oil can stimulate hair in cases of dandruff or infection as it moisturizes the scalp and relieves it from dead skin cells [7]. Marula oil contains healthy fatty acids. When used in cooking, it regulates the level of cholesterol in the body, which improves the health of the heart and blood vessels, thus reducing the possibility of circulatory diseases, e.g., stroke, heart attack, and atherosclerosis [8]. Marula oil was reported to help pregnant women with skin issues [9, 10]. Marula oil contains antioxidants. As a natural antimicrobial, it can serve as a wound sterilizer that prevents infection and germs from entering the body [11].

Marula leaves and fruit pulp can treat hypertension; the leaves are used against diabetes, dysentery, snake and scorpion bites, malaria, and inflammations. The plant is also utilized as a tonic, and the fruits are often fermented as a raw material for a refreshing drink. Chemical and pharmacological studies on the bark have reported antidiarrheal activity of the decoction. It is a source of phenolic compounds, such as procyanidins and (-)epicatechin-3-galloylester. No research has been done so far on the chemical composition of *S. birrea* leaves, although their extract was reported to exhibit the activity with Ca^{2+} mobilizing systems in muscle cells [12]. Methanolic extracts from different parts of the *S. birrea* tree were examined for antioxidant properties. They proved to contain phenolic compounds that inhibit the oxidation of linoleic acid and the subsequent bleaching of beta-carotene. The seed extract was more active, followed by extracts of roots, leaves, and bark [13].

S. birrea extract was tested against diabetes type II in an *in vitro* study, where it was found efficient in reducing blood pressure in diabetic rats [14]. *S. birrea* methanolic and aqueous extracts demonstrated antimalarial activities and were found effective against different plasmodia, the methanol extract being more active than the aqueous one [15]. In traditional African medicine, *S. birrea* treats hypertension, dysentery, infertility, schistosomiasis, constipation, abdominal cramps, stomachache, sore eyes, toothache, backache, body pains, and gastroenteritis. The lyophilized decoction of this plant showed great anti-diarrheic activity [16–21].

The bibliometric analysis and the literature review are tools of knowledge management, prospecting, and mapping [22]. Scientific research in medicinal plants is one of the richest fields of scientific exploration because it brings together many scientific fields, e.g., chemistry, pharmacology, veterinary sciences, botany, pharmaceutics, traditional knowledge, and computer science [23]. *S. birrea* is a wild tree that grows all over the African continent and is used in nutrition, cosmetics, and traditional medicine by many African nations. As a result, *S. birrea* is a popular research object and a source of numerous studies. However, it has acquired no bibliometric profile so far. This study fills in the gap by investigating into the patterns of scientific research and the most important researchers, universities, and countries that dealt with *S. birrea* in 1986–2022. Other factors involved research dynamics and development, collaboration, structure, and impact.

STUDY OBJECTS AND METHODS

Bibliometrics is a method of determining trends in publications and research in a certain field of study by analyzing data quantitatively [24, 25]. This study looks at author cooperation networks, scientific outputs and contributions, scientific impact, institutional partnerships, national shares, etc. The authors performed a complete analysis of data on involvement and collaborations among researchers worldwide, their affiliations and journals that publish articles on *Sclerocarya birrea* (A. Rich.) Hochst. The bibliometric study relied on the Scopus database. Such bibliometric studies are crucial for consistency and accuracy in data needed for analysis of prior works and identifying research prospects.

Selecting database and extracting bibliometric data. Scientific information can be retrieved from various databases, e.g., PubMed, Scopus, and Clarivate WOS [26]. We extracted 92, 346, and 302 publications from PubMed, Scopus, and Clarivate WOS, respectively. We chose Scopus because it is more comprehensive and contains much a greater number of research documents on the matter, compared to WOS and PubMed [27]. Also, PubMed does not contain scientific papers that are concerned with pure botanical research. Scopus is an Elsevier-produced platform that provides indexing and abstract database with research publication linkages. Scopus was founded in 2004 and now hosts over 70 million papers from a variety of disciplines [28]. It is popular among scholars and simple to use. Scopus also provides extensive data and insights on research papers across a wide range of fields, with life and natural sciences leading the way [29–31]. The database also includes detailed biographies of authors, their affiliations, funding sources, citation statistics, and number of publications, as well as the nations that lead in each study sector.

Selection criteria. The analysis involved only scientific articles and conference papers published after 1986. Books were excluded because they usually summarize research results published in scientific papers. Although the original sampling involved articles published in other languages, the research was limited to the English language and the existing indexing. We did not restrict the mechanism for selecting researchers and journals.

Search criteria. We limited the search to article titles that contained "*Sclerocarya birrea*". The search command was restricted to the following parameters: publication year (PUBYEAR > 1986 AND PUBYEAR January 11 2022) and document type (DOCTYPE Article OR Conference papers). The results of the Scopus database search instructions were exported as a CSV Microsoft Excel, RIS format, plain text in HTML format, and BibTex files. Figure 1 illustrates the approach we applied to this bibliometric analysis.

Bibliometric and bibliographic networks: constructing and visualizing. The VOSViewer software
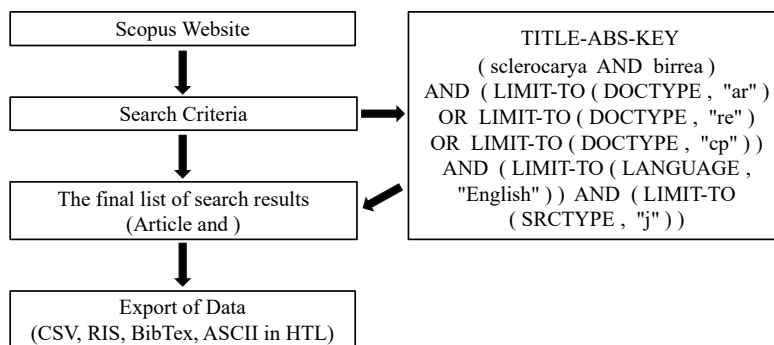
Figure 1 Search criteria

(Version 1.6.15, Leiden, Netherlands) is a program for creating and displaying bibliometric networks. These networks may be built via citation, bibliographic coupling, co-citation, or co-authorship relationships, and can comprise journal coupling, researchers, countries, institutional engagement, or individual articles. VOSViewer also has text mining capabilities, which may be used to build and display co-occurrence networks of key phrases retrieved from scientific literature [32, 33]. *S. birrea* proved to have yielded quite a lot of publications between 1986 and 2022.

