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Original Research Article

Research Productivity and Mapping on Neem: A Bibliometric Analytical Approach Indexed in Web of Sciences

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ABSTRACT

Azadirachta indica (Neem) A. Juss as an ethnobotanical has been used to treat various diseases due to its medicinal, insecticidal, and landscaping properties and has recently been used to synthesize other materials. The current study attempted to aggregate research innovations on Neem through a bibliometric analysis for articles published between 1925 and 2020, using the Web of Science and a validated extensive literature search query that included keywords such as "Neem", or "Neem tree", or "*Azadirachta indica*", or "*Melia azadirachta* L", or "Arya Veppu", or "Azad Dirakht", or "Nimba," or "Margosa." The HistCite, Bibliometrix package in R and the VOS viewer software were used to generate the bibliometric indices and mapping. The search query returned 2347 documents, including 2298 articles and 49 reviews papers, with findings indicating that India was the most productive country in terms of article number, with 923 articles and 865 reviews respectively, while that Siddiqui BS from the University of Karachi was a top pioneer and active author. Furthermore, our findings demonstrated the utility of bibliometrics in addressing the key evaluation of Neem research, which will aid researchers in gaining a better understanding of future research direction, addressing key research evaluation questions and methods for providing additional insight, and evaluating hypotheses related to the structure and development of a field.

***Keywords*:** Neem, Meliaceae family, Biodiesel production, Web of Science, VOSviewer software, Thematic evolution.

Introduction

For centuries, ethnobotanicals have been used to treat and cure numerous diseases. These ethnobotanicals are plants with multiple medicinally-important components used in the traditional or folklore medicines for treating various illnesses.[1] Traditional knowledge of the medicinal values of plants has served as the bedrock for the development of about 50% of all modern drugs obtained from the natural origin, e.g., the discovery of artemisinin and *Galega officinalis L.* based compounds such as metformin, phenormin, and buformin, which are widely used in the treatment of metabolic diseases even in developed countries.[2–4]

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Prominent amongst these ethnobotanicals is *Azadirachta indica* A. Juss (Neem) which has been used for more than 2000 years in India and neighbouring countries due to its medicinal, insecticidal, biological pest control and landscaping potentials.[5] Today, Neem trees have been domesticated in about 72 countries in Africa, Asia as well as Central- and South America.[6] Various Neem extracts are profoundly utilized in Indian folk medicines, and these extracts are prepared as decoctions, infusions, poultices or pounded pastes to be administered as recommended.[7,8] Neem is classified under Meliaceae, which originated from the Indian sub-continent.[9] Other plants of the *Meliaceae* family, such as *Carapa procera, Melia azaderach, Khaya senegalensis*, and *Trichilia emetic*, are also well known for their repellent and insecticidal effects.[10] Neem is a perennial, medium-sized, fast-growing tree which naturally withstands harsh weather conditions and thrives even on poor soils,[6] while the oval-shaped fruit, which turns from green to yellow-green when ripe, is about 2 cm long.[11] Neem comprises of several phytochemicals such as azadirachtin, meliantriol, and salanin.[12] Additionally, azadirachtin is regarded as a prominent biopesticide due to its mode of action and high concentrations, particularly in Neem fruits. 13 Studies have shown that different plant parts exhibit therapeutic, insecticidal, and pest control abilities effectively.[14] Extract of Neem bark treats gastric hypersecretion and gastro-duodenal ulcer.[15] The leaves are used in traditional medicine as antimicrobial, antioxidant hepato-protective, and anti-inflammatory agents. Five smoke-dried *Azadirachta indica*

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leaves also find their place as mosquitos repellent by adding the leaves to fire.[16] The kernel contains approximately 30–50% oil and many other biochemicals that are potent in the control of pests.[17] Researches also suggest that Neem can work effectively as anti-cancer, anti-diabetic, contraceptive, and sedative agents.[18–20] Moreover, azadirachtin, the major component of Neem oil, has been used against many pest arthropods, such as mites.[21] On another hand, due to its low mammalian toxicity, biodegradability, and broad-spectrum insecticidal action, Neem oil is considered a valuable substitute to synthetic pesticides,[22] while a lot of work has been conducted on Neem oil for renewable biodiesel production [23–26] and as environmental-benign innovative industrial anti-corrosive coatings.[27,28]

Today, the scourge and fatalities caused by the virulent Covid-19 pandemic in Africa are relatively lower than those recorded in developed continents.[29] This is partly due to Africans' reliance on medicinal plants, which are relatively inexpensive and widely available. In Africa, particularly Nigeria, Neem, along with other herbs such as guava leaves, mango leaves, lime, ginger, garlic, and so on, became commonplace. The infusion of the leaf and decoction of the bark was administered orally due to the hydroxychloroquine component of Neem thought to be an effective treatment of coronavirus infection.[30,31] This not only increased the popularity of Neem, but it also revealed the ancient medicinal asset presented to humanity by nature and aided in the domestication of the tree on tropical soil. Since this has thrown the plant into the spotlight, a review of the ethnobotanical benefits/blessings of the Neem tree is now more important than ever.

