Revisiting the ethnomedicinal and ethnopharmacological applications of *Baccharoides anthelmintica* (L.) Moench: A literature and bibliometric analysis of 70 years

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Review

Abstract

Background: Baccharoides anthelmintica (L.) Moench*,* commonly known as kaliziri, is a therapeutic plant of the Asteraceae family, used in Ayurveda for treating microbial, viral, and helminthic infections. The plant is broadly distributed, including in the Himalaya, and has gained scientific attention due to its bioactive potential. Therefore, in this review, we present the updated and quantified information on B. anthelmintica, along with a bibliometric analysis to measure the current research trends, hot topics, and key contributors.

Methods: A mixed-methods approach was employed in this study, combining bibliometric analysis and systematic literature review. For bibliometric analysis, 234 articles were retrieved from Scopus, and 194 were selected after screening. VOSviewer and Bibliometrix software were used to analyze publication trends, key authors, and research focus areas. For the literature review, 6606 were collected (6510 from Google Scholar and 96 from PubMed). After screening, 209 relevant articles were selected to assess traditional uses, phytochemistry, pharmacological potential, and toxicity of *B. anthelmintica*.

Results: The results indicate that: (1) publications on *B. anthelmintica* increased substantially since 2002, with an annual growth rate of 2.82 %; (2) India and China are the leading countries in terms of publication number and collaborations; (3) through the word cloud keyword analysis, the top three keywords identify the pharmacological significance of this plant; (4) Aisa H.A. and Turak A are the key authors and played significant roles in advancing the field. B. anthelmintica exhibits significant medicinal potential due to its bioactive compounds, which offer antioxidant, antimicrobial, and anticancer properties. Apart from this, there is a lack of clinical trials to confirm the safety and therapeutic efficacy of B. anthelmintica. It is also anticipated that upcoming research in this domain will emphasize molecular mechanisms and sustainable production of important bioconstituents.

Conclusions: This review presents a bibliometric analysis that maps seven decades of global research on B. anthelmintica, highlighting key contributors, publication trends, and research gaps. Additionally, the literature review compiles updated

information on the plant's ethnomedicinal uses, phytochemistry, and pharmacology. Together, these findings offer a valuable foundation for future research and therapeutic exploration.

Keywords: Baccharoides anthelmintica, Aster*aceae, Bibliometric analysis, VOSviewer, Bioactive properties.*

Background

Baccharoides anthelmintica (L.) Moench, synonymously known as *Vernonia anthelmintica* (L.) Willd. and *Centratherum anthelminticum* (L.) Kuntze is an herbaceous annual plant belonging to the Asteraceae family. It is widely distributed across various regions of the world, especially in the Indian Himalaya and Khasi Hills, where it grows up to 1650 meters above sea level. The species is also found in countries such as Pakistan, Bangladesh, Sri Lanka, Afghanistan, Brazil, the Democratic Republic of the Congo (Kinshasa), Nepal, Zimbabwe, and the United States. The plant thrives in open lands and produces its seed heads from May to June (Bhatia *et al.* 2008b; Senniappan *et al.* 2016; Prakash, 2023; Husain *et al.* 2024).

Morphologically, *B. anthelmintica* is an erect, pubescent annual herb that can grow up to 90 cm in height. It has elliptic-lanceolate leaves (5-9 cm long, 2.5-3.2 cm wide) with serrated edges and soft hairs on both sides, tapering from the base to the stem. The flower heads are relatively small, measuring 1.2-2 cm in diameter, and are flat-topped, with around 40 flowers in each cluster. The floral structure features thin, leaf-like bracts located near the apex of the flowering stem. The outer bracts are narrow, green, and prickly, but not like the inner bracts. Central bracts are short or nearly equal in size to the smallest bract by a few millimeters and are tipped with hair at the ends. The innermost bracts are the longest, paper-thin, and dry with a purple tip (Mehta *et al.* 2016). The plant's pappus is used for seed dispersal. It is feathery and reddish, with the outer pappus being short and left on the stem, while the inner pappus is flat and easily falls off. The fruits of *B. anthelmintica* are small, ellipsoid, and ridged with 10 ribs, measuring between 4.5 and 6 mm in length, with soft hairs (Ani, 2008). The seeds, commonly referred to as kaliziri or purple fleabane, are dark brown, rectangular, 4.5-6 mm long, and characterized by their bitter taste. They have a trichome coating and ridges that aid in distribution. The seed coat consists of a single-cell epidermal layer that contains lipid globules and storage proteins (Bhatia *et al.* 2008b). It is interesting to note that in India, *Nigella sativa* and *Bunium persicum* (Boiss.) are also known as kaliziri, but they belong to different plant families (Amir & Chin, 2011; Singh *et al.* 2012).

Traditionally, *B. anthelmintica* has been utilized in Ayurvedic medicine as a multipurpose remedy. Its seeds are employed in treating a variety of ailments, including fever, cough, diarrhoea, kidney disorders, asthma, and intestinal worms. Moreover, the plant is valued as a general tonic (Purnima *et al.* 2009; Manvar & Desai, 2012; Chinnadurai *et al.* 2016; Dogra *et al.* 2018; Akbar & Akbar, 2020; Singh *et al.* 2024). Various pharmacological studies have reported several therapeutic properties of this plant, like anti-inflammatory (Ashok *et al.* 2010; Arya *et al.* 2012c; Looi *et al.* 2013lb), anti-diabetic (Arya *et al.* 2012a, d; Looi *et al.* 2013b), anti-cancer (Looi *et al.* 2013 a&c; Husain *et al.* 2024), antioxidant (Bian *et al.* 2022), antibacterial (Ani, 2008; Mehta *et al.* 2010), antifungal (Mehta *et al.* 2010; Patel *et al.* 2011), anti-diuretic (Koti & Purnima, 2008), larvicidal (Srivastava *et al.* 2008), anti-tubercular (Mehta *et al.* 2016), and anti-parasitic (Dogra *et al.* 2020; Kumar *et al.* 2024).

While previous reviews on *B. anthelmintica* have primarily focused on its ethnomedicinal uses, phytochemical composition, pharmacological and toxicological properties (Amir & Chin, 2011; Manvar & Desai, 2012; Dogra *et al.* 2020; Singh *et al.* 2024), the present review provides a novel and more comprehensive perspective. It not only consolidates updated phytochemical and pharmacological findings but also integrates a bibliometric analysis that spans seven decades of global research. Bibliometric analysis is the method that examines published materials, including research papers, books, and datasets, along with their related metadata, such as keywords, abstracts, and citations. This method enables researchers to identify key contributors, prominent institutions, collaborative networks, emerging themes, and potential future directions (Donthu *et al.* 2021; Ninkov *et al.* 2022). By integrating both quantitative bibliometric insights and conventional ethnopharmacological evidence, this review presents a multidimensional understanding of the scientific landscape surrounding *B. anthelmintica*. It highlights research trends, scientific impact, and underexplored areas, offering valuable insights that can direct future investigations and translational research. Such an integrative review is significant for researchers, pharmacologists, and ethnobotanists aiming to explore *B. anthelmintica* as a viable source of therapeutic agents. The paper focuses on answering the following questions:

Question 1: How has the research output on the *B. anthelmintica* changed over time?
Question 2: Which journals, authors, countries or regions, and institutions are leading in this field based on publication?
Question 3: What are the main and merging themes based on keyword analysis?
Question 4: Which papers have significantly influenced the field?

Question 5: What is the current state of knowledge regarding the ethnomedicinal uses, bioactive compounds, and pharmacological properties of *B. anthelmintica*?

Materials and Methods

Data source

The study employed a dual-method approach, combining a bibliometric analysis and literature review to ensure robust and wide-ranging insights into the research on *B. anthelmintica*. The bibliometric data was retrieved from Scopus, whereas literature review data were sourced from PubMed and Google Scholar. All articles published up to November 5, 2024, were considered in this study.

Search strategies

A systematic search was conducted concurrently for both the bibliometric analysis and the literature review on 05 November 2024, without applying any time restrictions. For the bibliometric analysis, the core keywords- "*Baccharoides anthelmintica*", "*Vernonia anthelmintica*", and "*Centratherum anthelminticum*"- were used to retrieve relevant articles from the Scopus database. The search was applied to the titles, abstracts, or keywords (referred to as TITLE-ABS-KEY) fields using the Boolean operator "OR" to capture all naming variations of the species.

For the literature review, the same core keywords ("*Baccharoides anthelmintica*", "*Vernonia anthelmintica*", and "*Centratherum anthelminticum*") were used along with additional terms such as "phytochemistry", "secondary metabolites", "biological activities", "ethnobotany", and "medicinal uses". These were combined using Boolean operators "AND" and "OR" to broaden the search. Searches were conducted in Google Scholar and PubMed to identify studies covering the plant's traditional uses, chemical composition, pharmacological effects, and toxicity.

Inclusion and exclusion criteria

To ensure data quality and relevance, specific criteria were applied during the screening process. For the bibliometric analysis, a broader inclusion strategy was adopted. All English-language, final-stage Scopus articles, book chapters, conference papers, reviews, and short surveys addressing any aspect of target plants were included for further analysis. This wider scope was chosen to capture a more comprehensive bibliometric landscape, enabling the identification of research trends, collaborative networks, and emerging themes within the broader domain of medicinal plant research. Including a wide range of plant-related publications provides contextual depth and a more comprehensive understanding of where *B. anthelmintica* research is positioned within the larger field of phytomedicine and plant-based pharmacological studies. In contrast, the literature review followed a more focused approach. Only peer-reviewed articles, reviews, and book chapters that specifically focused on the phytochemical profile, pharmacological potential, and traditional applications of *B. anthelmintica* or its synonyms were included. Articles were excluded if they were not available in English, lacked scientific rigor, were duplicate entries, or were conference abstracts.

Data cleaning and preparation

For the bibliometric study, data were exported from Scopus and imported into Microsoft Excel in Comma-Separated Value (CSV) format for further screening. In this step, duplicate entries and irrelevant articles, those not related to *B. anthelmintica,* were identified and removed based on a review of titles and abstracts. After that, VOSviewer (version 1.6.19; https:// www.vosviewer.com/) (Van Eck & Waltman, 2010) and Bibliometrix on R studio (version R.4.3.0; https:// www. bibliometrix.org/home/) (Aria & Cuccurullo, 2017) software were used for the analysis and visualization of bibliometric information of selected articles (Gargi *et al.* 2024; Singh *et al.* 2023, 2024). In parallel, the selected articles from PubMed and Google Scholar for the literature review were downloaded, thoroughly reviewed, and critically analyzed to extract relevant information on ethnomedicinal and ethnopharmacological applications of *B. anthelmintica*.

Bibliometric data analysis tool

VOSviewer was used to generate bibliometric maps based on co-authorship, citations, and references, while Bibliometrix was used to conduct a detailed analysis of documents and network visualization (Aria & Cuccurullo, 2017). Bibliometrix, an R package, provides an extensive analysis of publications, including yearly scientific output, citation metrics, and key contributors such as countries, institutions, authors, and journals. It also helps in creating thematic maps and word clouds, as well as identifying trending topics within the research domain (Aria & Cuccurullo, 2017).

Search results

For the bibliometric analysis, 234 records were initially found in the SCOPUS database. After limiting the search to language (English) and publication stage (final), only 221 articles remained. Following the abstract screening, 194 relevant articles were selected for bibliometric analysis. For the literature review, a total of 96 documents from PubMed and 6510 papers from Google Scholar were found. After a thorough screening process, 209 relevant articles were selected based on their focus on the bioactive composition, antimicrobial activity, and antioxidant potential of *B. anthelmintica* (Figure 1).