Table 1 Types of Scopus publications on *Sclerocarya birrea* (A. Rich.) Hochst.

Type of documents	Number	Percentage, %
Article	328	89.1
Review	26	7.0
Conference Paper	10	2.6
Book Chapter	4	1.0
Editorial	1	0.3
Total records	368	100.0

RESULTS AND DISCUSSION

In this study, we set the time frame from 1986 to January 2022 because we found no alternative bibliometric studies on *Sclerocarya birrea* (A. Rich.) Hochst. for reference. The first paper on *S. birrea* was published in the *Botanical Journal of the Linnean Society*. All in all, we retrieved 369 research documents, 349 of which were original research papers, 25 belonged to review articles, and two could be classified as conference proceedings. Hover, Table 1 gives the total number of publications as 368, including articles (89.1%), reviews (7.0%), conference papers (2.6%), book chapters (1.0%), and editorials (0.3%). Such a substantial time frame made it possible to predict the research trends by analyzing its history.

International patterns. The time interval we identified for our analysis represented a milestone in the *S. birrea* research. The last fourteen years of the XX century (1986–2000) saw only 22 research papers (6.4%). In the new millennium, the publication rate reached 93.6% (n = 324) (Fig. 2). *S. birrea* prominence and potential cross-field applications may also be related to the prolific research output. The new publications revealed that every component of the *S. birrea* tree has some beneficial properties. The scientific community seems to have recognized its socioeconomic and medicinal potential [12, 17, 34–36]. Figure 2 shows that, despite the numerical increase in the research documents, the broken curve does not have a fixed frequency in the number of research papers for all years, with an average of 9.6 papers per year. The years 2008, 2011, 2016, and 2021 saw the largest numbers of publications with 20, 28, 20, and 21 documents, respectively. However, no scientific paper on *S. birrea* appeared in 1994.

Interdisciplinary areas of research, citations, and geographical distribution in 1986–2022. The *S. birrea*-related publications appeared to cover a versatile range of interdisciplinary research areas. All in all, the sampling demonstrated 22 fields of studies. Agricultural and biological sciences led in terms of research outputs, accounting for 35.8% of the overall number. Pharmacology, toxicology, and pharmaceutics (11.9%), medicine (10.5%), biochemistry, genetics and molecular biology (9.6%), as well as environmental science (9.1%) accounted for 41.1% (Fig. 3). Veterinary studies on *S. birrea* represented 1.7%. This result indicated the importance of *S. birrea* in African countries for treating and feeding domestic animals. It proved efficient against such endemic parasites as Trypanosoma, worms, and ticks [37–41]. Other ethnoveterinary treatments included the use of indigenous medicinal herbs to prevent and treat a variety of animal diseases. This application of *S. birrea* in farming can be termed traditional knowledge [42].

According to the VOSViewer analysis of worldwide research involvement by countries, 63 nations published original research articles or conference papers (Table 2). South Africa occupied the first place in the number of publications, i.e., 32.16%. Publications from outside the African continent were responsible for 34.57% with the highest number of citations being 3781. The United States, Germany, and the United Kingdom were the leading Western countries involved in the *S. birrea* studies. Kenya, the Republic of the Sudan, Zimbabwe, Burkina Faso, Nigeria, Namibia, and Cameroon participated with 3.14, 3.14, 3.14, 2.59, 2.59, 2.40, and 2.22%, respectively. African countries provided research representing 65.43% of the total global *S. birrea* research (Fig. 4) because Africa
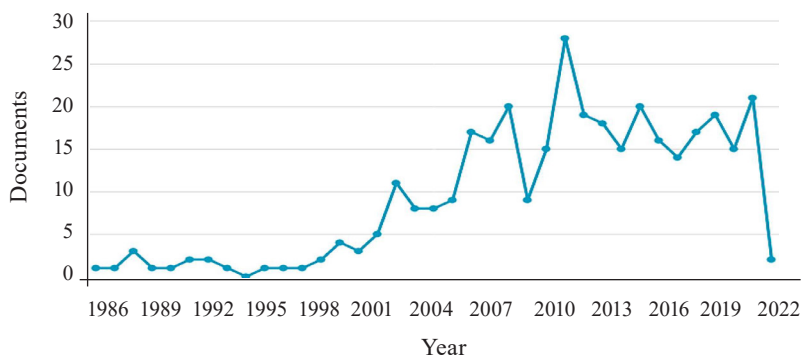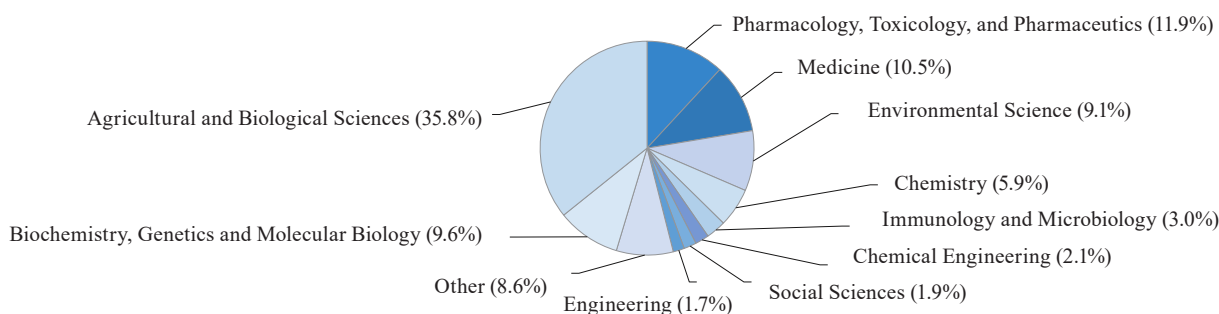
Figure 2 International pattern of publications