As a result, this study used a bibliometrics research method to provide the researcher with a new perspective on research productivity in the Neem field. For accountability and estimation of research progress, bibliometric methods have been used in various fields.[32–35] This research method identifies the top contributing authors and countries. Similarly, trending articles and hot topics accurately understand Neem-related research focus and the most conceptualized frameworks to aid future research direction.

Materials and Methods

Data collection

For the study, we used Thomson Reuters' Web of Science (https://www.webofscience.com/), which includes three databases (the Social Sciences Citation Index (SSCI), Science Citation Index Expanded (SCI-Expanded), and the Arts & Humanities Citation Index (AHCI). An extensive literature search was conducted using keywords as follows: Title "Neem", "Neem tree", "*Azadirachta indica*", "*Melia azadirachta* L", "Arya Veppu", "Azad Dirakht", "Nimba", "Margosa", "Neeb" "Nimtree", "Vepu", "Vempu", "Vepa Bevu", "Kohomba', "Indian Lilac", "Mwarobaini". Refined by language: Only articles published in English were included in the final set of articles for further review. Documents type consists of both "research articles" OR "reviews". Timespan: All years. Indexes: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (A&HCI). Boolean operators "OR" were used in the "title" tab of the Web of Science database for searching the research papers published between 1925 and 2020 were included in our study. Initially, a total of 2,347 bibliographic information, including article title, article type, authors, institutional, affiliations, keywords, number of citations, journal, publication year, country or region, research categories, and funding agencies, were retrieved from the search result (Table 1). The metadata was exported to.csv and plain text format files for future analysis. Ethical approval was not necessary since the data used in this study were obtained from public databases and did not involve direct interaction with human or animal subjects. The article screening was performed by two researchers (THM & OO), and bibliometric data were extracted within a single day (August 27, 2021) to avoid updating the citation while we were using the open-source database.

Table 1: Main Information about data

Description	Results	Description	Results
Timespan	1925:2020	Review	49 (2.08%)
Sources (Journals, Books, etc)	857	**Document Contents**	
Documents	2,347	Keywords Plus	4,108
Total citation ns	44,959	Author's Keywords	4,957
Without self citations	35,371	**Authors**	
H-index	73	Authors	6,527
Country	84	Author Appearances	9,909
Web of Science Research area	103	Authors of single-authored documents	109
Organization enhance research	1804	Authors of multi-authored documents	6,418
Funding agencies	731	**Authors Collaboration**	
Average years from publication	14.9	Single-authored documents	135
Average citations per documents	19.15	Documents per Author	0.36
Average citations per year per doc	1.61	Authors per Document	2.78
References	49,487	Co-Authors per Documents	4.22
Document Types		Collaboration Index	2.9
article	2298 (97.91%)		

Statistical Analysis

The Bibliometrix package in R. was used.[36] In addition, Microsoft Excel and VOSviewer (Van Eck & Waltman, Leiden University, The Netherlands) were used for mapping and network analysis,[37] while GraphPad Prism v5,[38] HistCite,[39] Bibliometrix app." (Using R),[40] and SPSS ver 19 were employed to run the association between the factors correlating to each other.

Results and Discussion

The Annual Trend and Citation Analysis

According to the findings, the annual number of published Neem articles peaked in 2020. The annual number of publications and the Mean of Total citations increased as indexed in the Web of Science from 1925 to 2020 (Figure 1).

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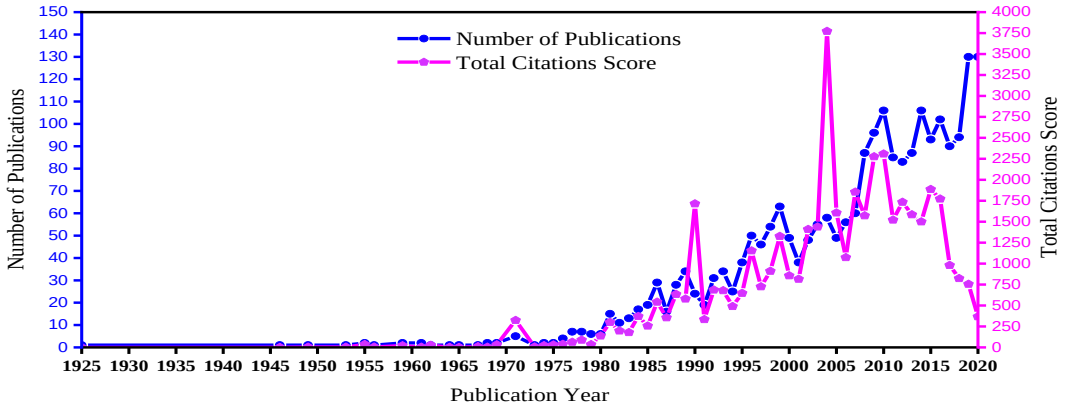

Figure 1: Annual growth and citation score, 1925-2020.