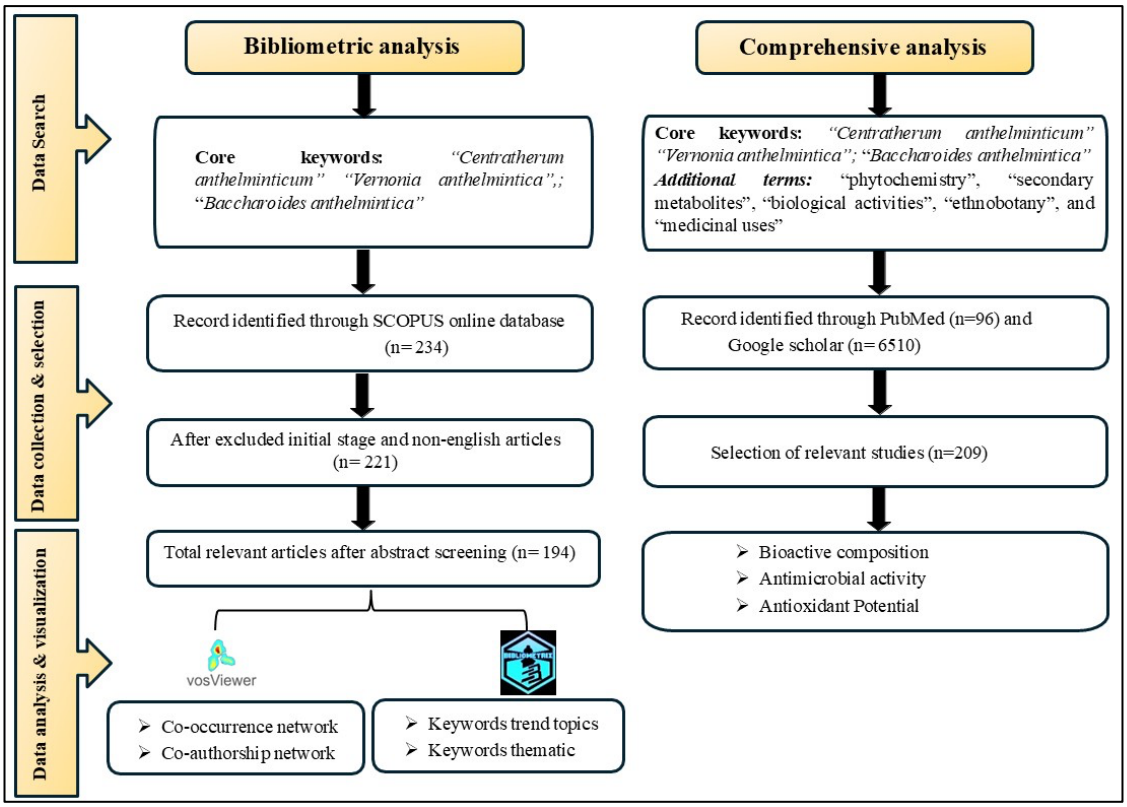


Figure 1. Data mining flow chart of literature and bibliometric screening

Results and Discussion

Bibliometric analysis

Description of data

The bibliometric analysis spanned the period from 1954 to 2024 (as of November 5, 2024), examining 116 sources or journals and a total of 194 documents; their descriptions are listed in Table 1. The annual growth rate of publications in this field is 2.82%, with an average document age of 20.2 years and an average of 18.26 citations per document. The study identified 2546 keywords plus (ID) and 449 author-provided keywords (DE). A total of 587 authors contributed to these publications, with only seven authors producing single-authored documents. There were also seven single-authored documents overall. The average number of co-authors per document was 4.26. In terms of publication types, the analysis revealed 181 articles, 1 book chapter, 2 conference papers, 2 erratum, 7 reviews, and 1 short survey.

Table 1. Main information about data.

Description	Results
Timespan	1954-2024
Sources (Journals, Books, etc)	116
Documents	194
Annual Growth Rate %	2.82
Document Average Age	20.2
Average citations per doc	18.26
Keywords Plus (ID)	2546
Author's Keywords (DE)	449
Authors	587

Authors of single-authored docs	7
Single-authored docs	7
Co-Authors per Doc	4.26
Articles	181
Book chapter	1
Conference paper	2
Erratum	2
Review	7
Short survey	1

Annual Publications

The number of annual publications between 1954 to 2024 (as of November 05, 2024) has shown consistent growth, with an annual growth rate of 2.82%. Linear growth was observed from 1954 to 2024 (as of November 5, 2024), with an average of 2.77 articles per year. The publishing trend over the past 70 years can be divided into three phases: introductory, steady, and growth. Between 1954 and 1970, an introductory phase occurred, characterized by a near-minimal average number of publications per year. The second phase exhibited steady growth from 1971 to 1999, although it was not without some fluctuations. However, the most significant growth was observed from 2000 to 2024, which marked a rapid rise in the publication trend, indicating the growth phase. The observed publication time frame for the plant species reflects a combination of historical, scientific, and technological factors over the last 70 years. The introductory phase had a minimal number of publications due to the limited scientific interest, lack of advanced research tools, and restricted accessibility of the species. Additionally, the global focus was more on major staple or economically significant crops. In the second phase, the increasing trend in publications reflects the growing awareness of plant biodiversity, ethnobotany, phytochemistry, improved taxonomy, and global collaboration, leading to a gradual increase in research publications. However, the limited availability of molecular tools and databases may have slowed the pace. The rapid growth in publication trends during the third phase may be driven by technological advancements, increased interest in medicinal plants, conservation concerns, and digitization of data and journals. These are some possible reasons for the fluctuations in publication trends. A linear regression graph was developed between the number of publications per year and the number of published articles, yielding an R^2 value of 0.6189 (Figure 2a).

Average citation

The number of average citations between 1954 to 2024 (as of November 5, 2024) has shown consistent growth, with an annual growth rate of 2.82%. The citation counts from 1954 to 2001 were very low. However, a very high citation count was found between the year 2002 to 2021. In 2013, we found the highest average number of citations (n = 3.82), which is related to *B. anthelmintica* plant. It means the author's work had a significant influence on the *B. anthelmintica* plant. Moreover, articles published in 2021 secured second place (n = 3.62), and articles published in 2003 secured third place (n = 2.95) in terms of average citations per year (Figure 2b).

Subject distribution

Research on *B. anthelmintica* spans a broad spectrum of scientific disciplines, resulting in diverse areas of research and perspectives. Figure 2c shows the distribution of subjects related to this research field, indicating Pharmacology, Toxicology, and Pharmaceutics dominate the research landscape, accounting for 18% of the papers. Close behind are the fields of Chemistry and Biochemistry, Genetics, and Molecular Biology, each contributing 17%. Agricultural and Biological sciences represent 13%, while Medicine accounts for 12% and Chemical Engineering holds 10%. This distribution reflects the extensive interdisciplinary research efforts focused on plant studies, highlighting the broad relevance of *B. anthelmintica* across life sciences and related disciplines.

Contribution of countries/regions

The assessment of contributions from different countries or regions was determined by the affiliation of at least one author listed in each published paper. To do this, the publications were linked to the countries where each author is based. As a result, a single publication can be credited to multiple countries. However, if a publication has two authors from the same country, it is counted only once to avoid counting the same article multiple times for that country (Viana-Lora & Nel-lo-Andreu, 2022). From 1954 to 2024 (till November 05, 2024), researchers from 22 different countries or regions contributed to these studies. From the analysis, India ranked first with 260 publications, followed by China with 208, and Pakistan with 111 (Table 2).

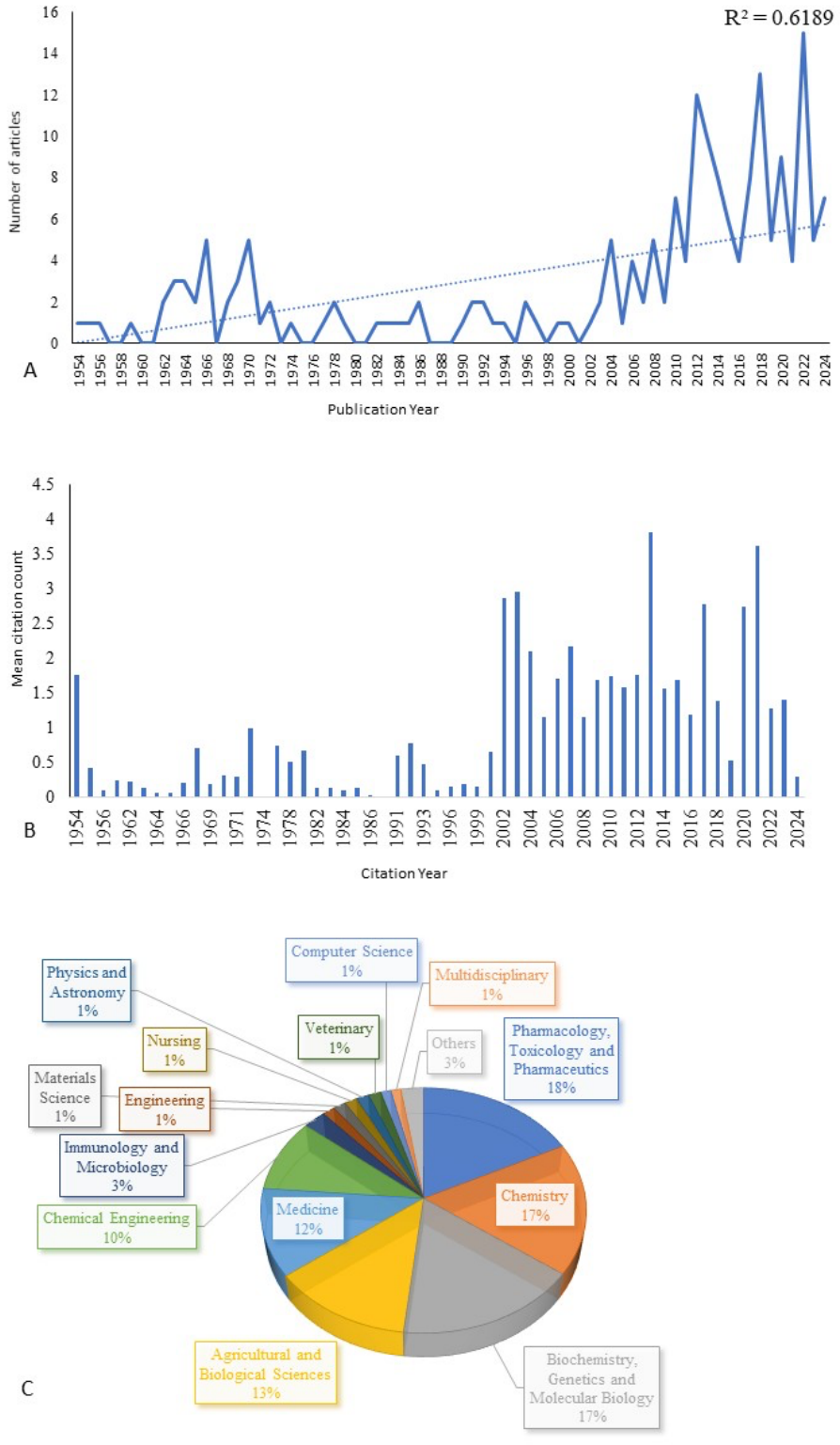


Figure 2 (a). Annual aggregate of published articles, (b). Average citation counts of articles per year, (c). Map representing the distribution of subjects based on their categories.