Figure 3 Distribution of Scopus-extracted documents related to *Sclerocarya birrea* (A. Rich.) Hochst. by subject area

Table 2 Worldwide research involvement, citation, and total link strength by countries

| Country	Number of documents	Percentage	Citations	Average citation per publication	Total link strength
South Africa	174	32.16	3781	21.73	746
United States	24	4.44	753	31.38	148
Germany	21	3.88	527	25.10	120
United Kingdom	21	3.88	751	35.76	200
Kenya	17	3.14	669	39.35	115
Sudan	17	3.14	466	27.41	135
Zimbabwe	17	3.14	325	19.12	102
Burkina Faso	14	2.59	320	22.86	51
Nigeria	14	2.59	250	17.86	72
Namibia	13	2.40	279	21.46	193
Cameroon	12	2.22	264	22.00	115
Botswana	11	2.03	179	16.27	46
France	10	1.85	138	13.80	53
Denmark	9	1.66	173	19.22	61
Sweden	9	1.66	162	18.00	21
Benin	8	1.48	100	12.50	64
Malawi	8	1.48	155	19.38	88
Senegal	8	1.48	137	17.13	18
Spain	8	1.48	138	17.25	96
Australia	7	1.29	265	37.86	180
Belgium	7	1.29	220	31.43	61
Italy	7	1.29	272	38.86	62
Netherlands	7	1.29	194	27.71	44
Switzerland	7	1.29	119	17.00	54
Tanzania	7	1.29	219	31.29	29
China	6	1.11	64	10.67	67
India	6	1.11	110	18.33	17
Swaziland	6	1.11	60	10.00	22
Israel	5	0.92	46	9.20	32
Mali	5	0.92	177	35.40	40
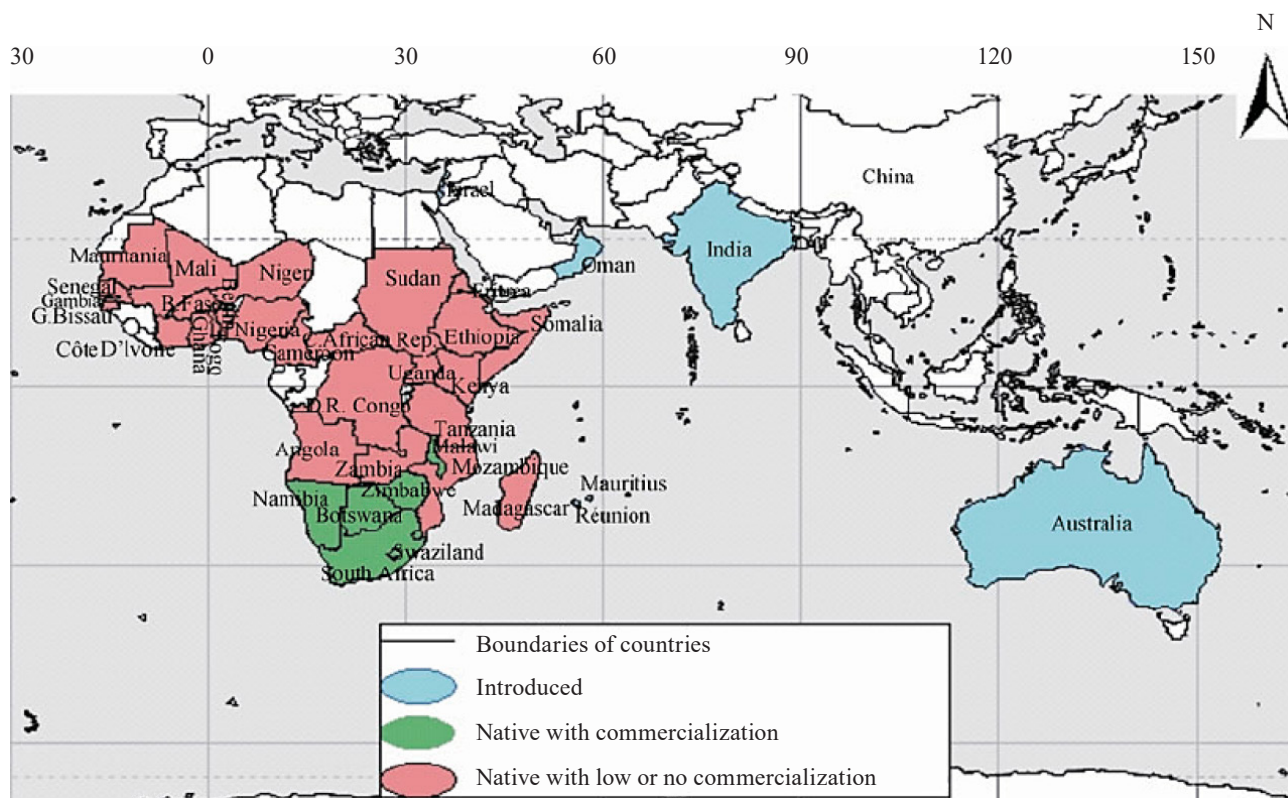
Figure 4 Geographical Distribution of *Sclerocarya birrea* (A. Rich.) Hochst. [43]

is its natural habitat with the tropical conditions it needs for growth [43]. In spite of the fact that marula also grows in India and Australia, these two countries contributed as little as 2.4% from the global research on *S. birrea*.