Top most cited articles

Table 2 shows the top ten most cited papers based on the number of citation scores received, used as indicators for the quality of work gain scientific value, which is more critical and has attracted a global readership. According to the findings, the article "Rapid Synthesis of Au, Ag, and bimetallic Au core-Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth" is the most cited with 1,531 citations and has had a massive impact as a hot and top cited among all the papers.[41]

Productivity of author

According to the search results, 6,527 authors contributed to 2,347 documents. Among the total number of authors, only the top 10 authors with the largest number of papers published in Neem are listed in Table 3. Siddiqui BS from the University of Karachi, Int Ctr Chem & Biol Sci, Karachi from Pakistan was the first active author (H_index=21; TC=1046; and TNP=52), followed by Faizi S University of Karachi, HEJ Res Inst Chem, Karachi, Pakistan (H_index=20; TC=895; and TNP=40), and Baral R from Chittaranjan Natl. Canc Inst, Dept Immunoregulat & Immunodiagnost, Kolkata, India (H_index=18; TNC=655; and TNP=33). Further analysis of citations for each researcher was considered an indicator of impact.

Journal Productivity

The 2347 documents examined were published in 857 different journals. Table 4 shows the top ten journals in terms of the total number of publications, H index, and most recent impact factors (IF). The majority of the authors preferred publishing in the "Journal of Economic Entomology," which had 50 published articles, followed by the "Journal of Ethnopharmacology," which had 38 articles, and "Phytoparasitica," which had 35 articles (Table 4).

Table 2: Top most cited articles

	Title	Source Title	Year	TC
1	Rapid Synthesis of Au, Ag, and bimetallic Au core-Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth	Journal of Colloid and Interface Science	2004	1531
2	Properties and Potential of Natural Pesticides from The Neem Tree, *Azadirachta indica*	Annual Review of Entomology	1990	862
3	Kinetics and thermodynamics of Methylene Blue adsorption on Neem (*Azadirachta indica*) leaf powder	Dyes and Pigments	2005	544
4	Biological activities and medicinal properties of Neem (*Azadirachta indica*)	Current Science	2002	473
5	Green synthesis of silver nanoparticles using *Azadirachta indica* aqueous leaf extract	Journal of Radiation Research and Applied Sciences	2016	413
6	*Azadirachta indica* leaf powder as an effective Biosorbent for dyes: a case study with aqueous Congo Red solutions	Journal of Environmental management	2004	336
7	Removal of malachite green from dye wastewater using Neem sawdust by adsorption	Journal of Hazardous Materials	2009	309
8	Antioxidant activity of phenolic components present in barks of *Azadirachta indica*, *Terminalia arjuna*, *Acacia nilotica*, and *Eugenia jambolana* Lam. trees	Food Chemistry	2007	279
9	Insecticidal and Antifeedant Bioactivities of Neem Oils and their Relationship to Azadirachtin Content	Journal of Agricultural and Food Chemistry	1990	276

10	Adsorption characteristics of the dye, Brilliant Green, on Neem leaf powder	Dyes and Pigments	2003	254

TC: Total Citations

Table 3: The Top 10 authors in Neem research

	Element	Affiliations	h_index	TC	TNP	PY_start
1	Siddiqui BS	University of Karachi, Int Ctr Chem & Biol Sci, Karachi, Pakistan	21	1046	52	1984
2	Faizi S	University of Karachi, HEJ Res Inst Chem, Karachi, Pakistan	20	859	40	1984
3	Baral R	Chittaranjan Natl Canc Inst, Dept Immunoregulat & Immunodiagnost, Kolkata, India	18	655	33	2004
4	Bose A	Chittaranjan Natl Canc Inst Dept Immunoregulat & Immunodiagnost Kolkata, India	16	528	30	2006
5	Siddiqui S	University of Karachi, HEJ Res Inst Chem Karachi, Pakistan	17	662	30	1984
6	Nagini S	AnnamalA.IUniversity Fac Sci, Annamalainagar, Tamil Nadu, India	19	894	27	1997
7	Ley SV	University of Cambridge, Dept Chem, Cambridge, England	17	615	25	1988
8	Koul A	Panjab University, Dept Biophys, Chandigarh, India	12	274	20	2006
9	Saxena RC	OP Chaudhry Hosp & Res Ctr, Lucknow, Uttar Pradesh, India.	12	377	20	1982
10	Isman MB	University of British Columbia, Fac Land & Food Syst, Vancouver, BC, Canada	16	988	19	1990

TC: Total citations; TNP: Total Number of Publications; PY_Start: Active Year authors start contribution to neem research

Table 4: The Top 10 Productive Journals in Neem research

	Element	h_index	TC	NP	PY_start	IF (2020)
1	Journal of Economic Entomology	24	1303	50	1978	2.381
2	Journal of Ethnopharmacology	23	1514	38	1986	4.360
3	Phytoparasitica	14	560	35	1976	1.439
4	Current Science	11	844	30	1981	1.102
5	Parasitology Research	20	866	28	2006	2.289
6	Crop Protection	18	725	27	1990	2.571
7	Phytochemistry	18	664	26	1971	4.072
8	Phytotherapy Research	12	470	24	1993	5.878
9	Zeitschrift Fur Pflanzenkrankheiten Und Pflanzenschutz-journal of plant diseases and Protection	8	182	23	1980	0.373
10	Journal of Agricultural and food Chemistry	16	897	22	1988	5.279