Table 2. Top 10 major contributing countries/regions

Rank	Country	Frequency
1.	INDIA	260
2.	CHINA	208
3.	PAKISTAN	111
4.	USA	89
5.	MALAYSIA	65
6.	ITALY	24
7.	JAPAN	18
8.	SWITZERLAND	9
9.	UK	6
10.	UZBEKISTAN	6

The analysis of co-authorship between countries helps us to understand how researchers from different nations collaborate and share knowledge. Figure 3a represents the network analysis map of co-authorship between countries. In the network, the size of each node represents the number of publications from that country, while the thickness of the connecting lines shows the strength of collaboration between nations. China has the highest number of collaborations (n = 5), collaborating with the United States, Pakistan, Japan, Kazakhstan, and Uzbekistan. Other countries with strong research contributions include India (n = 4 collaborations), the United States (n = 4 collaborations), Japan (n = 4 collaborations), Pakistan (n = 4 collaborations), and Uzbekistan (n = 2 collaborations). Moreover, countries with research collaboration are Malaysia (n = 1 collaboration), Libya (n = 1 collaboration), Myanmar (n = 1 collaboration), Afghanistan (n = 1 collaboration), Australia (n = 1 collaboration), Saudi Arabia (n = 1 collaboration), and Kazakhstan (n = 1 collaboration).

Contribution of authors

Author contribution is usually the quantifiable output of researchers, often measured by the number of publications, citations, and co-authorship (Hirsch, 2005). A total of 587 authors contributed to these studies (till November 05, 2024). Aisa HA stands out as the leading author with 18 articles, followed by Turak A with 11 articles, and then Krewson CF with 10 articles. Table 3 provides a clear overview of the top 10 contributing authors ranked by their total number of articles. A co-authorship network map was also made with VOSviewer to illustrate the authors' cooperation links. Only authors who earned at least two citations and had at least two documents were considered for this study. Out of the 585 authors, 114 met this threshold. Figure 3b provides valuable insights into the collaborative structure among authors from different countries. Authors such as Aisa H.A., Mehta B.K., and Krewson C.F. have numerous connections with other researchers, indicating that they frequently collaborate with others and play a significant role in this field. The larger node sizes represent the higher contributions in terms of co-authored publications, while the color-coded clusters suggest different research groups or thematic areas.

Table 3. Top 10 most contributing authors.

S. No.	Authors	Articles	Articles Fractionalized
1.	Aisa HA	18	4.75238095
2.	Turak A	11	3.25952381
3.	Krewson CF	10	3.86666667
4.	Mehta BK	10	3.33333333
5.	Arya A	9	1.34285714
6.	Looi CY	6	0.76785714
7.	Rustamova N	6	1.09285714
8.	Scptt WE	6	2.58333333
9.	Yili A	6	1.09285714
10.	Ahmad I	5	1.83333333

Most influential affiliations and co-authorship Networks

The contributions of the top 10 influential affiliations are presented in Table 4, which helps us to determine which institutions or organizations make the largest contributions to this field. The Xinjiang Technical Institute of Physics and Chemistry is a leading organization in this field, with 67 published articles. The University of Malaya holds the second position, with 64 published articles, while the Eastern Regional Research Laboratory holds the third position, with 33 published articles, among

the top 20 influential affiliations. These observations demonstrate their significant emphasis on expanding knowledge in this field.

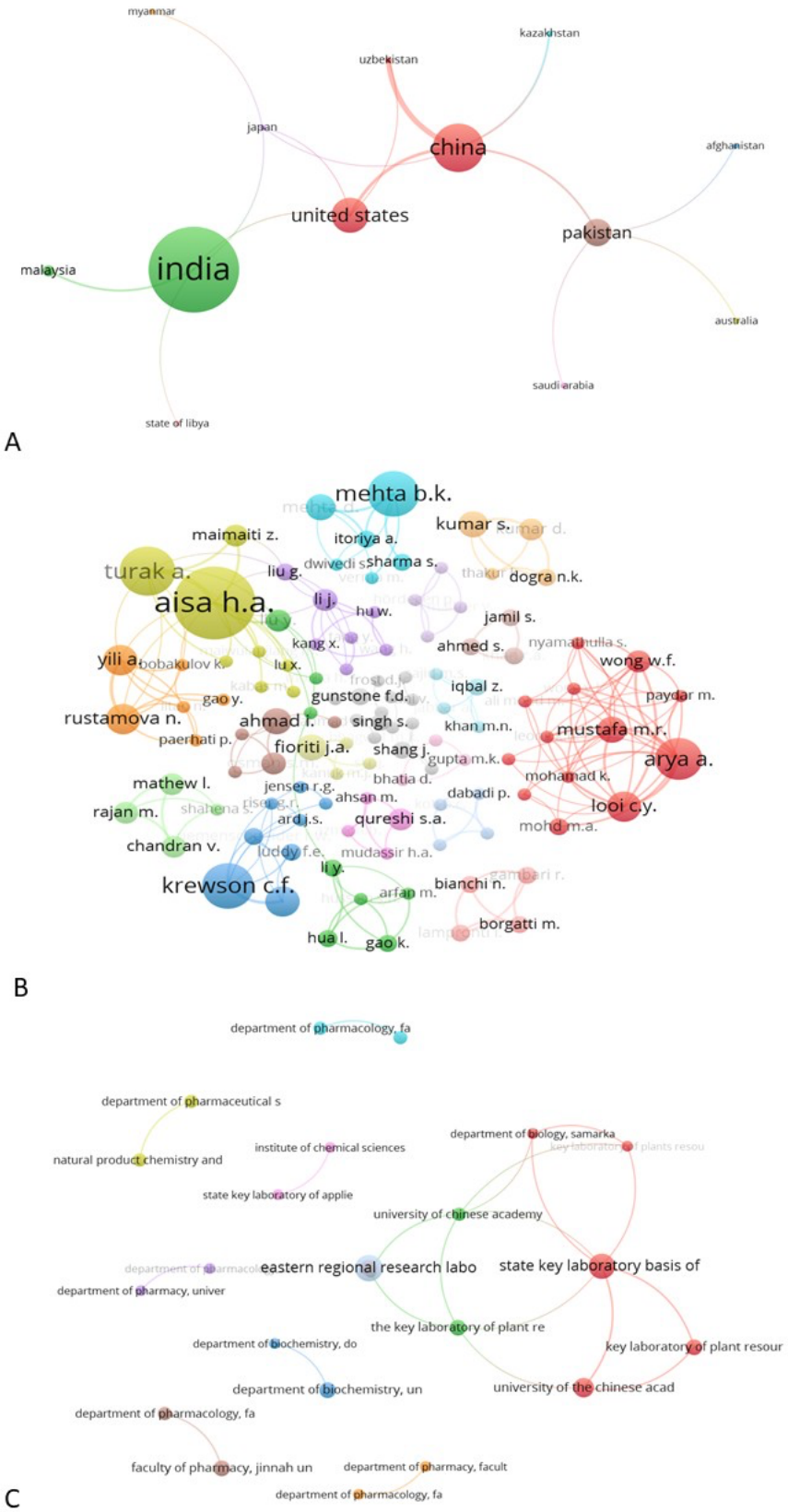


Figure 3 (a). Network analysis map of co-authorship between countries, (b). Network analysis map of co-authorship among authors, (c). Network analysis map of co-authorship among affiliations.

Table 4. Top 10 affiliations of the authors.

S. No.	Affiliation	Articles
1.	XINJIANG TECHNICAL INSTITUTE OF PHYSICS AND CHEMISTRY	67
2.	UNIVERSITY OF MALAYA	64
3.	EASTERN REGIONAL RESEARCH LABORATORY	33
4.	VIKRAM UNIVERSITY	29
5.	UNIVERSITY OF KARACHI	21
6.	MAHATMA GANDHI UNIVERSITY	17
7.	UNIVERSITY OF AGRICULTURE	17
8.	ALIGARH MUSLIM UNIVERSITY	15
9.	CHINA PHARMACEUTICAL UNIVERSITY	15
10.	XINJIANG CLINICAL RESEARCH CENTER FOR DERMATOLOGIC DISEASES	14

The paper also examined how institutions collaborate in scientometrics research by analyzing co-authorship networks based on author affiliations. Authors from the same institution were grouped as a single point in the network, while connections between different institutions represented co-authorship relationships (Mohammadamin *et al.* 2012). Co-authorship among affiliations refers to the collaboration between researchers from other institutions or countries, as shown in Figure 3c. Researchers from departments such as pharmacy, biochemistry, and pharmacology are collaborating across universities and key laboratories to push the boundaries of knowledge. These partnerships help share expertise, resources, and ideas, making research more impactful and effective. Institutions such as the State Key Laboratory and the Eastern Regional Research Laboratory play a big role in bringing experts together to solve complex problems. Only authors who earned at least two documents from an organization and had at least two citations were taken into consideration for this study. Out of the 327 organizations selected, 29 met this threshold.

Most relevant journal

The impact of the most relevant journal is measured by the number of articles published and the frequency of citations (Dzikowski, 2018). A total of 115 journals contributed to these studies. The “Journal of the American Oil Chemist’s Society” leads with 20 articles, followed by “Journal of Ethnopharmacology” and “Pakistan Journal of Pharmaceutical Sciences” with 7 articles, and “Natural Product Reserch” with 6 articles. Table 5 represents the top 10 most relevant journals based on their total number of articles.

Keywords

To facilitate the indexing and retrieval of the manuscript in scientific databases, keywords are typically chosen to reflect the primary concepts of the study. Keyword analysis in bibliometric studies can highlight frequently researched themes, reveal trends in research topics, and identify new areas or knowledge gaps. For instance, the most popular research themes may be indicated by keywords that are often used in a particular field, while less common phrases may suggest speciality areas of study. The visibility of the publication to researchers interested in related subjects is ensured by careful keyword selection. Keywords also help in network analysis, where co-occurrence patterns can provide insights into the relationships between different research topics (Eck & Waltman, 2010). The co-occurrence network shown in Figure 4a provides a clear visualization of how different keywords in the research domain are interconnected. At the center of the network, terms like "article," "plant extract," and "anthelmintic" appear prominently, indicating their crucial role in the study. Around these central keywords, distinct clusters can be seen, each represented by a unique colour.

The red and orange clusters relate to pharmacological and experimental research, while the green cluster is more focused on chemical structures and biological activities. On the other hand, the blue cluster highlights research on antibacterial and antimicrobial properties. Strong connections between terms such as "drug isolation," "biological activity," and "anthelmintic agent" suggest a major emphasis on bioactive compounds and their medicinal potential. This visualization effectively captures the key themes and research directions within the field, offering valuable insights into current trends and future possibilities.

Figure 4b represents the world cloud map based on the main keywords. Studies on *Vernonia anthelmintica* and other associated plants have drawn attention due to their medicinal property, particularly in drug screening and phytotherapy. The prominence of keywords such as "plant extract," "unclassified drug," and "antioxidant activity" identifies the

pharmacological significance of such plants. Figure 4c represents the thematic map of strategic keywords for publications on *B. anthelmintica*. Thematic Keyword analysis indicates emerging areas of investigation in the future, including its application in antimicrobial activity, diabetes management, and melanogenesis. It also identifies its potential applications in regulating apoptosis, estrogen biosynthesis, and managing vitiligo. The overview aims to classify the available knowledge on *Vernonia anthelmintica*, encompassing its potential in pharmacology and its significance in medicinal plant science.