Citation analysis is a method of determining the relevance of an author or an article by counting the number of references to this author or article in other publications. National research assessments are conducted on a regular basis in numerous countries. They make it possible to compare citation indicators and peer ratings [44]. In this research, the Republic of South Africa appeared to have the largest number of citations, followed by the United States, Germany, the United Kingdom, Kenya, the Sudan, Zimbabwe, Burkina Faso, Nigeria, Namibia, Cameroon, Botswana, and France. The large number of citations obtained by Western countries indicated the global interest in *S. birrea* because of its medicinal and nutritional values [17, 34, 37, 38].

International collaboration and co-authorship links between countries. We analyzed the collaborative networks between various nations with a minimum of five documents published using VOSViewer (Fig. 5). The analysis revealed six clusters. We used the association method of normalization. Maximal iterations were 1000 steps, and the step size convergence was 0.001. Individual components (circled) were assembled to create a cluster and connected together by lines to represent partnerships or networks and their strength [25, 32, 33].

Among all the countries (n = 63) that published *S. birrea* research, only 30 countries fulfilled the criteria of five

documents. We connected these groups by lines to represent the strength of co-authorship and scientific collaboration. South Africa had the largest network of research collaboration as presented in Cluster 1 with the total link strength of 56. In this cluster, South Africa had the highest number of documents, followed by the United Kingdom and the United States with link strengths of 11 and 10, respectively. This fact could be evidenced by the size of the dark red circle (Fig. 5). Cluster 2 (green) had 7 countries; France and Burkina Faso had the highest collaboration network with other countries in this cluster with total link strengths of 19 and 13, respectively. Cameroon, China, Swaziland, Switzerland, and Zimbabwe fell in Cluster 3 (blue). Zimbabwean researchers showed the highest strength in their international collaboration with total link strength and the number of documents of 12 and 17, respectively. Cluster 4 (gold) included three countries, namely Belgium, Spain, and Senegal. The importance of bibliometric analysis in understanding the role of impactful research is visible by the differences in the members of Cluster 4. Thus, Spain (3) and Senegal (12), regardless of their differences nominal GDP rankings, showed great variation in the total link strength indicator. The United States, Kenya, and Malawi were grouped together in Cluster 5 (purple) with total link strengths of 34, 21, and 9, respectively. Cluster 6 involved Germany, the Sudan, and Nigeria with 29, 17, and 14 publications, respectively. Although Nigeria had 14 publications, the total link strength showed that their international collaboration network was low, compared to other topmost
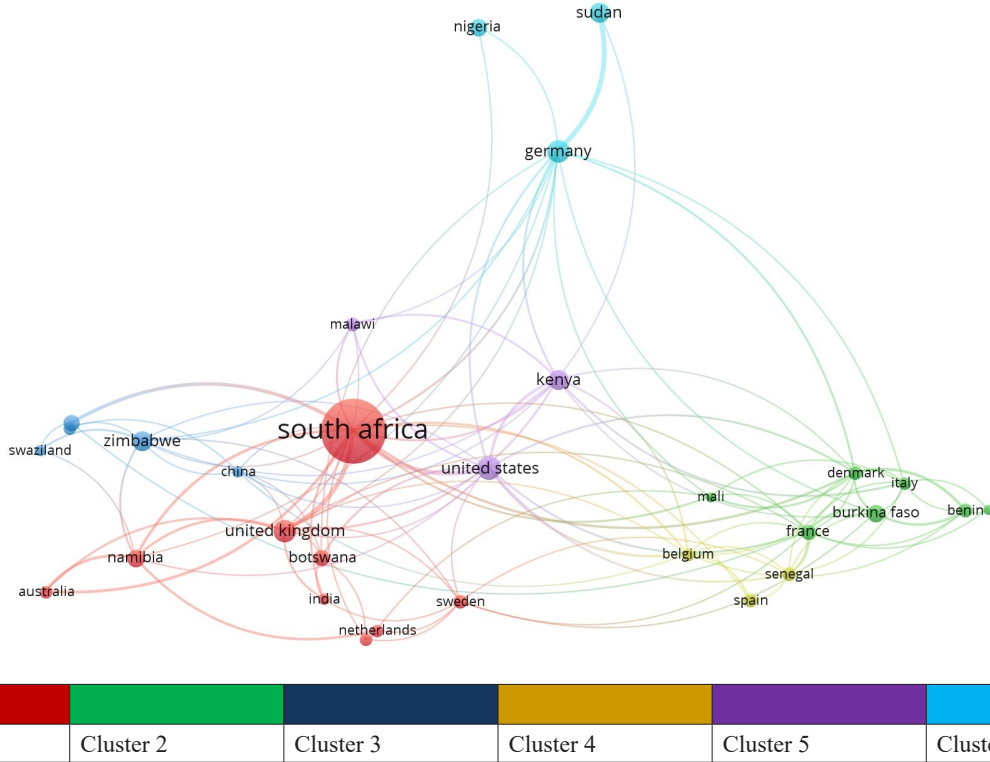
Figure 5 International collaborations with countries with a minimum of five publications in 1986–2022
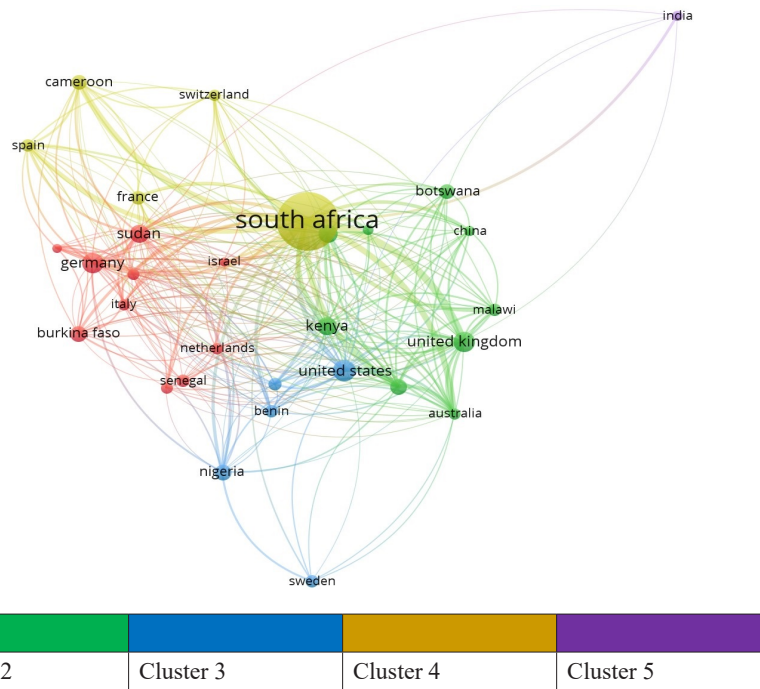