TC: Total Citations; NP: Number of papers. IF: Impact factor; PY_Start: Active Year Journal start publishing neem research

Distribution of articles by corresponding Authors' country

The analysis in Table 5 shows the top ten leading corresponding Authors' countries in Neem research, which sheds some light on the effect of single country publications (SCP) and multiple country publications (MCP), in addition to the countries' annual contribution to research productivity per year (Figure 2). Authors from India are the top contributors in global Neem research, with 923 articles, followed by Pakistan with 130 articles and the United States of America (USA) with 124 articles. On the subject of multiple country publications, we discovered that India ranks first with 58 reported articles, followed by the United States with 21 articles, and Brazil with 20 articles (Table 5). Inter-State relations between countries are

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reported alongside annual trends for these countries during the study period (Figure 2). According to the country's annual trend, most articles published in the previous year were written by Indian researchers.

Analysis of partnership in Neem research
As illustrated in Figure 3, the Neem study represented a situation in which many countries collaborate globally. India, Brazil, the United States, Pakistan, China, and Italy published the most documents, and cooperation between the countries was relatively close, as indicated by the different line colors.

Top 25 Web of Science Categories
There are multidisciplinary differences in the frequency of 25 different categories, particularly in the publication number. According to Figure 4, the majority of research is published in the categories of Entomology (319 papers), Plant Science (317 papers), and Pharmacology pharmacy (187) papers, with Agronomy, Chemistry Medicinal, Environmental Sciences, and Biochemistry Molecular Biology trailing behind with 172, 159, 144, and 141 papers, respectively (Figure 4).

Productivity by funding agencies organizations enhanced
Based on the selection criteria of presenting funding organizations, the top 25 funding organizations with enhanced Neem research are represented in Figure 5. Among these funding organizations, the Indian Council of Agriculture Research is ranked as the first organization with 149 documents, followed by the Council of Scientific Industrial Research, CSIR India (74 documents), while the University of Karachi trailed behind with 71 documents (Figure 5).

Table 5: Top 10 leading corresponding Authors' country in Neem research

	Country	Articles	Freq	SCP	MCP	MCP_Ratio	TC (R)
1	India	923	0.427315	865	58	0.0628	20398 (1)
2	Pakistan	130	0.060185	120	10	0.0769	1820 (3)
3	USA	124	0.057407	103	21	0.1694	2960 (2)
4	Brazil	123	0.056944	103	20	0.1626	
5	Nigeria	101	0.046759	87	14	0.1386	1730 (4)
6	Canada	60	0.027778	49	11	0.1833	1472 (6)
7	China	60	0.027778	49	11	0.1833	818 (9)
8	Germany	54	0.025000	26	28	0.5185	1730 (4)
9	United Kingdom	49	0.022685	31	18	0.3673	1056 (7)
10	Italy	44	0.020370	25	19	0.4318	986 (8)

TC: Total Citations; R: Rank; SCP: Single Country Publication; MCP: Multiple Country Publication