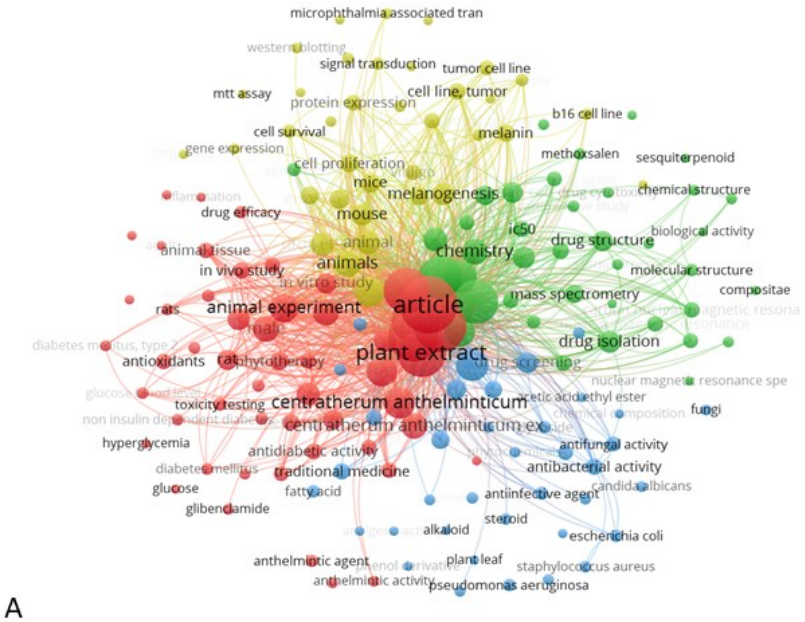
Table 5. Top 10 most relevant journals

S. No.	Sources	Articles	Impact factor
1.	JOURNAL OF THE AMERICAN OIL CHEMIST'S SOCIETY	20	2
2.	JOURNAL OF ETHNOPHARMACOLOGY	7	5.4
3.	PAKISTAN JOURNAL OF PHARMACEUTICAL SCIENCES	7	0.8
4.	NATURAL PRODUCT RESEARCH	6	2.2
5.	JOURNAL OF THE SCIENCE OF FOOD AND AGRICULTURE	5	4.1
6.	BMC COMPLEMENTARY AND ALTERNATIVE MEDICINE	4	-
7.	CHEMISTRY OF NATURAL COMPOUNDS	4	0.8
8.	FETTE, SEIFEN, ANSTRICHMITTEL	4	0.8
9.	FITOTERAPIA	3	3.4
10.	INDIAN DRUGS	3	-

There are 46 most trending topics contributed to these studies (till November 05, 2024). Fatty acids are represented with a frequency of 5, followed by Haemonchus contortus and plant with a frequency of 6. A total of 46 trending topics contributed to these studies. Over the past two decades, there has been a notable increase in research on plant-based compounds, antioxidants, and their impact on health. Interest in these topics began to grow in the early 2000s and experienced a sharp rise around 2010. There has been a specific focus on areas such as phytotherapy, medicinal plants, and flavonoids, driven by a trend towards natural products and their potential therapeutic applications. Researchers have also focused extensively on plant extracts, such as *Vernonia anthelmintica*, and their metabolites, including saponins, using methods like solvent extraction to explore their properties. The large number of citations for methods such as high-performance liquid chromatography and mass spectrometry indicates the growing use of advanced analytical tools to gain a deeper understanding of these compounds. Overall, the trend indicates a strong shift towards natural product research, particularly in drug discovery and phytochemistry.

Most cited papers

Bibliometric analysis has emerged as a vital method for assessing the impact of research within various fields, particularly by identifying the most cited papers. This study examines the top-most cited papers published between 1954 to 2024 (till November 5, 2024) across various journals. The most cited article, "*Induction of apoptosis in human breast cancer cells via caspase pathway by vernodalin isolated from Centratherum anthelminticum* (L.) *seeds*", has received 125 citations. This review explores the active compounds in the chloroform extract of *Centratherum anthelminticum* seeds, which have shown antioxidant effects against TNF-α-induced growth of human breast cancer cells. The second most cited publication, *"Fatty acids. Part II. The nature of the oxygenated acid present in Vernonia anthelmintica* (Willd.) *seed oil*", has received 124 citations; this study examines the type of oxygenated fatty acid found in *V. anthelmintica* seed oil. While the third-ranked article, "*The anthelmintic efficacy of five plant products against gastrointestinal trichostrongylids in artificially infected lambs*" has been referenced 114 times, this paper evaluates the anthelmintic efficacy of five plant products against *gastrointestinal trichostrongylids* in artificially infected lambs, highlighting *C. anthelminticum* as the most potent treatment, demonstrating significant parasite reduction and offering a promising natural alternative for controlling helminth infections. Table 6 shows the top 10 most cited papers and their description.



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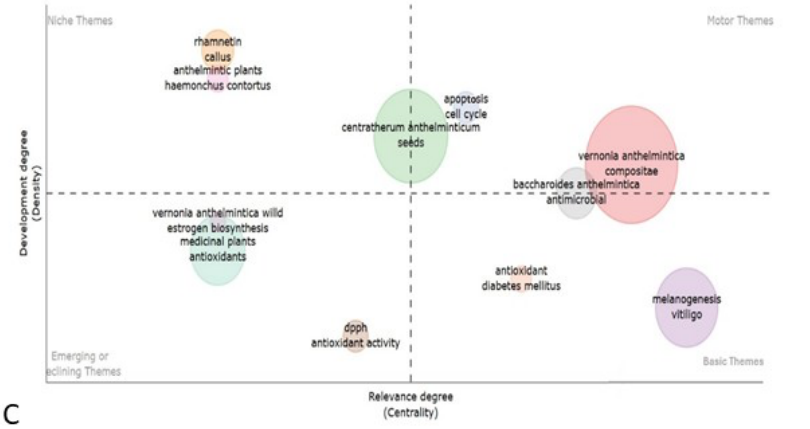

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Figure 4 (a). Map represents the overlay visualization of co-occurrence between all keywords, (b). World cloud map based on the main keywords, (c). Strategic keywords thematic map of publication on the *B. anthelmintica.*

Table 6. Top 10 most cited papers, their journals and total citations.

Rank	Title of the articles/ DOI	Year of Publication	Journal name	Types of publication	Total Citation	Total Citation per year	References
1.	Induction of apoptosis in human breast cancer cells via caspase pathway by vernodalin isolated from *Centratherum anthelminticum* (L.) seeds. 10.1371/journal.pone.0056643	2013	PLOS One	Research	125	10.42	Looi *et al.* 2013a
2.	Fatty acids. Part II. The nature of the oxygenated acid present in *Vernonia anthelmintica* (Willd.) seed oil. 10.1039/JR9540001611	1954	Journal of the Chemistry Society	Research	124	1.75	Gunstone, 1954
3.	The anthelmintic efficacy of five plant products against gastrointestinal trichostrongylids in artificially infected lambs. 10.1016/j.vetpar.2003.07.027	2003	Veterinary Parasitology	Research	114	5.19	Hordegen *et al.* 2003
4.	Effects of extracts from Bangladeshi medicinal plants on in vitro proliferation of human breast cancer cell lines and expression of estrogen receptor alpha gene	2004	International Journal of Oncology	Research	111	5.29	Lambertini etb al. 2004
5.	In vitro screening of six anthelmintic plant products against larval Haemonchus contortus with a modified methyl-thiazolyl-tetrazolium reduction assay. 10.1016/j.jep.2006.04.013	2006	Journal of Ethnopharmacology	Research	94	4.95	Hordegen *et al.* 2006
6.	Sterol additives as polymerization inhibitors for frying oils. 10.1007/BF02637578	1972	Journal of the American Oil Chemists' Society	Research	87	1.65	Sims et al.1972
7.	Kaliziri extract upregulates tyrosinase, TRP-1, TRP-2 and MITF expression in murine B16 melanoma cells. 10.1186/1472-6882-14-166	2014	BMC Complementary and Alternative Medicine	Research	78	7.1	Tuerxuntayi *et al.* 2014
8.	Separation of flavonoids from the seeds of *Vernonia anthelmintica* willd by high-speed counter-current chromatography. 10.1016/j.chroma.2004.07.072	2004	Journal of Chromatography A	Research	75	3.58	Tian *et al.* 2004
9.	Syiiergism between cyclopropenoid fatty acids and chemical carcinogens in Rainbow Trout (Salmo gairdneri)	1968	Cancer Research	Research	72	1.27	Lee *et al.* 1968
10.	Brine shrimp lethality bioassay of selected Indian medicinal plants. 10.1016/S0367-326X(02)00182-X	2002	Fitoterapia	Research	66	2.87	Padmaja *et al.* 2002

Literature Review

Ethnomedicinal uses

The pharmacological uses of *B. anthelmintica* have been widely documented in various regions, highlighting their broad applications in traditional systems of medicine. In China, the whole plant is still used in managing respiratory and digestive ailments, including cough, diarrhoea, and fever (Wu *et al.* 2018). In India, the seeds are frequently used to treat leukoderma, skin disorders, ulcers, kidney issues, and inflammatory swelling. They are also valued for their purgative effects and are used in the treatment of hiccups (Ashok *et al.* 2010). Both the seeds and roots are widely used in India for various purposes, including the treatment of skin irritations, kidney problems, psoriasis, and respiratory conditions such as asthma (Chance & Greenstein, 1952; Chakravarthy *et al.* 1980; Goutam & Kapoor, 2020). Additionally, Bhatia *et al.* (2008b) have also highlighted its supportive role in improving immunity and overall digestive health. The seeds of the plant are used to reduce nausea during pregnancy, relieve indigestion, and alleviate symptoms of carpal tunnel syndrome and morning sickness, while also serving as a diuretic, antiulcer, and anti-phlegmatic agent (Ani, 2008). Recently, findings by Husian *et al.* (2024) further emphasize the plant's potential in managing skin diseases, vitiligo, and even hyperglycemia. The leaves of the plant are particularly noted for their effectiveness in treating conditions like rheumatism, chronic fevers, phlegmatic coughs, and skin problems (Goutam & Kapoor, 2020). In Malaysia, traditional healers use the entire plants as stomachics, diuretics, and anthelmintics, as well as for relieving symptoms of cough, diarrhoea, and fever (Arya *et al.* 2012a, b, c, d; Looi *et al.* 2013a). Similarly, Indian practices also attributed therapeutic effects to the seed for treating fever, cough, and gastrointestinal issues (Sahoo *et al.* 2012). A few other ethnomedicinal applications are mentioned in Table 7.

Table 7. Some traditional applications of *B. anthelmintica* in different countries.