Figure 6 Visual representation of citations with countries with a minimum of five citations in 1986–2022

productive countries in the same cluster, e.g., the Sudan. One of the co-authors of this article participated in the international collaboration between Sudan and Germany with a link strength of 12. This co-authorship was a product of joint research between the Max Rubner Institute, Germany, and the Sudan University of Science and Technology, which yielded 10 publications [4, 13, 45–52].

Figure 6 provide a visual representation of citations for countries with a minimum of five citations in 1986–2022. Five clusters were extracted using association as a method of normalization. Maximal iterations were 1000 steps; the step size convergence was 0.001. Cluster 1 (dark red) involved ten countries with a total link strength of 1526. This cluster included the Republic of

Table 3 Institutions with at least eight publications on *Sclerocarya birrea* (A. Rich.) Hochst.

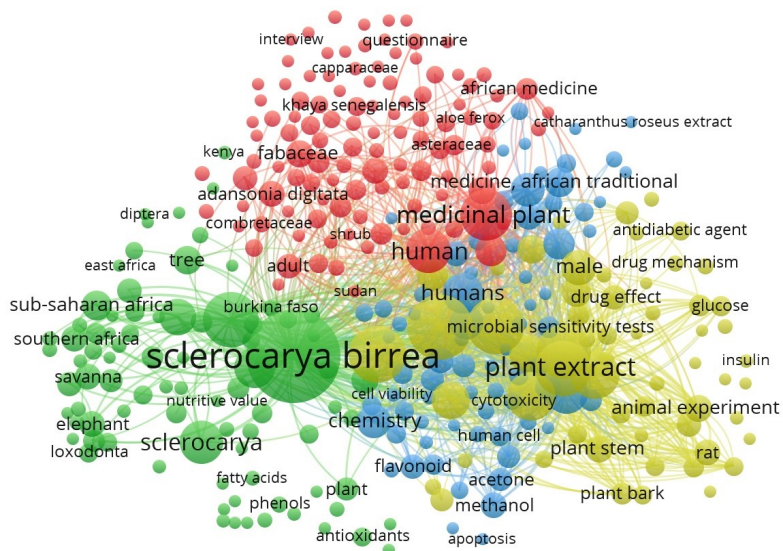| Institution	Country	Total publications	Total citations
University of Pretoria	South Africa	29	757
University of the Witwatersrand	South Africa	28	563
University of KwaZulu-Natal	South Africa	20	444
University of Limpopo	South Africa	19	225
University of Fort Hare	South Africa	16	284
Sudan University of Science and Technology	Sudan	11	243
University of South Africa	South Africa	10	42
Tshwane University of Technology	South Africa	10	191
The Council for Scientific and Industrial Research	South Africa	10	383
University of Zululand	South Africa	10	305
Max Rubner Institute	Germany	10	227
Rhodes University	South Africa	9	350
University of Gezira	Sudan	9	200
University of Witwatersrand	South Africa	9	295
University of Cape Town	South Africa	8	232

the Sudan, Germany, Italy, Belgium, Burkina Faso, the Netherlands, Mali, Israel, Tanzania, and Senegal, with the Total Link Strength of 135, 120, 62, 61, 51, 44, 40, 32, 29, and 18, respectively. The Sudan and Germany were the most cited countries in this cluster. The greater number of citations for the Sudan gave it preference in this group, despite the greater number of documents for Germany. Clusters 2 (green), 3 (blue), 4 (gold), and 5 (purple) comprised 9, 5, 5, and 1, respectively. India was the only representative of Cluster 5.

Institutions and universities involved in *S. birrea* research in 1986–2022. A total of 160 institutions contributed to *S. birrea* studies, with 37 having at least five publications. Table 3 also shows the number of publications and citations for the universities with a minimum of eight documents. The number of universities and institutes from the Republic of South Africa represented about 70.05%, while the Sudan, Germany, and Namibia represented about 29.5%. The University of Pretoria, South Africa, had 29 publications and 757 total citations, which makes it university number one in the world in *S. birrea* research production and impact. Quantitative measures, such as citation counts, are often used to assess the research impact [53]. We used this index to compare the number of citations for the three universities that appeared to have the same number of scientific papers but differed in the number of citations. The University of South Africa, the Tshwane University of Technology, and The Council for Scientific and Industrial Research delivered 10 scientific papers, each with the number of citations as 42, 191, and 383, respectively (Table 3).

Mapping knowledge structure by keyword co-occurrence. The co-occurrence analysis provides an overview of the structure of the subjects researched, as assessed by the number of occurrences. The data are visualized as nodes of different size [54]. In the analysis of keyword co-occurrence, 362 out of 5617 keywords met the threshold of at least five occurrences, producing five clusters, 5532 links, and a total link strength of 16 413

(Fig. 7). The different colors indicate different general research foci. "*Sclerocarya birrea*" was the most popular key word (n = 262) with 153 links and a total link strength of 5532. In the analysis of the co-occurrence of authors' keywords, 24 out of 1134 keywords met the threshold with a minimum of five occurrences, producing six clusters, 45 links, and a total link strength of 80 (Fig. 8). The top occurrences were: *Sclerocarya birrea* (n = 66), marula (n = 29), and medicinal plants (n = 21). Figure 9 visualizes the co-occurrence of 4480 index keywords, i.e., those chosen by publishers and standardized using publicly accessible vocabularies. Unlike authors' keywords, indexed keywords take into consideration synonyms, spelling variations, and plurals [55]. VOSViewer extracted four clusters, 19 173 links, and a total link strength of 48 712. When we compared the number of all keywords (5617) with the index keywords (4480), we found out that the authors used all the indexed keywords.