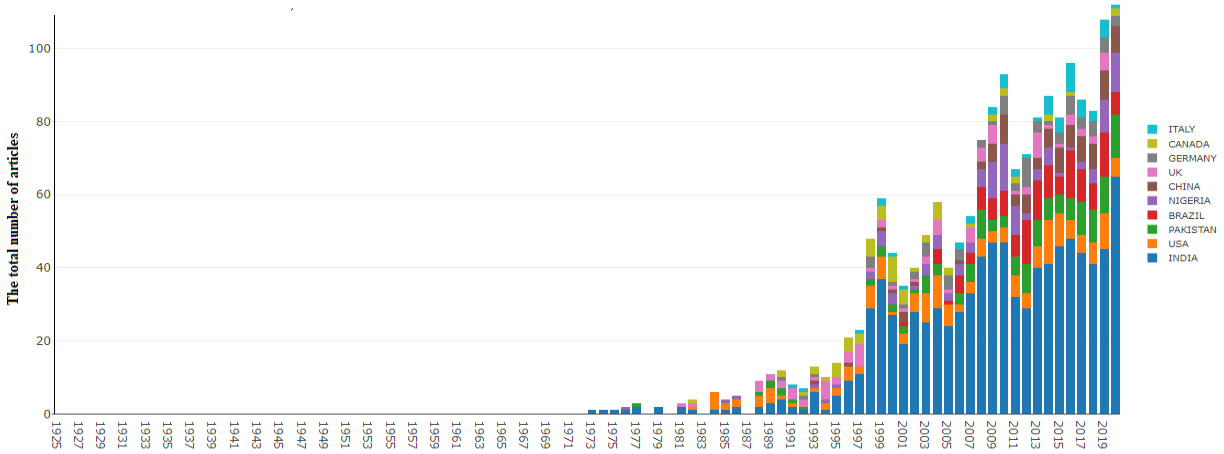

Figure 2. Change in the number of articles over the years with top 10 countries

Frequency of keyword
The frequency analysis of the top 200 keywords Plus is presented in Figure 6, which are considered indicators for the studies focused within the scope of Neem research based on the frequency. The search terms such as "azadirachta-indica (163), "azadirachtin" (98), "growth" (95), "extracts" (94), "pesticides" (94), "tree" (92), "oil" (87), "toxicity" (74), "neem" (69), "extract" (67), "in-vitro" (63), "resistance" (63), "efficacy" (58), "plants" (53), "inhibition" (47), "leaf extract" (47), "leaves" (47), "insecticides" (46), "acid" (42), "larvae" (41), "limonoids" (40), "coleoptera"(38), "identification" (38), "optimization" (38), "products" (38), are key indicators of topics associated with a particular line of Neem research.

Factorial analysis using Multiple Correspondence Analysis
The analysis of Keywords was further explored using Multiple Correspondence Analysis for reported 50 Keywords Plus terms that could capture an article's content. The method gives a better understanding and the depth of research topics (A), Author Keywords which provided topic and information consisting of a list of terms that authors believe best represent the content of their document (B), and Article title which identifies the topic as well as provides attention to the readers (C) for 100 documents on Neem distributed in5 clusters. The findings showed how the topics were distributed and similar to each other during the study period (Figure 7A-C).

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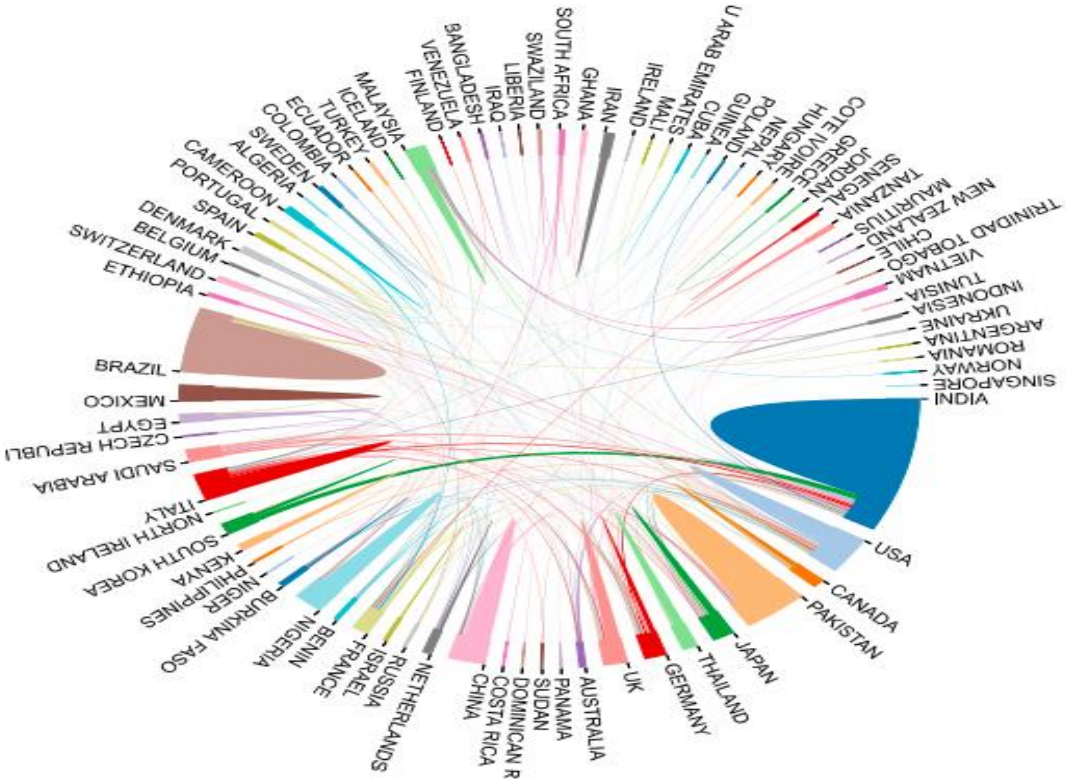