Plant part used	Use(s)	Preparation methods	Country/ region	References
Seeds	Leucoderma (skin disorder)	Oil is prepared by combining the seeds of *V. antihelmintica* with sesame oil, according to Thaila Paribhasha, and applied to leucoderma patches. This oil helps to turn the leucoderma patches into a brown colour.	Sri Lanka	Ediriweera (2007)
Seeds	Ant-ischistosomal activity (Veterinary uses)	The processed herb (in capsules) was given orally to the subject animals.	Pakistan	Niaz *et al.* 2015
Seeds	Veterinary uses	A combination of 50 g seed and 50 g chilli, mixed with 25 g table salt and 25 g black salt, was administered orally to the subject animal.	Pakistan	Sindhu *et al.* 2012
Seeds	Anthelmintic activities	The crude seed extract/decoction is recommended for this activity.	Pakistan	Iqbal *et al.* 2006
Seeds	Fever and diabetes	The overnight soaked seeds (5 g), along with the filtrate, are given to the patient.	India	Singh and Beg, 2015
Seeds	Gynecological disorder	Dough/paste is prepared by grinding all the methnohnoaterials. Peasized pills are made from this dough. It is used thrice a day (empty stomach in the morning, after lunch, and after dinner).	India	Modak *et al.* 2015
Seeds	Respiratory disorders	Baked seeds mixed with milk are used to treat respiratory diseases and asthma.	India	Jagtap *et al.* 2013
Seeds	Anti-vitiligo activity (skin disorder)	-	China	Wu *et al.* 1991
Seeds	Vermicide	The powder of the seeds was boiled on a low flame, and the decoction was used.	China	Ondaatje, 1883
Seeds	Anti-vitiligo activity (skin disorder)	A mixture of seed powder and water, sometimes with sesame oil, is applied topically to white patches of skin.	China	Cheng and Shi, 1987

Leaves	Chronic cough and hypertension	Juice of green leaves is taken 2 times to treat chronic cough and hypertension.	Nepal	Rana *et al.* 2025
Whole plant	Fever	A decoction of the whole plant is traditionally used to treat fever.	India	Singh and Beg, 2015
Seeds	Migraine	All ingredients (with other species) are mixed to prepare a paste. This paste is used on the forehead as an ointment for 3 days.	India	Day *et al.* 2017

Bioactive compounds

A previous paper on bioactive compounds found the presence of glycosides, phenols, saponins, tannins, sterols, and flavonoids as the main bioactive compounds (Bhatia *et al.* 2008b). Among the flavonoids, the noteworthy compounds are 2',3,4,4-tetrahydroxychalcone (Butein), 7,3',4'-trihydroxydihydroflavone, and 5,6,7,4'-tetrahydroxy flavone (Tian *et al.* 2004). Further sterols such as vernosterol, avernosterol, sterol-4-alpha-methylvernosterol (Akihisa *et al.* 1992) and steroid-like (24a/R)-stigmasta 7-en-3-one, 24(a/R)-stigmasta-7,9(11)-dien-3-one, 24(a/S)-stigmasta-5 and 22-dien-3ß-ol, stigmasta-7and 22-dien-3ß-ol (Mehta *et al.* 2005) have been known in *B. anthelmintica*. Further quantification of extracts through high-performance liquid chromatography (HPLC) revealed the presence of kaempferol-3-p-coumaroylglucoside, ferulic acid, and malvidin-3-(6-caffeoyl)-glucoside (Shoaib *et al.* 2023) (Table 8). These secondary metabolites of *B. anthelmintica* are responsible for the therapeutic action, including antitumor activity (Turak *et al.* 2017; Wang *et al.* 2018), antidiabetic activity (Fatima *et al.* 2010), auto-immune disease (vitiligo) (Hu *et al.* 2024), antibacterial activity (Hua *et al.* 2012a), etc.

Biological properties

B. anthelmintica possesses various biological activities such as antioxidants, antibacterial, antifungal, anticancer, antidiabetic, anti-inflammatory, antiparasitic, antitubercular, antidiuretic, and larvicidal. The following sections provide an overview of the functional biological activities of *B. anthelmintica.*

Antioxidant activity

Several research workers reported that *B. anthelmintica* displayed strong antioxidant potential (Table 9) through utilizing different kinds of antioxidant assays, like Oxygen Radical Absorbance Capacity (ORAC), 2,2-Diphenyl-1-picrylhydrazyl (DPPH), Nitric oxide (NO), 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid (ABTS), Cupric ion-reducing antioxidant capacity (CUPRAC), and Ferric Reducing Antioxidant Power Assay (FRAP) (Dogra & Kumar, 2010; Arya *et al.* 2012b; Jawaid *et al.* 2014; Jamil *et al.* 2017; Mudassir *et al.* 2018b; Andleeb *et al.* 2020; Bian *et al.* 2022; Husain *et al.* 2024). Using experiments, fractions of fixed oils were found to inhibit lipid peroxidation and increase the activity of antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) (Baig *et al.* 2022). The studies also determined that the defensive mechanisms of this plant against oxidative stress include the modulation of key signaling pathways, such as the Nrf2/Keap1/HO-1 pathway. This pathway is crucial for regulating antioxidant proteins, thereby enhancing cellular defence mechanisms against reactive oxygen species (ROS). In addition, it has been observed to downregulate pro-inflammatory markers associated with TNF-α and IL-1ß, further supporting its role in reducing oxidative stress-related damage. Such findings highlight the potential of *B. anthelmintica* as a valuable natural source of antioxidants, suggesting its potential use in therapeutic approaches to combat diseases associated with oxidative stress (Baig *et al.* 2022; Arya *et al.* 2012c).

Table 8. List of major bioactive components identified in the plant extract (*B. anthelmintica*).

Bioactive compounds identified in the plant extract	Solvents used for the extraction process	Plant part used	References
Abscisic acid	Methanol	Leaf	Sanyal *et al.* 1970
4α-methylsterol, 4-Demethylsterol, 4α-Demethylsterol	Methanol, Acetone, Hexane, Ethyl acetate	Seed	Akihisa *et al.* 1992
8,5'-dimethoxy 3',4'-methylenedioxy 3,7-dihydroxy flavone	-	Seed	Yadav & Barsainya, 1997
3-0-[ß-D-glucopyranosyl-(1→3)-α-L-rhamnopyranosyl-(1→2)-α-L-arabinopyranosyl]-28-0-[ß-D-glucuronopyrranosyl-(1→4)-α-L-rhamnopyranosyl-(1→3)-ß-D-glucopyranosyl]-hederagenin	Methanol	Seed	Mehta *et al.* 2004
2',3,4,4'-tetrahydroxychalcone, 5,6,7,4'-tetrahydroxyflavone, 7,3',4'-trihydroxydihydroflavone (butin)	Ethanol, Aqueous	Seed	Tian *et al.* 2004
Hexatetracontane-16-ol, 6,9-eicosadiene, Butyl 11-hydroxy octadecanoate, Hexyl 3-hydroxynonanoate, Hexyl 9-hydroxyheptatriacontanoate, Heptadecyl nonadecanoate	Ethanol	Seed	Verma *et al.* 2004
(24α/R)-stigmasta-7-en-3-one, (24α/R)-stigmasta-7,9(11)-dien-3-one, (24α/S)-stigmasta-5, 22-dien-3ß-ol, (24α/S)-stigmasta-7,22-dien-3ß-ol	Benzene, Acetone, Ethanol	Seed	Mehta *et al.* 2005
Vernodalidimers A, Vernodalidimers B	n- hexane	Seed	Liu *et al.* 2010
3-0-[ß-D-glucopyranosyl-(1→2)-α-L-rhamnopyranosyl-(1→2)-α-L-arabinopyranosyl]-28-0-[ß-D-xylopyranosyl-(1→4)-α-L-rhamnopyranosyl-(1→3)-ß-D-glucopyranosyl]-23-hydroxylean-12-en-28-oic acid,	Methanol, Acetone, Aqueous	Seed	Mehta *et al.* 2010
2-Pentanone-4-hydroxy-4-methyl, 2-Morpholinoethyl isothiocyanate, d-Allose, Drostanolone AC, 3(2H)- Benzofuranone, 2,6-dimethyl, Nonadecanoic acid, ethyl ester, Hexadecanoic acid, 1,1-dimethylethyl ester, Adipic acid monoamide, d-Mannitol,1-thiohexyl, Ethyl 4-isothiocyanatobutyrate, Octadecanoic acid, Butyl ester, Arabino-hetitol	Chloroform	Seed	Arya *et al.* 2012b
Quercetin glycoside, 3,4-0-dicaffeoylisoquinic acid, caffeic acid, naringenin-7-0-glucoside, kaempferol	Methanol	Seed	Arya *et al.* 2012c
Vernoanthelcin A-I, Vernoantheloside A-B	Methanol	Aerial part	Hua *et al.* 2012
Vernoanthelsterone A, 24ξ-hydroperoxy-24-vinyllathosterol, (24R)-stigmast-7,22(E)-dien-3β-ol, and other steroidal compounds	Methanol	Aerial part	Hua *et al.* 2012b
Ethyl vernolate, 1,3-Divernolin, 1-Vernolin	n- hexane	Seed	Liu *et al.* 2012a
Centratherumnaphthyl pentol, Centratherumnaphthyl hexol, Glyceryl diolien, Glyceryl diricin, Glyceryl ricinolpalmitein	Petroleum ether, Ethanol, Chloroform, Aqueous, Methanol-acetone-aqueous	Seed	Singh *et al.* 2012

Caffeic Acid, 3,4-di-O-caffeoylisoquinic Acid, Quercetin Glycoside, Kaempferol	Ethanol	Seed	Wang *et al.* 2012
12,13-dihydroxyoleic acid, Vernodalin	Ethanol	Seed	Looi *et al.* 2013c
4-*O*-caffeoylquinate, 3-*O*-caffeoylquinate, 5,7,3',4'-Tetrahydroxy-flavone-3-*O*-glucoside, 3,4-di-*O*-Caffeoylquinic acid, Liquiritigenin, Luteolin, Butein, Apigenin, Methoxyisorhamnetin, Kaempferide, Vernodalinol, Vernodalol, Vernodalin	-	-	Tuerxuntayi *et al.* 2014
Vernodalidimer C, Vernodalidimer D, Vernodalidimer E	Petroleum ether	Seed	Turak *et al.* 2015
Vernonilide B, Vernonilide A, Vernomelitensin, Odalin, Vernolepin, Acetylvernodalin, Acetylvernomelitensin	-	Seed	Ito *et al.* 2016
Hexanoic acid, 2- hexenyl ester, Isoxazole, Trimethyl, Propane, Dedanoic Acid, Beta -D-Glucopyranoside, methyl, Decanoic Acid, n- hexadecenoic acid, Allo-Inositol, Hexadecenoic acid, Benzenmethanol, 2,5- dimethoxy, Oleic Acids	Ethanol	Leaf callus	Kalimuthu *et al.* 2016
1-Dodecanol, 2-Undecene, 3-methyl-, (Z)-, 1-Tetradecanol, Undecene, 3-Methyl-, (Z)-, 1-Tridecene, n-Nonadecanol-1, 2-Undecene, 3-Methyl-, (Z)-, 2,6,10-Trimethyl,14-Ethylene-, 4-Hexen-1-Ol, 2-Isopropenyl-5-,3,7,11,15-Tetramethyl-2-hexadecen-1-o, 1-(+)-Ascorbic acid 2,6-dihexadecanoat, 1-Pentadecene	Ethanol	Leaf	Kalimuthu *et al.* 2016
2-Oxo-pentanoic acid, Henicosanoic acid, 26-Phenoxy-hexacosanoic methanoate, Hexadecanoic acid methyl ester, Hexadecanoic acid,	Ethanol	Seed	Mehta *et al.* 2016
Benzoyal-vernovan, 2-(4'-hydroxyphenyl)-6-methyl-4H-pyran-4-one	Petroleum ether	Seed	Maimaiti *et al.* 2017
Vernodalidimer F, Vernodalidimer G, Vernodalidimer H, Vernonilide C, Vernonilide A	Petroleum ether	Seed	Turak *et al.* 2017
Liquiritigenin (7,4'-Dihydroxyflavanone), Butin (7,3',4'-Trihydroxyflavanone), 3-*O* -Methylquercetin, Butein (3,4,2',4'-Tetrahydroxychalcone), Luteolin (5,7,3',4'-Tetrahydroxyflavone)	Petroleum ether, methanol	Seed	Rakhymbay *et al.* 2019
Vernosides A, Vernosides B, Vernosides C	-	Seed	Liu *et al.* 2020
2-(1-Metthylcyclopropyl) aniline, Methyl 12-methyltetradecanoate, Diisobutyl phthalate, Methyl 14 – methyltetradecanoate, Di-sec-butyl phthalate, Dibutyl phthalate, Methyl 14-methylhexadecanoate	-		Rustamova *et al.* 2020a
Methyl 13 – methyltetradecanoate, Methyl 12 – methyltetradecanoate, Methyl 14 – methylhexadecanoate, Undecanoic acid, Oleic Acid, Palmitic acid, Di-*sec*-butyl phthalate	-	Roots	Rustamova *et al.* 2020a
Methyl 12-methyltetradecanoate, Diisobutyl phthalate, Methyl 14-methylpentaecanoate, Di-sec-butyl phthalate, Methyl oleate, Bis(2-ethylhexyl) adipate, Bis (2- ethylhexyl) phthalate, 1,4-Benzendicarboxylic acid, Bis (2- ethylhexyl) sebacate, Methyl 13- methyltetradecanoate	Petroleum ether (1D), petroleum ether ethyl-acetate (2D)	Root	Rustamova *et al.* 2020a
1H-indol-7-ol, Tryptophol, 3-indole-propionic, 3,3-di(1H-indol-3-yl) propane-1,2-diol, Dihydrocinnamic	Ethyl acetate	Roots	Rustamova *et al.* 2021