Source of publications and bibliometric coupling. Between 1986 and 2022, a total of 187 periodicals published research works on *S. birrea*, i.e., original papers and conference proceedings. Table 4 focuses on journals with a minimum of five publications. Only ten journals satisfied this criterion, with *Ethnopharmacology* (Elsevier) having published 25 papers on *S. birrea*. Most of the journals are hosted by Elsevier, Springer, and Wiley Publishers. However, the *South African Journal of Science* became a standalone source. The *Journal of Ethnopharmacology* (Elsevier) and *Forests, Trees, and Livelihoods* (Taylor & Francis) took the lead in terms of average citation per journal. According to the data indexed in Scopus, agricultural and biological sciences led in terms of research outputs on *S. birrea*. The top three journals fell in the scope of this field. Figure 10 visualizes the analysis of coupling of all journals: 10 out of 187 journals met the threshold of at least five bibliometric couplings, producing three clusters, 42 links, and a total link strength of 1284. When two works in a bibliography refer to the same third work, it is known as bibliographic coupling.

Bibliographic coupling is a sign that the two works are likely to be about the same thing. When two documents share one or more citations, they are said to be bibliographically connected [56]. The *South African Journal of Botany* had the highest total link strength (531) followed by the *Journal of Ethnopharmacology* (521). The *Tropical Animal Health and Production* had the lowest total link strength (25).

Authors' contribution in *S. birrea* research in 1986–2022. A total of 1114 researchers were identified as *S. birrea* research authors. Only 21 of these co-authors satisfied the minimal requirement of five marula-related articles within the specified time frame. Table 5 depicts the most prolific *S. birrea* authors. With 11 total publications, Alfred Maroyi of the University of Fort Hare, South Africa, had the most prolific research output. Bertrand Matthäus from the Max Rubner Institute, Germany, had 11 publications. Finnie, van Staden, and Witkowski delivered 10 articles. The role of bibliometric analysis is to combine various data, such as citations and number of

Figure 7 Visual representation of co-occurrence for all keywords with a minimum of five keywords in 1986–2022

Figure 8 Visual representation of co-occurrence for authors' keywords with a minimum of five keywords in 1986–2022

Figure 9 Visual representation of co-occurrence of index keywords with a minimum of five keywords in 1986–2022

Table 4 Journals with a minimum of five publications in 1986–2022

Source (Publisher)	Documents	Citations	Average citation per journal	Total link strength	ISI-impact factor
Journal of Ethnopharmacology (Elsevier)	28	1256	44.86	40	4.36
South African Journal of Botany (Elsevier)	21	361	17.19	41	2.315
Agroforestry Systems (Springer)	9	233	25.89	24	2.549
African Journal of Biotechnology (Academic Journals)	6	114	19.00	11	NA
African Journal of Ecology (Wiley)	6	85	14.17	11	1.426
Forest Ecology and Management (Elsevier)	6	146	24.33	26	3.558
Forests, Trees, and Livelihoods (Taylor & Francis)	6	266	44.33	20	NA
Phytotherapy Research (Wiley)	6	211	35.17	23	5.882
South African Journal of Science (Stand Alone)	5	65	13.00	5	2.197
Tropical Animal Health and Production (Springer)	5	12	2.40	1	1.559
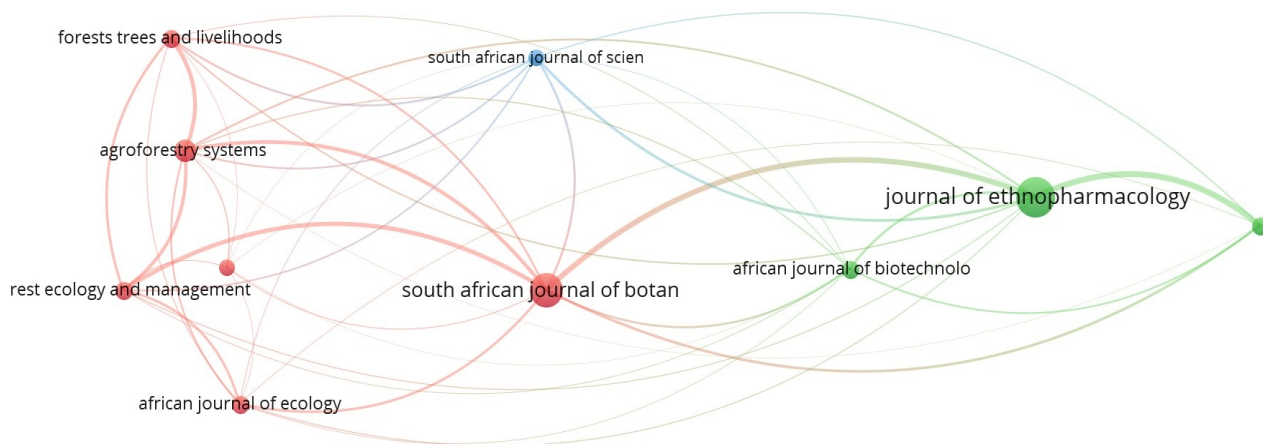
Figure 10 Visual representation of bibliographic coupling based on journals with a minimum of five keywords in 1986–2022