Figure 3: Analysis of partnership in Neem research

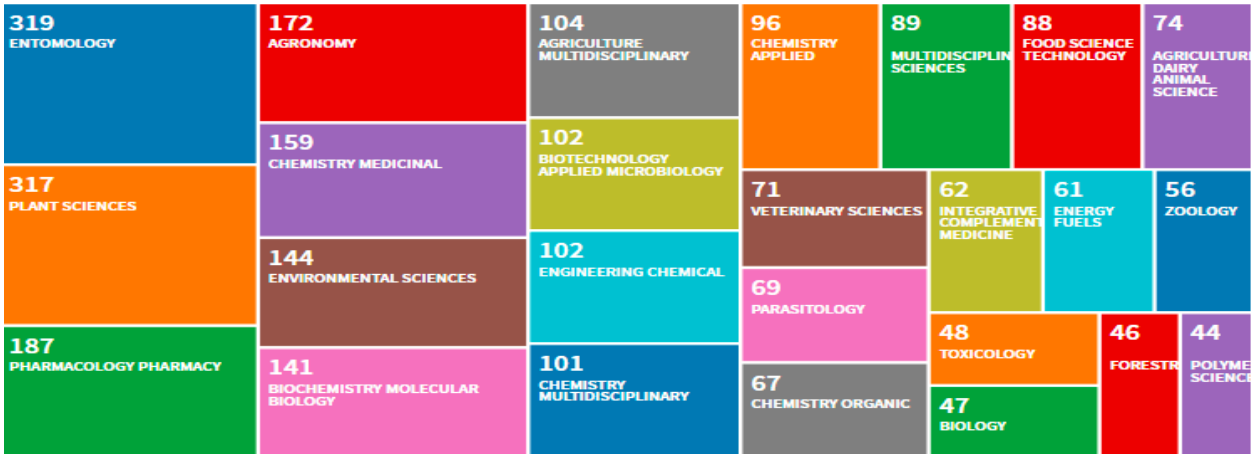

Figure 4: Top 25 Web of Science Categories

Existing and emerging themes in Neem topic

Figure 8 represented the themes in Neem topic-based Keywords plus (A), Authors Keywords (B), and Article title using thematic evolution analysis within Three-time Slices (1925-1999), (2000-2009), (2010-2015), and (2016-2021). The analysis further revealed the topics during the study period, which clearly shows the past and present while also offering indicators for future research direction.

Co-authorship networks of most influencing authors and organizations

The networks' visualisation was performed using the VOSviewer software package, which offers the co-authorship networks based on total length strength between authors. A total of 6656 authors have contributed to Neem research, with the average number of authors per article being 2.79. In addition, three documents were selected to carry out the co-occurrence analysis between authors, resulting in 157 authors meeting the threshold. Moreover, only 56 items are presented in the map within 8 clusters with Total length (L=175) and Total Length Strength (TLS=398). The most influential authors based on co-authorship were Ley SV (TLS=58), followed by Sawinm AMZ (TLS=26), Saxena, RC (TLS=17), and Isman, MB (TLS=13), amongst others (Figure 9A).

Furthermore, in the analysis of co-occurrence between organizations, the selected three documents resulted in 328 documents per organization meeting the threshold, while only 147 items are presented in the map within 8 clusters with Total length (L=224) and Total Length Strength (TLS=417). King Saud University was revealed as the most influential organization (TLS=45), followed by the University of Copenhagen (TLS=35), Bharathiar University (TLS=33), and University Pisa (TLS=32) (Figure 9B), while India, USA, Germany, and England led the most influential countries (Figure 9C).

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Figure 5: Top 25 Organizations enhanced research productivity

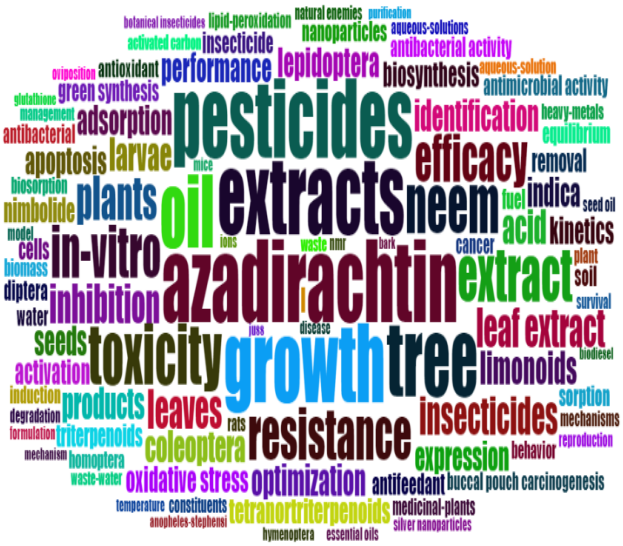

Figure 6: Concurrence analysis of Keyword Plus using WordCloud

This study is the first to use the WoS database to examine the bibliometric analysis of global scientific research output on *Azadirachta indica* (A.I) to the authors' knowledge. The investigation reveals that aside from the documented traditional medicinal uses of A.I, extensive research works have been done to advance the application of A.I as biopesticides, [42,43] biofuel, [23,44] and modern drug development.[45,46] . An estimated 2347 A.I-based journals were indexed from 1925 to 2020, 2298 emanated from original research, while 49 were review articles. Moreover, there was a notable rise in the number of publications from 2005 with an upward trend and peaked in 2020. This increase may be attributed to the hydroxychloroquine constituent of Neem, which became more prominent in combating the deadly coronavirus pandemic, as well as the utilization of Neem oil for renewable biodiesel production. Findings show that Journals of Entomology, the Journal of Ethnopharmacology, Phytoparasitica, Current Science, Parasitology Research, Crop Protection, and Phytochemistry extensively explored the insecticidal capacity of A.I with many publications, making them the top 10 journals in Neem publications.