Caryophyllene, n-Hexadecanoic, Octadecadienoic acid, Ricinoleic acid, Dihydroxypropyl ester, Octadedecadienoic acid methyl ester	n-hexane	Seed	Sadiqa *et al.* 2021
Chlorogenic acid, Luteolin-7-O-ß-glucuronide, Quercetin, Isochlorogenic acid B, Isochlorogenic acid A, Isochlorogenic acid C, ß-daucosterol, Syringaresional, Scutellarin, Luteolin,	Aqueous methanol	Seed	Bian *et al.* 2022
3',4',5,6,7 pentahydroxyflavanone, 3',4',5,7,8 pentahydroxyflavanone, Butein	Methanol	Seed	Kumar *et al.* 2022
CQA hexosy hexoside-a, CQA hexosy hexoside-b 3- CQA, CQA hexosy hexoside-c, Trihydroxycinnamoy diCQA-c, Trihydroxycinnamoy diCQA-d, CoCQA-a, Trihydroxycinnamoy diCQA-e, Trihydroxycinnamoy diCQA-f	Petroleum ether	-	Liu *et al.* 2022
Ferulic Acid, Sinapoyl Hexoside, Kaempferol, 3-Caffeoylquinic acid	Ethanol	Seed	Shoaib *et al.* 2023
Quinic acid, Gentisic acid, 2-Acetylthiophene, Trans-chlorogenc acid, Vanillin, Soraphen A, 3-Acetyl-6-methoxybenzaldehyde, Irisolidone 7-O-glucuronide, Flavine mononucleotide, 4-Methoxycinnamoyloleanolic acid methyl ester, 3-Carboxyethenyl-3,5-cyclohexadiene-1,2-diol, 3-Methylindolepyruvate	n-hexane	Seed	Kumar *et al.* 2024

Table 9. Antioxidant activity shown by different plant extracts of *B. anthelmintica.*

Plant Part	Solvent System	Name of assay	Antioxidant activity	References
Seed	Methanol	DPPH	14.89-90.40%	Dogra and Kumar, 2010
		DPPH	IC_{50}= 20.8 µg of AMAECA	
Seed	Chloroform	DPPH	IC_{50}= 22.56µg/mL	Arya *et al.* 2012b
		FRAP	1048.3µmol/L	
		ORAC	992.34TE	
Whole Plant	n-hexane	DPPH	IC_{50}= 47.83 µg/mL	Jawaid *et al.* 2014
		FRAP	2.64mM Fe(II)/g	
	DCM	DPPH	IC_{50}= 38.89 µg/mL	
		FRAP	2.30mM Fe(II)/g	
	Ethyl acetate	DPPH	IC_{50}= 30.43 µg/mL	
		FRAP	606.95mM Fe(II)/g	
Leaves	Aqueous	DPPH	ND	Soni and Chauhan, 2015
	Methanol	DPPH	IC_{50}=124 µg/mL	
Leaf	-	DPPH	13.55-62.55%	Kalimuthu *et al.* 2016
		FRAP	0.12-0.52%	
Leaf callus	-	DPPH	6.97-52.15%	
		FRAP	0.07-0.44%	
Seed	Hexane	DPPH	ND	Jamil *et al.* 2017
	Ethanol	DPPH	IC_{50}=95.10 mg/mL	
Seed	Ethanol	DPPH	67.36%	Mudassir *et al.* 2018b
Seed	Methanol	NO	IC_{50}= 25-39.4µg/mL	Andleeb *et al.* 2020
	n-hexane	NO	IC_{50}= 9-17.24µg/mL	
Seed	Methanol	DPPH	11.63-21.25mg TE/g	Bian *et al.* 2022
		ABTS	12.13-34.11mg TE/g	
		CUPRAC	35.57-109.37mg TE/g	
		FRAP	23.29-49.51mg TE/g	
		Reducing Power Assay	30.85-65.11mg TE/g	
Seed	Methanol	DPPH	8.80-14.40%	Prakash, 2023
	Acetone	DPPH	5.32-13.20%	
Seed	Aqueous	DPPH	20-48%	Husain *et al.* 2024

Note : DPPH- 2,2-Diphenyl-1-Picrylhydrazyl; FRAP- Ferric Reducing Antioxidant Power Assay; ORAC- Oxygen Radical Absorbance Capacity; NO- Nitric oxide; ABTS- 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid; CUPRAC- Cupric ion-reducing antioxidant capacity; ND- Not Determined.

Antimicrobial activity

B. anthelmintica seed exhibits antibacterial (Table 10) and antifungal (Table 11) activities against many pathogens. Researchers have quantified the effectiveness of *B. anthelmintica* extracts using methods like agar well diffusion, disc diffusion, and microdilution. For instance, the chloroform extract has exhibited promising antibacterial potential against Gram-negative bacteria, such as *Escherichia coli* and *Pseudomonas aeruginosa*, with minimum inhibitory concentration (MIC) ranges of 0.0020 µg/mL to 0.006 µg/mL, respectively (Negi et al., 2014). Moreover, the zone of inhibition values measured using agar diffusion indicate a substantial antimicrobial effect, primarily against Gram-negative bacteria and some fungal species (Negi *et al.* 2014). The essential oil of *B. anthelmintica* also exhibited strong antifungal activity, with the ZOI value ranging from 23.3 ± 0.33 to 75.7 ± 4.33 mm/µL against various *Candida* spp. The MIC values of different oil components and a mixture of oil components were recorded from the range of 1.25 to 2.5 µ/mL (Gopalkrishna *et al.* 2016). These findings indicated that *B. anthelmintica* may be highly effective against antibiotic-resistant strains and spoilage microbes. The promising results underline the potential for further exploration of its bioactive compounds in innovative applications, particularly in health and food perspectives, to address the growing concerns regarding antimicrobial resistance.

Table 10. Antibacterial activity caused by different plant extract of *B. anthelmintica.*

S. No.	Plant part	Solvent system	Concentration of extract (mg/mL)	Microorganisms	Agar well diffusion method/ agar disc diffusion method/ micro-dilution techniques		Region	References
					ZOI mm	MIC		
1.	Seeds	Aqueous: Methanol: Acetone	1-10	*Bacillus subtilis*	26.5	-	India	Ani, 2008
				Bacillus cereus	31.0	50 µg/mL		
				Enterobacter sp.	14.5	-		
				Escherichia coli	5.5	-		
				Listeria monocytogenes	17.0	700 µg/ml		
				Staphylococcus aureus	24.5	260 µg/mL		
				Yersinia enterocolitica	6.0	-		
2.	Seeds	Methanol	100	*Staphylococcus aureus*	12-14	-	India	Mehta *et al.* 2010
				Bacillus licheniformis	6.8-8.0	-		
				Salmonella typhimurium	6.8-8.0	-		
				Klebsiella pneumoniae	9.0-11.0	-		
				Micrococcus luteus	12-14	-		
				Arthobacter sp.	16-20	-		
				Shigella flexneri	6.8-8.0	-		
				Escherichia coli	6.8-8.0	-		
3.	Seeds	Acetone	100	*Staphylococcus aureus*	9.0-11.0	-	India	Mehta *et al.* 2010
				Bacillus licheniformis	NA	-		
				Salmonella typhimurium	NA	-		
				Klebsiella pneumoniae	6.8-8.0	-		
				Micrococcus luteus	9.0-11.0	-		
				Arthobacter sp.	12-14	-		
				Shigella flexneri	NA	-		
				Escherichia coli	6.8-8.0	-		
4.	Seeds	Methanol	-	*Pseudomonas aeruginosa*	-	<10 mg	Pakistan	Jahan *et al.* 2010
				Citrobacter sp.	-	<10 mg		
				Shigella flexneri	-	<10 mg		
				Yersinia aldovae	-	ND		
				Escherichia coli	-	<1 mg		

				Staphylococcus aureus	-	<1 mg		
5.	Seeds	Methanol	1	*Escherichia coli*	14	-	India	Ravula *et al.* 2012
				Pseudomonas aeruginosa	12.2	-		
				Staphylococcus aureus	11.2	-		
6.	Seeds	Ethanol	40	*Pseudomonas aeruginosa*	1-9	2 mg/mL	India	Patel *et al.* 2012
				Proteus vulgaris	1-9	5 mg/mL		
				Klebsiella pneumoniae	1-9	2.5 mg/mL		
				Bacillus cereus	1-9	10 mg/mL		
				Bacillus pumilus	1-9	10 mg/mL		
				Escherichia coli	1-9	10 mg/mL		
				Micrococcus luteus	1-9	10 mg/mL		
				Salmonella typhi	1-9	40 mg/mL		
7.	Seeds	Dichloromethane	5	*Xanthomonas campestris*	16.7	-	India	Bhagwat & Datar, 2013
				Xanthomonas axonopodis pv. punicae	14.7	-		
				Erwinia sp.	10.7	-		
				Pseudomonas syringae	10.3	-		
				Xanthomonas citri	11	-		
8.	Seeds	Chloroform	15	*Staphylococcus aureus*	-	ND	India	Negi *et al.* 2014
				Escherichia coli	-	0.0020 µg/mL		
				Pseudomonas aeruginosa	-	0.006 µg/mL		
				Bacillus subtilis	-	ND		
9.	Seeds	Hexane	20	*Staphylococcus albus*	13.0	-	India	Mehta *et al.* 2016
				Staphylococcus aureus	3.0	-		
				Staphylococcus haemolyticus	11.0	-		
				Vibrio cholerae	2.0	-		
				Pseudomonas aeruginosa	3.0	-		
				Klebsiella aerogenes	8.0	-		
				Escherichia coli	6.0	-		
				Pseudomonas pyocyanea	5.0	-		
				Diplococcus pneumoniae	3.0	-		
10.	Seeds	Acetone	20	*Staphylococcus albus*	3.0	-	India	Mehta *et al.* 2016
				Staphylococcus aureus	14.0	-		
				Staphylococcus haemolyticus	14.0	-		