Table 5 Authors with a minimum of five publications

Author	Documents	Citations	Total link strength
van Staden, J.	13	319	37
Maroyi, A.	11	131	37
Matthäus, B.	11	247	59
Finnie, J.F.	10	270	33
Witkowski, E.T.F.	10	179	46
Hussein, I.H.	9	200	41
Mariod, A.	9	218	44
Moyo, M.	9	272	33
Semenya, S.S.	8	114	18
Van Vuuren, S.F.	8	289	45
Eichner, K.	7	182	37
Eloff, J.N.	7	205	31
Ojewole, J.A.O.	7	284	48
De Wet, H.	6	295	40
Ndip, R.N.	6	161	26
Dimo, T.	5	98	31
Helm, C.V.	5	116	40
Kamtchouing, P.	5	98	31
Lykke, A.M.	5	112	11
Shackleton, C.M.	5	191	45
Shackleton, S.	5	164	19

Table 6 Top ten cited articles

No.	Title	Number of citations	Journal	Reference
1	Whole plant extracts versus single compounds for the treatment of malaria: synergy and positive interactions	73	Malaria Journal	[59]
2	Phenolic composition, antioxidant and acetylcholinesterase inhibitory activities of *Sclerocarya birrea* and Harpephyllum caffrum (Anacardiaceae) extracts	59	Food Chemistry	[60]
3	Antidiabetic screening and scoring of 11 plants traditionally used in South Africa	37	Journal of Ethnopharmacology	[61]
4	Chemical composition and antioxidant activity of phenolic compounds from wild and cultivated *Sclerocarya birrea* (*Anacardiaceae*) leaves	24	Journal of agricultural and food chemistry	[12]
5	Towards the development of Miombo fruit trees as commercial tree crops in Southern Africa	20	Forests, Trees and Livelihoods	[62]
6	Improving discrimination of Savanna tree species through a multiple-endmember spectral angle mapper approach: canopy-level analysis	20	IEEE Transactions on Geoscience and Remote Sensing	[63]
7	Ethnobotanical study of medicinal plants in the Blue Nile State, South-Eastern Sudan	18	Journal of Medicinal Plants Research	[64]
8	Antifungal activity of some Tanzanian plants used traditionally for the treatment of fungal infections	11	Journal of Ethnopharmacology	[65]
9	Polyphenol content and antioxidant activity of fourteen wild edible fruits from Burkina Faso	11	Molecules	[66]
10	Host plants and host plant preference studies for *Bactrocera invadens* (Diptera: Tephritidae) in Kenya, a new invasive fruit fly species in Africa	6	Annals of the Entomological Society of America	[67]

publications, and produce some indicators to evaluate the real knowledge impact of particular researchers [57, 58]. Therefore, Maroyi proved to have a greater number of publications than van Staden, but Maroyi had a greater impact on generating knowledge and research quality (Table 5). Table 6 sums up the top cited articles.

We determined the average number of publishing and active years of an author's outputs using a co-authorship analysis. Figure 11 shows a VOSViewer-based co-author-ship analysis. The co-authorship network of authors was limited by a minimum of three publications made in 1986–2022. We extracted 28 clusters using the method
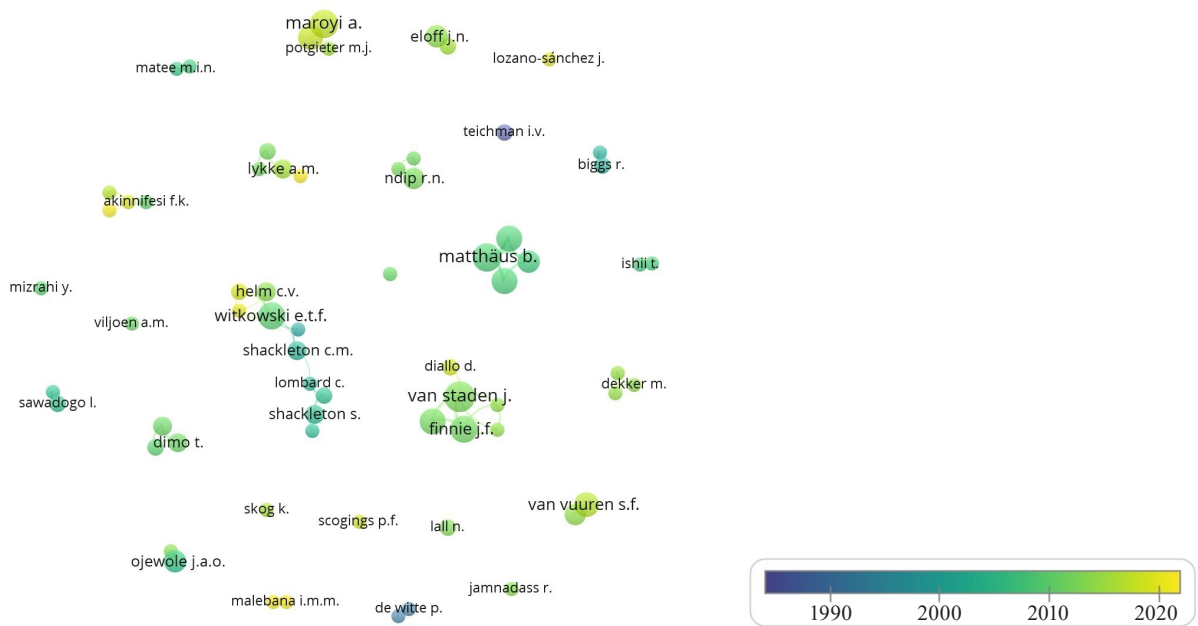
Figure 11 Co-authorship network of authors with a minimum of three publications in 1986–2022 based on average publications per year
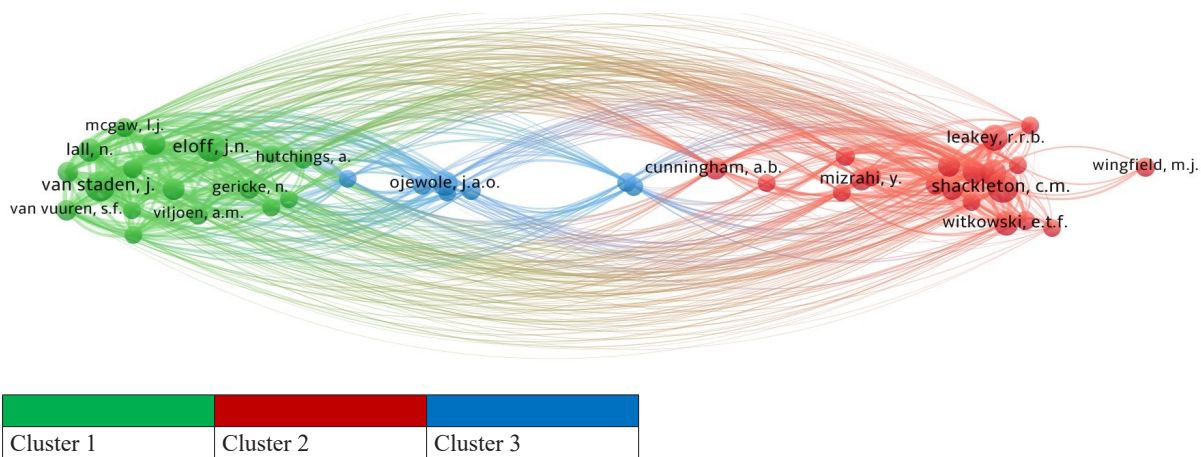