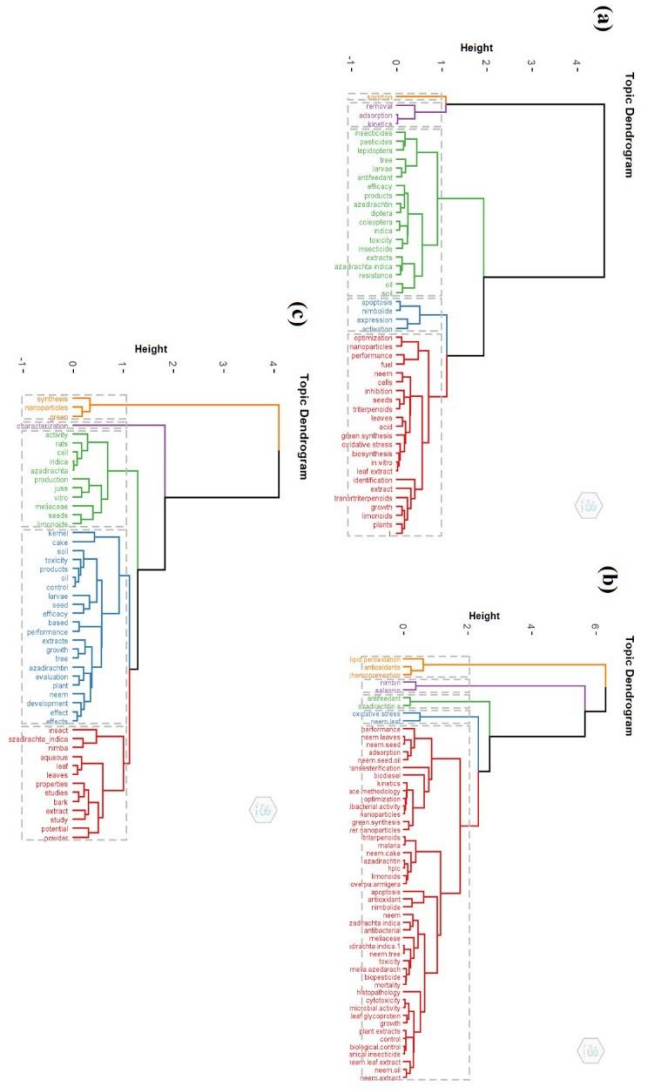

Figure 7: Factorial analysis using Multiple Correspondence Analysis (MCA) method for 50 Keywords Plus (A), Authors Keyword (B), Article title (C), for number of 100 documents on Neem distributed in 5 clusters

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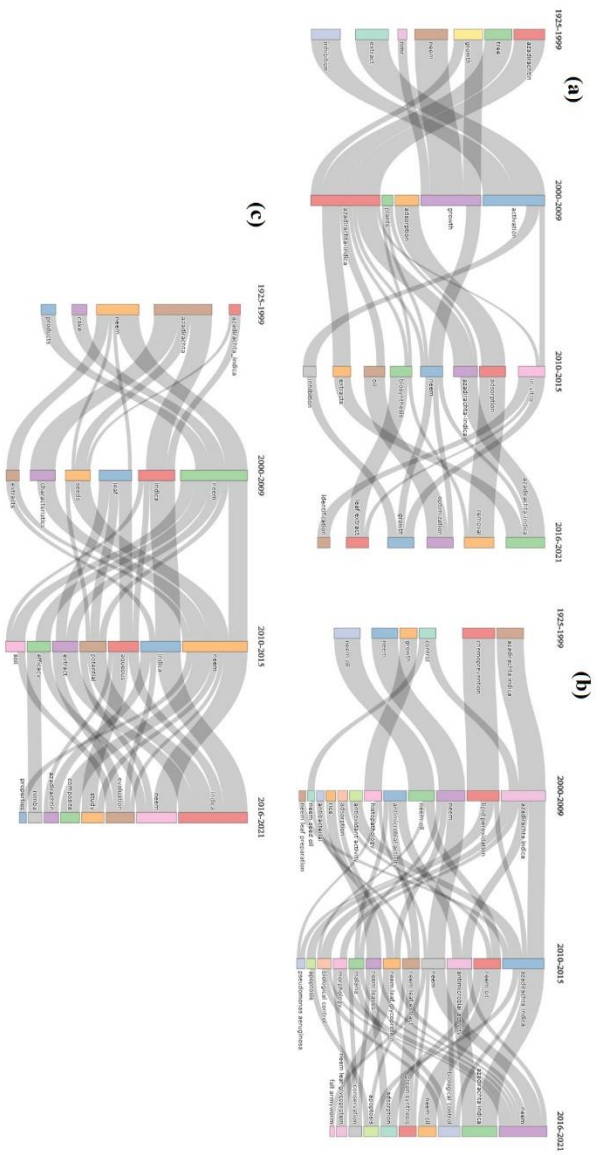

Figure 8: Existing and emerging themes in Neem topic based Keywords plus (A), Authors Keywords (B), and Article title by using Thematic Evolution analysis within Three time Slices (1925-1999), (2000-2009), (2010-2015), and (2016-2021).