				Vibrio cholerae	3.0	-		
				Pseudomonas aeruginosa	3.0	-		
				Klebsiella aerogenes	4.0	-		
				Escherichia coli	6.0	-		
				Pseudomonas pyocyanea	6.0	-		
				Diplococcus pneumoniae	5.0	-		
11.	Seeds	Ethanol	20	*Staphylococcus albus*	14.0	-	India	Mehta *et al.* 2016
				Staphylococcus aureus	16.0	-		
				Staphylococcus haemolyticus	9.0	-		
				Vibrio cholerae	6.0	-		
				Pseudomonas aeruginosa	8.0	-		
				Klebsiella aerogenes	4.0	-		
				Escherichia coli	8.0	-		
				Pseudomonas pyocyanea	3.0	-		
				Diplococcus pneumoniae	9.0	-		
12.	Seeds	Methanol	20	*Staphylococcus albus*	3.0	-	India	Mehta *et al.* 2016
				Staphylococcus aureus	11.0	-		
				Staphylococcus haemolyticus	14.0	-		
				Vibrio cholerae	3.0	-		
				Pseudomonas aeruginosa	5.0	-		
				Klebsiella aerogenes	5.0	-		
				Escherichia coli	12.0	-		
				Pseudomonas pyocyanea	3.0	-		
				Diplococcus pneumoniae	5.0	-		
13.	Leaves	Ethanol	-	*Streptococcus pyogenes*	20.15	-	India	Kalimuthu *et al.* 2016
				Staphylococcus aureus	6.1	-		
				Escherichia coli	20.0	-		
				Klebsiella pneumoniae	18.0	-		
14.	Leaves callus	Ethanol	-	*Streptococcus pyogenes*	7.1	-	India	Kalimuthu *et al.* 2016
				Staphylococcus aureus	22.2	-		
				Escherichia coli	18.1	-		
				Klebsiella pneumoniae	8.0	-		
15.	Seeds	Chloroform	200	*Bacillus cereus*	ND	-	India	Pandya *et al.* 2019
				Escherichia coli	11.34	-		

				Klebsiella pneumoniae	19.56	-		
				Salmonella typhi	ND	-		
				Staphylococcus aureus	ND	-		
				Streptococcus agalactiae	ND	-		
16.	Whole plant	-	-	*Escherichia coli*	6.0	-	China	Rustamova *et al.* 2020b
				Staphylococcus aureus	11.0	-		
17.	Seeds	Methanol	-	*Escherichia coli*	-	220 µg/mL	India	Thara, 2020
				Pseudomonas aeruginosa	-	200 µg/mL		
				Klebsiella pneumoniae	-	150 µg/mL		
				Proteus mirabilis	-	150 µg/mL		
				Staphylococcus aureus	-	160 µg/m		
18.	Seeds	Aqueous	-	*Escherichia coli*	-	250 µg/mL	India	Thara, 2020
				Pseudomonas aeruginosa	-	440 µg/mL		
				Klebsiella pneumoniae	-	250 µg/mL		
				Proteus mirabilis	-	220 µg/mL		
				Staphylococcus aureus	-	260 µg/mL		
19.	Seeds	Aqueous	-	*Enterobacter aerogenes*	0.3	-	Pakistan	Sadiqa *et al.* 2021
				Escherichia coli	0.1	-		
				Klebsiella pneumoniae	0.3	-		
				Pseudomonas aeruginosa	0.2	-		
				Staphylococcus aureus	0.4	-		
				Bacillus subtilis	0.4	-		
				Lactiplantibacillus plantarum	ND	-		
				Staphylococcus epidermidis	ND	-		

Note : ZI- Zone of inhibition; **MIC-** Minimum zone of inhibition; **ND-** Not Determined; **NA-** No activity. *Diplococcus pneumoniae* (now accepted as *Streptococcus pneumoniae*) and *Enterobacter aerogenes* (reclassified as *Klebsiella aerogenes*).

Table 11. Antifungal activity caused by different plant extracts of *B. anthelmintica.*

S. No.	Plant part	Solvent system	Concentration of extract (mg/mL)	Microorganisms	Agar well diffusion method/ agar disc diffusion method/ micro-dilution techniques		Region	References
					ZOI (mm)	MIC		
1.	Seeds	Methanol	100	*Trichothecium roseum*	12-14	-	India	Mehta *et al.* 2010
				Candida albicans	9-11	-		
				Fusarium solani	12-14	-		
				Penicillium notatum	ND	-		
2.	Seeds	Acetone	100	*Trichothecium roseum*	9-11	-	India	Mehta *et al.* 2010
				Candida albicans	6.8-8.0	-		
				Fusarium solani	6.8-8.0	-		
				Penicillium notatum	ND	-		
3.	Seed	Methanol	-	*Saccharomyces cerevisiae*	-	ND	Pakistan	Jahan *et al.* 2010
				Candida albicans	-	ND		
				Aspergillus parasiticus	-	ND		
				Macrophomina	-	ND		
				Fusarium solani	-	ND		
				Trichophyton rubrum	-	<50 mg		
4.	Seeds	Ethanol	0.1	*Aspergillus fumigatus*	-	IC_{50}=20.12 µg/mL	India	Patel *et al.* 2011
				Candida albicans	-	IC_{50}=36.30 µg/mL		
				Candida parapsilosis	-	IC_{50}=18.46 µg/mL		
				Candida tropicalis	-	IC_{50}=15.05 µg/mL		
				Cryptococcus albidus	-	>100		
				Cryptococcus laurentii	-	>100		
				Issatchenkia orientalis	-	IC_{50}=63.3 µg/mL		
5.	Seeds	Chloroform	0.1	*Aspergillus fumigatus*	-	IC_{50}=21.33 µg/mL	India	Patel *et al.* 2011
				Candida albicans	-	IC_{50}=58.06 µg/mL		
				Candida parapsilosis	-	IC_{50}=35.67 µg/mL		
				Candida tropicalis	-	IC_{50}=29.88 µg/mL		
				Cryptococcus albidus	-	>100		
				Cryptococcus laurentii	-	>100		
				Issatchenkia orientalis	-	IC_{50}=62.88 µg/mL		
6.	Seeds	n-Hexane	0.1	*Aspergillus fumigatus*	-	>100	India	Patel *et al.* 2011
				Candida albicans	-	>100		
				Candida parapsilosis	-	>100		
				Candida tropicalis	-	>100		
				Cryptococcus albidus	-	>100		
				Cryptococcus laurentii	-	>100		

				Issatchenkia orientalis	-	>100		
7.	Seeds	Diethyl Ether	0.1	*Aspergillus fumigatus*	-	>100	India	Patel *et al.* 2011
				Candida albicans	-	>100		
				Candida parapsilosis	-	>100		
				Candida tropicalis	-	>100		
				Cryptococcus albidus	-	>100		
				Cryptococcus laurentii	-	>100		
				Issatchenkia orientalis	-	>100		
8.	Seeds	Petroleum Ether	0.1	*Aspergillus fumigatus*	-	>100	India	Patel *et al.* 2011
				Candida albicans	-	>100		
				Candida parapsilosis	-	>100		
				Candida tropicalis	-	>100		
				Cryptococcus albidus	-	>100		
				Cryptococcus laurentii	-	>100		
				Issatchenkia orientalis	-	IC_{50}=7.936 µg/mL		
9.	Seeds	Methanol	20	*Aspergillus flavus*	13	-	India	Singh *et al.* 2012
				Candida albicans	18	-		
				Penicillium citrinium	17	-		
10.	Seeds	Chloroform	15	*Colletotrichum gloeosporioides*	-	0.025 µg/mL	India	Negi *et al.* 2014
				Phomopsis dalbergiae	-	0.025 µg/mL		
				Trichoderma piluliferum	-	0.025 µg/mL		
11.	Leaves	Ethanol	-	*Candida albicans*	7.2	-	India	Kalimuthu *et al.* 2016
				Trichoderma viride	6.1	-		
12.	Leaves callus	Ethanol	-	*Candida albicans*	14.2	-	India	Kalimuthu *et al.* 2016
				Trichoderma viride	8.2	-		
13.	Seeds	Aqueous		*Candida albicans*	-	450 µg/mL	India	Thara, 2020
				Aspergillus niger	-	ND		
14.	Seeds	Methanol		*Candida albicans*	-	250 µg/mL	India	Thara, 2020
				Aspergillus niger	-	ND		

Note: ZI- Zone of inhibition; MIC- Minimum Zone of Inhibition; ND- Not Determined.

Anti-cancer activity

B. anthelmintica plant has been under intense study over the last decade due to its purported anti-cancer activity (Table 12). Experiments have shown that vernodalin, an alkaloid isolated from seeds, inhibits the growth of human breast cancer cells strongly by inducing apoptosis via the caspase pathway (Looi *et al.* 2013a). Furthermore, chloroform fraction of *B. anthelmintica* seeds have been reported to be cytotoxic to melanoma A375 cells by inducing apoptosis by modulating NF-kB, p53 and Bcl-2 pathways (Looi *et al.* 2013c). Green synthesis of silver nanoparticles using *B. anthelmintica* seed extract also exhibited high cytotoxicity towards MDA-MB-231 breast cancer cells (Husain *et al.* 2024). The findings demonstrate the potential of *B. anthelmintica* as a source of anticancer compounds that are active against various types of concerns by multiple mechanisms.

Anti-diabetic activity

B. anthelmintica, also known as bitter cumin, has long been known in traditional Ayurvedic medicines for its anti-diabetic properties (Table 13) and hypoglycemic effects. Research has demonstrated that the methanolic extract from its seeds exhibits significant anti-diabetic activity. Both in-vitro and in-vivo studies have shown that this extract enhances insulin secretion and improves glucose uptake in pancreatic ß-TC6 (beta-TC6) cells. Furthermore, they have been found to lower blood glucose levels in streptozotocin-induced diabetic rats in a dose-dependent manner. The extract enhances insulin sensitivity by upregulating glucose transporter proteins, specifically GLUT-2 (Glucose Transporter Type-2) and GLUT-4 (Glucose Transporter Type-4) and reduces markers of oxidative stress. Moreover, it enormously decreased the levels of pro-inflammatory cytokines, which are typically elevated in diabetic conditions. These findings suggest that *B. anthelmintica* can be utilized as a promising natural drug in the management of diabetes, and its active compounds and mechanisms warrant further investigation (Arya *et al.* 2012a, d; Looi *et al.* 2013b).

Anti-inflammatory activity

Researchers have documented that *B. anthelmintica* possess significant anti-inflammatory properties, particularly in managing diabetes-related inflammation. Studies have shown that the methanolic seed fractions of *Centratherum anthelminticum*, known as CAMFs (*Centratherum anthelminticum* methanolic fraction), act as potent inhibitors of NF-κB activation (Nuclear Factor kappa-light-chain-enhancer of activated B cells), a key mediator in inflammatory processes. In vitro experiments demonstrated that CAMFs inhibited the H_2O_2-induced translocation of NF-kB in ß-TC6 cells, resulting in lowering the pro-inflammatory cytokines such as TNF-α and IL-1ß (Looi *et al.* 2013b). In-vivo studies using streptozotocin-nicotinamide-induced diabetic rats further supported these findings, as CAMFs treatment reduces oxidative stress markers while improving antioxidant status by elevating glutathione levels and reducing malondialdehyde levels (Arya *et al.* 2012c). Furthermore, petroleum ether and alcoholic extracts of *B. anthelmintica* have demonstrated significant anti-inflammatory effects by inhibiting prostaglandin synthesis and reducing myeloperoxidase activity (Ashok *et al.* 2010). These studies showed the therapeutic potential of *B. anthelmintica* as a natural anti-inflammatory agent.

Anti-parasitic activity

B. anthelmintica is scientifically documented for its strong anti-parasitic activity, particularly against filarial parasites. A recent study by Kumar *et al.* (2024) demonstrated its effectiveness against the lymphatic filarial parasite *Setaria cervi*, utilising ex-vivo biochemical and proteomic approaches. Their findings showed that treatment with the plant extract significantly reduced the mortality and viability of the parasites. The study also revealed increased lipid peroxidation and oxidative stress, suggesting that the extract causes cellular damage in the parasites, which contributes to its anti-parasitic effects. Collectively, these findings support the promise of *B. anthelmintica* in parasitic control, although further research is needed to fully elucidate its mechanisms and therapeutic potential.