Figure 12 Co-citation network of authors with a minimum of 60 citations in 1986–2022

of co-authorship analysis based on author mapping with 67 items, 58 links, and a total link strength of 198. According to our research, Matthäus, Mariod, Eichner and Hussein belonged to the same cluster and worked closely as a research collaboration team. Their research scope was *S. birrea* kernel oil [4]. This team is presented by green nodes in Fig. 11. van Staden and other five authors fell in Cluster 2. These researchers shared the same interests in ethnobotany and bioactive properties of *S. birrea* [60, 68].

The co-citation analysis has become a leading tool of empirical insight into the structure of scientific communication. Unlike bibliographic coupling, which is retroactive, the co-citation analysis assesses document similarity in advance. Co-citation frequencies may alter in the future as a result of the development of an academic area [69]. Figure 12 shows clusters arranged by the VOSViewer software. The co-citation network of the cited

authors had a total link strength of 37 949 for authors with a minimum of 40 citations, and only 44 authors met this threshold. We classified them into three clusters. van Wyk, Elof, Lall, and van Staden belonged to Cluster 1 (green) with a total link strength of 3651, 4078, 4830, and 7500, respectively. Cluster 2 (red) included Shackleton, who showed the highest total link strength of 3126. Shackleton is a full-time research professor at the Department for Environmental Science at Rhodes University, Grahamstown, South Africa. Matthäus proved to be the most prolific researcher in Cluster 3 (blue).

CONCLUSION

The leaves, bark, root, and fruit of *Sclerocarya birrea* (A. Rich.) Hochst., also known as marula, are used in nutrition and traditional medicine in many African

countries. Farmers eat its fruit raw, make marula wine, add seed juice to porridge, make jam, soda drinks, etc. The seed is surrounded by a delicate white kernel that is high in protein and oil. The oil, in its turn, is high in oleic, palmitic, myristic, and stearic acids, while the kernel protein is high in amino acids, with glutamic acid and arginine dominating. Extracts from various botanical parts of marula are known for their excellent total phenolic compounds, radical-scavenging capabilities, and antioxidant activities. Numerous studies have proved anti-diabetic, anti-inflammatory, analgesic, anti-parasitic, antibacterial, and antihypertensive properties of *S. birrea*. In addition, the tree provides shade in agricultural fields and is utilized to store maize plant remnants for animal feed later in the spring. Its parts serve as cattle forage. To sum it up, the numerous utility options and therapeutic properties of this tree led to scientific and research efforts that spread all over the world. It has become the focus of many scientific papers, books, conference proceedings, doctoral dissertations and Master's theses. Some of these works entered the Scopus database, from which the authors of this research retrieved 370 papers in English, French, Japanese, and Chinese.

This study represented the first bibliometric analysis of publications related to *S. birrea*. It covered worldwide publishing patterns, national and international partnerships, institutional engagement, the role of individual researchers and scientific journals, etc. The Republic of South Africa appeared to be the leading country in *S. birrea* research, followed by the United States, Germany, Britain, Kenya, the Republic of the Sudan, and Zimbabwe. In spite of the fact that the tree does not grow in Europe, the wide involvement of European countries is evidence of strong academic cooperations. Many postgraduate students from African countries completed their studies in Europe. Some researchers send their samples to European universities to be examined by advanced instruments.

The goal of any bibliometric analysis is to integrate diverse data, such as citations and the number of publications, as well as to develop certain indications that may be used to assess the true knowledge effect of various academics. In our study, Maroyi and van Staden appeared to have a lot of publications on the matter, but Maroyi proved to have a greater impact on creating knowledge and improving the overall quality of *S. birrea* research. Most publications were in agriculture and forestry (35.8%). However, many South-African researchers in the fields of pharmacy and medicine published their research materials in the *Journal of Ethnopharmacology*, which became the top journal on *S. birrea* with its 28 articles. Between 1986 and 2022, a total of 187 periodicals published marula-related articles. The prospects are such that *S. birrea* studies might one day become a bridge for research cooperation between Africa and the West. We expect that many scientific papers on the beneficial properties of marula will be published in the agricultural, environmental, and medical fields in the near future as researchers are urged to develop food and pharmaceutical products for commercialization.

CONTRIBUTION

All authors have contributed equally to this project.

CONFLICT OF INTEREST

The authors declared no conflict of interest regarding the publication of this article.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

There is no form of human subject involved in this manuscript; therefore, ethics approval is not needed.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIAL

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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