According to the standard competition ranking of top authors, Siddiqui B.S. from the University of Karachi, Pakistan, is the most productive author in A.I research, closely followed by Faizi S. from the same university. Collaborations were also observed amongst authors, with thousands of co-authors churning out multi-authored documents. Regrettably, this survey does not show any authors among the top 10 from any African country or institution. India and Pakistan are the most prominent contributors to Neem research publications. In addition, the University of Karachi, Pakistan, and Chittaranjan National Cancer Inst., Kolkata, India, are the leading institutions in A.I.-based research publications. Although evidence shows the increase in Neem research publications and mean total citations, the shortfall of Neem-based research publications, particularly from developing countries, is of significant concern. To address the poor representation from developing countries, a research-friendly environment, well-equipped laboratories, workshops, funding from governmental and non-governmental organizations is essential.

The keyword analysis revealed that the most frequently used keywords are *Azadirachta indica*, Neem, effect, adsorption, toxicity, Juss, apoptosis, and biodiesel, which are potential indicators of the direction of A.I research. However, it should be noted that this study has limitations in that we only used databases as indexed in Web of Science and that only research articles and review publications were considered for this work, with conference proceedings, book chapters, research notes, and editorials excluded. It is also thought that older articles may receive more citations than newer ones. Furthermore, researchers may artificially boost their scientific impact by citing their work, which may impact the findings. The criteria mentioned above may affect the precision of the outcome of this study.

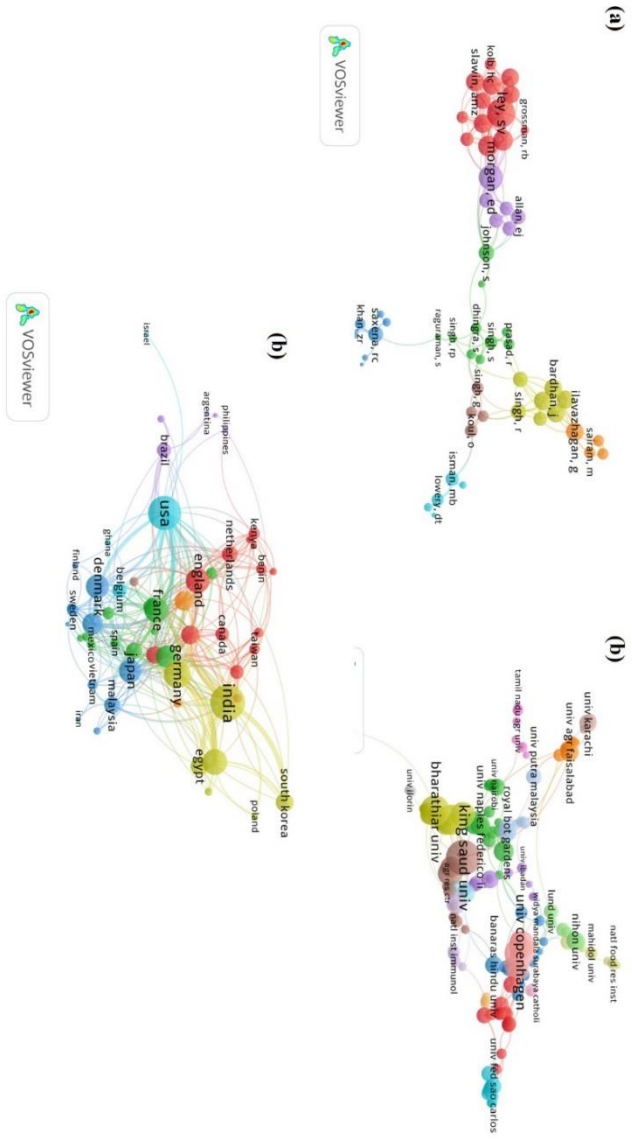

Figure 9: Co-authorship network of the most influential authors (A), organization (B), countries (C), based on total link strength (TLS) between authors.

Conclusion

This study looked at the annual growth in the number of Neem-based publications and the mean total citation per year, as well as the top 10 authors, top 10 journals, keyword plus visualization using Wordcloud, top 10 corresponding authors' country, and factorial analysis, to name a few things. Between 1925 and 2020, there was an increased number of publications and the mean total citation per year retrieved from the Web of Sciences. However, developing countries such as India and Pakistan were the leading authors' countries, Nigeria being the only African country on the list of top corresponding authors. This lag

necessitates immediate global interventions to bridge the gap. Furthermore, the high churning of articles in these high-rated developing countries could be attributed to increased research to eliminate the scourge of high temperate-related diseases such as malaria, poliovirus, Dengue virus, and others. Furthermore, recent trends show that A.I. is gaining more attention in entomology and parasitology; therefore, extensive research actions in these areas should be encouraged further, as non-synthetic pesticides are less toxic to humans and environmentally friendly thereby mitigating environmental pollution.

Conflict of Interest

Authors declare no conflict of interest

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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