Toxicity studies

Limited studies have evaluated the toxicity of *B. anthelmintica*. For instance, Purnima *et al.* (2009) reported that alcoholic and petroleum extracts do not cause toxicity at the dose level of up to 2000mg/kg. Similarly, Mudassir & Qureshi (2015) found the ethanolic seed extract to be non-toxic at a dose of 3000 mg/kg in experimental rabbits. Ashok *et al.* (2010) conducted acute toxicity tests on albino mice by the guidelines of the Organisation for Economic Co-operation and Development (OECD). They determined that the maximum non-lethal dose was 2000 mg/kg without observing any adverse effects. Doses of 100 and 200 mg/kg were selected to confirm the safety of the extracts for further pharmacological studies.

Anti-tubercular efficacy

B. anthelmintica has been scientifically documented for its anti-tubercular efficacy against *Mycobacterium tuberculosis*, the bacterium responsible for the infectious disease tuberculosis. The seed extract of the plant significantly inhibited bacterial

growth at low concentrations, ranging from 10 to 1 µg/mL. The results suggest that *B. anthelmintica* could be a valuable natural alternative to conventional therapies for tuberculosis, highlighting the need for further investigation into its potential as a complementary treatment (Mehta *et al.* 2016).

Larvicidal

B. anthelmintica also shows the highest larvicidal activity against the malaria vector *Anopheles stephensi*. Laboratory studies revealed that crude extracts from both the fruits and leaves of *B. anthelmintica* exhibited larvicidal properties, with the petroleum ether extract from the fruit being the most potent. The LC50 values for the fruit and leaf extract were 162.60 ppm and 522.94 ppm, respectively, after 24 hours of exposure. The fruit extract in petroleum ether exhibited considerably higher toxicity than the leaf extract, showing 11.66, 2.15, and 1.32 times greater potency at LC90 after 24, 48, and 72 hours of exposure, respectively. At the LC50 level, the differences were 3.22, 1.83, and 1.19, respectively. Overall, the petroleum ether extract of the *B. anthelmintica* fruit is a potent agent for controlling *Anopheles* larvae (Srivastava *et al.* 2008).

Anti-diuretic

The chloroform, alcohol, and petroleum extracts of seeds were tested for the diuretic effect in rats at a dose of 200 mg/kg. The alcohol extract demonstrated the strongest diuretic effect, followed by the chloroform, while the petroleum ether extract did not show any significant activity. In addition, both the alcohol and chloroform extracts significantly reduced potassium levels by more than half, suggesting a possible effect on electrolyte balance. The reduction in potassium, along with the diuretic effect, supports the traditional use of *B. anthelmintica* seeds in hypertension therapy (Koti & Purnima, 2008). The various medicinal properties of *B. anthelmintica* are illustrated in Figure 5.

Figure 5. Different medicinal benefits of the plant species.

Table 12. Anti-cancer activity *of B. anthelmintica* plant extract as reported by different researchers.

Model/ Cancer cell lines	Ic_{50} value	Mechanism	Pharmacological action	References
MCF-7, PC-3, A549, WRL-68	8.1 µg/mL, 22.61 µg/mL, 31.42 µg/mL, 54.93 µg/mL	Inhibited release of TNF-α at 0.012 µg/mL, inhibited NF-κB activation	Prevent NF-κB translocation from cytoplasm to nucleus crucial for inflammation and cancer progression	Arya *et al.* 2012b
A375	<10 µg/mL	Nuclear membrane condensation, plasma membrane blebbing, cell structure disruption, reduced mitochondria, increased lysosomes, caspase-9 and 3/7 activation, downregulation of Bcl-2 and upregulation of p53 protein	Inhibit cell proliferation and induces apoptosis via many mechanisms like ROS-mediated mitochondrial dysfunction, release of cytochrome c from mitochondria, activation of the intrinsic caspase pathway, inhibition of NF-kB translocation	Looi *et al.* 2013c
MCF-7	2.0 mg/mL	Reduction in phalloidin stain, loss of stress fibre, cell shrinkage, increase in ROS species, downregulation of Bcl-2 and Bcl-xl, release of cytochrome c, cleavage of PARP, activation of caspase 7 and 9	Induces cell cycle arrest at the G0/G1 phase, triggers apoptosis, disrupts the cytoskeleton, reduces mitochondrial membrane potential, and leads to PARP cleavage and DNA damage	Looi *et al.* 2013a
MCF-7, MDA-MB231	-	Increased the expression of FOXO3a, upregulated the level of p27Kip1, p21, and Bim, downregulated the level of cyclin D1, cyclin E, and Akt kinase activity	Controls cell cycle progression, help in nuclear translocation of FOXO3a transcription factor, activates FOXO	Sadagopan *et al.* 2015
HeLa	-	Caused cell shrinkage, aggregation, and death	Exhibits anti-proliferative action	Chinnadurai *et al.* 2016
NB4, KG-1a, HL-60	65.72 µM, 76.4 µM, 67.83 µM	Upregulated p2, Bim, PTEN Bax, Bad, and Cdc25, downregulated B1, mTOR, Bcl-2, and Mcl-1, inactivated PARP and caspase cascade, released cytochrome c and SMAC, phosphorylation of Akt	Induces cell cycle arrest at G2/M phase and triggers apoptosis through mitochondrial (intrinsic) pathway, in addition to inhibiting the PI3K/Akt/MTOR signalling pathway	Wu *et al.* 2018

Note: MCF-7: Michigan Cancer Foundation-7 (breast adenocarcinoma); **PC-3:** Prostate Cancer-3 (prostate adenocarcinoma); **A549:** Alveolar Adenocarcinoma Human Lung Cell Line; **WRL-68:** Human Embryonic Liver Cell Line; **PANC-1:** Human Pancreatic Carcinoma Cell Line; **A375:** Human Amelanotic Melanoma Cell Line; **NB4:** Acute Promyelocytic Leukemia Cell Line; **KG-1a:** Human Acute Myelogenous Leukemia Cell Line; **HL-60:** Human Promyelocytic Leukemia Cell Line; **MDA-MB-231:** Human Breast Cancer Metastatic Cell Line; **HeLa:** Henrietta Lacks (human cervical cancer cell line).

Table 13. Anti-diabetic activity *of B. anthelmintica* plant extract as reported by different researchers.

Tested compounds	Dosage	Study Model	Potential mechanisms	Reference
Methanol: Acetone	50-200 mg/kg body weight	CFT-Wistar rats (In vivo), In vitro assay	Increase in sucrose, maltase, PNG-G hydrolysis, α-amylase, reduction in postprandial plasma glucose level	Ani & Naidu, 2007
Aqueous extract	200 mg/kg, 500 mg/kg	Alloxan-Induced Diabetes in Adult Albino Rats (In vivo)	Decrease in blood glucose levels	Bhatia *et al.* 2008a
Ethanol	0.02-0.75 g/kg body weight, 100 mg/kg body weight	Streptozotocin (STZ)-induced diabetic male Wistar albino rats (In vivo)	Decrease in blood glucose level, HbA1c, increase in protein and glycogen level, reduction in TG, cholesterol, LDL-c, VLDL-c, free fatty acids, PL, urea, uric acid, creatinine, plasma insulin	Fatima *et al.* 2010
Methanolic fraction	10-500 mg/kg	Streptozotocin (STZ)-nicotinamide-induced type 2 diabetes Sprague-Dawley rat model (In vivo), ß-TC6 cells (In vitro)	Increase in TNF-α, IL-6, IL-1ß, Oxidative stress, H_2O_2-induced NF-kB translocation, decrease in Blood glucose level	Arya *et al.* 2012d
Ethanol (50%)	250 mg/kg, 500 mg/kg, 750 mg/kg	Adult albino rats (In vivo)	Decrease in blood glucose levels	Bhatia & Paliwal, 2015
Ethanol	200-600 mg/kg	Fructose-induced type 2 diabetic test rabbits (In vivo)	Reduction in blood glucose level, serum insulin, TG, TC, LDL, increase in HDL	Mudassir & Qureshi, 2015
Crude seeds powder	200 mg, 400 mg	Human clinical study on Healthy Volunteers and Type 2 Diabetic Patients (In vivo)	Decrease in blood glucose level, LDL-c, VLDL-c	Mudassir *et al.* 2018a
Chloroform, methanol, aqueous	200-1000 µg/mL	In vitro Assay	Increase in α-amylase, α-glucosidase	Patel *et al.* 2019
Ethanol	100-300 mg/kg body weight	Streptozotocin (STZ)-induced diabetic rats (In vivo)	Decrease in LDL, TG, VLDL, FFA, PL, TC, LPO, increase in HDL, SOD, CAT, GPx, GST, GSH, direct and total bilirubin, protein level in liver	Goutam & Kapoor, 2020
Hexane, Chloroform, Ethanol	50-200 mg/kg	Streptozotocin (STZ)-induced diabetic rats (In vivo)	Reduction in blood glucose level, serum insulin, increase in HbA1c level, SOD, CAT, GPx, GSH, NF-Kb p65, Bcl-2, decrease in TNF-α, IL-1ß, COX-1, Nrf-2, Keap 1, HO-1	Baig *et al.* 2022
Seed capsule	500 mg	Human Clinical Study on Type 2 Diabetic Patient (In vivo)	Decrease in fasting blood sugar and HbA1c levels	Mudassir *et al.* 2023

Note: LDL- Low density lipoprotein; **TG-** Triglycerides; **VLDL-** Very low-density lipoprotein; **FFA-** Free fatty acid; **PL- Phospholipids; TC-** Total cholesterol; **HDL-** High density lipoprotein; **LPO-** Lipid peroxidation; **SOD-** Superoxide dismutase; **CAT-** Catalase; **GPx-** Glutathione S transferase; **GST-** Glutathine S transferase; **GSH-** Reduced glutathione; **LDL-c-** Low density lipoprotein cholesterol; **VLDL-c-** Very low-density lipoprotein cholesterol.

Conclusions and Future Prospective

B. anthelmintica possesses considerable pharmacological potential due to its bioactive constituents, which offer antioxidant, antimicrobial, and anticancer properties. Its traditional uses are supported by scientific evidence, making it a promising natural source for nutraceutical and pharmaceutical applications. However, to fully harness its potential, further in vivo studies and well-designed clinical trials are needed to confirm its safety and therapeutic efficacy.

Complementing these therapeutic insights, the bibliometric analysis of publications from 1954 to 2024 reveals a steady annual growth in research on *B. anthelmintica*. China and India are the two prominent countries in terms of publications, with China leading in international collaborations. Leading journals such as the Journal of the American Oil Chemists' Society and the Journal of Ethnopharmacology have contributed significantly to the dissemination of relevant findings. The keyword analysis reveals a dominant occurrence of terms such as "traditional medicine," "antioxidant activity," and "ethnopharmacology," reflecting significant interdisciplinary integration of indigenous ethnobotanical knowledge into therapeutic applications of *B. anthelmintica*. This trend marks an increasing shift toward validating ethnomedicinal knowledge through modern, evidence-based scientific research.

Besides this, the present study also consists of several limitations: (i) only the SCOPUS web database was used for the data extraction for bibliometric analysis, (ii) the literature published only in the English language was included, (iii) citation number is solely an implied measure of research implication and may be affected by several factors, including access and reputation journal.

Looking ahead, future research should focus on expanding clinical trials to validate the therapeutic potential of *B. anthelmintica*, while interdisciplinary approaches can further explore its applications in pharmaceuticals and nutraceuticals. Additionally, biotechnological interventions such as tissue culture and metabolic engineering can enhance the sustainable production of important bioactive compounds. Interdisciplinary collaboration among ethnobotanists, pharmacologists, and stakeholders is also suggested to facilitate the translation of laboratory research into commercially viable and therapeutically effective products.

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