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Global output of Boswellia serrata research (1969-2020): An Indian traditional medicinal plant with potential therapeutic value

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ABSTRACT

This scientometric study examines the global research output on Boswellia serrata Roxb. ex Colebr., a traditional medicinal plant in India known by various names such as Salai/Salai guggul, Indian frankincense, and Indish incense. Boswellia serrata belongs to the Burseraceae family and has been used in Ayurveda for its potential therapeutic properties. We analyzed a total of 284 relevant documents from the Scopus database published between 1969 and 2020 to identify prominent activities associated with Boswellia serrata, including anti-inflammatory, anti-cancer, anti-ulcer, anti-asthmatic, anti-hypertensive, hepato-protective, anti-diarrheal, anti-platelet, anti-arthritic, anti-hyperlipidemia, toxicology, and immunomodulatory effects. More recent research has focused on micropropagation, nanoparticle formulation for cancer treatment, and neuroprotective activity. We recommend that future research investigates how Boswellia serrata alleviates asthma, ulcers, arthritis, diabetes, and liver diseases, exhibits diuretic action and anti-convulsant activity, and treats renal failure. This study offers a comprehensive overview of research activities on Boswellia serrata to date and emphasizes the potential for further research into its therapeutic properties. The findings of this study hold value for researchers, healthcare professionals, and policymakers involved in developing and utilizing traditional medicinal plants for therapeutic purposes.

KEYWORDS: *Boswellia serrata*, Salai guggul, Scopus, Scientometrics, Herbal medicine

INTRODUCTION

The *Boswellia serrata* Roxb. ex Colebr. Tree, commonly referred to as Salai or Salai guggul, thrives as an evergreen species in arid mountainous regions across India, Northern Africa, and the Middle East. Within Ayurvedic medicine, this tree has been traditionally revered for its efficacy in addressing a range of inflammatory ailments, including

osteoarthritis and chronic bowel diseases. The gum resin derived from *B. serrata*, known as Salai, is an exudate tapped from the tree trunk, gradually solidifying into amorphous, tear-shaped formations imbued with an enchanting fragrance.

The traditional Ayurvedic and Unani scriptures meticulously document the usage of B. serrata as a potential therapeutic agent for a diverse array of conditions, encompassing fevers, skin and blood disorders, dysentery, diarrhea, ringworm, boils, cardiac health, oral ulcers, sore throats, pulmonary afflictions, congenital infections, jaundice, hemorrhoids, hair loss, syphilis, and hepatic diseases. Despite its extensive historical employment in traditional medicinal practices, a notable need remains for scientometric analysis of cations-centered around B. serrata.

Notably, scientometric studies have been previously conducted on medicinal plants such as *Glycyrrhiza glabra*[1], *Curcuma longa*[2], *and Ocimum sanctum*[3]. Thus, undertaking a comprehensive scientometric analysis of publications focused on *B. serrata* becomes imperative to elucidate the existing research landscape and advancements in this field. Such an analysis will shed light on the most frequently cited publications concerning *B. serrata*, encompassing their citation counts, research focal points, publishing journals, and eminent authors who have contributed significantly to the literature in this domain.

Materials and Methods

We systematically identified and analyzed pertinent publications on *B. serrata* for this scientometric study. The following steps were undertaken:

1. Given its extensive scientific literature collection across diverse disciplines, we selected the Scopus database as our primary resource, ensuring a comprehensive representation of research publications on *B. serrata*.
2. To capture relevant publications, we devised a search strategy incorporating various terms such as "Boswellia serrata," "Salai," "Salai guggul," and "Indian frankincense." This strategy aimed to retrieve articles closely aligned with our study objective.
3. To ensure the inclusion of suitable articles, we established specific criteria. Publications focusing on Boswellia serrata, its therapeutic properties, or related aspects were considered. The timeframe for inclusion spanned from 1969 to 2020.

We extracted key details from the selected publications, including titles, authors, publication years, journals, and citation counts. Additionally, we identified the research areas and activities associated with *B. serrata* discussed in each publication.

The extracted data underwent analysis to identify notable research activities related to *B. serrata*. We categorized these activities based on their focus, such as anti-inflammatory, anti-cancer, anti-ulcer, anti-asthmatic, anti-hypertensive, hepato-protective, anti-diarrheal, anti-platelet, anti-arthritic, anti-hyperlipidemia, toxicology, and immunomodulatory effects. Furthermore, we explored recent research trends, including micropropagation, nanoparticle formulation for cancer treatment, and neuroprotective activity.

Drawing from our analysis findings, we provided recommendations for future research directions. These recommendations highlight specific areas, such as asthma, ulcers, arthritis, diabetes, liver diseases, diuretic action,

anti-convulsant activity, and renal failure, that merit further investigation into the mechanisms and therapeutic potential of *B. serrata*.

Following this systematic approach, we obtained a comprehensive overview of the research output on *B. serrata* and identified promising avenues for future exploration. The methodological rigor ensures our scientometric study's reliability and validity, making it relevant for researchers, healthcare professionals, and policymakers engaged in traditional medicinal plant research and utilization.

DATA SOURCE AND ANALYSIS

We collected data from the largest peer-reviewed literature database, Scopus, covering the period between 1969 and November 2020. The data collection took place in November 2020, and we conducted the search using the keywords "Boswellia serrata" and "Salai guggul" in the article title, abstracts, and keywords fields. We included various document types, such as articles, reviews, conference papers, book chapters, notes, letters, editorials, short surveys, and errata, resulting in 856 document types. We only considered documents written in English for analysis and excluded retracted articles. Our focus was explicitly on studies exclusively centered around *B. serrata* while excluding others, resulting in a final data set of 284 documents. All document types were reviewed by two authors, with any discrepancies resolved by a third author.

Results: From 1969 to 2020, the *B. serrata* research output yielded 284 documents, accumulating 7703 citations. We calculated the average number of citations per paper during this period to be 27.35. Table 1 presents information on the 10-year periodic growth of Boswellia serrata publications from 1969 to 2020.

Table 1. A 10-year periodic development of *Boswellia serrata* publications during 1991-2020 (n=284)

Year range	Documents	Citations
1961-1970	1	17
1971-1980	0	0
1981-1990	2	190
1991-2000	19	1487
2001-2010	77	3571
2011-2020	182	2438

From 1991 to 2000, there were 19 publications on Boswellia serrata. This number increased to 78 publications from 2001 to 2010 and further rose to 182 publications from 2011 to 2020. These findings indicate an active ongoing research interest in Boswellia serrata. To gain insights into the annual publication distribution, we refer to Table 2.

Table 2. The annual *Boswellia serrata* publications during 1969-2020

Year	**No of publications**	**Citations**	**ACPP**
1969	1	17	17
1970	0	0	0
1971	0	0	0
1972	0	0	0
1973	0	0	0

1974	0	0	0
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	0	0	0
1984	0	0	0
1985	0	0	0
1986	1	152	152
1987	0	0	0
1988	1	38	38
1989	0	0	0
1990	0	0	0
1991	1	169	169
1992	2	390	195
1993	0	0	0
1994	0	0	0
1995	2	58	29
1996	4	126	31.5
1997	1	194	194
1998	4	392	98
1999	3	3	1.0
2000	2	155	77.5
2001	4	353	88.25
2002	7	482	68.86
2003	6	376	62.67
2004	6	239	39.83
2005	6	271	45.17
2006	8	319	39.87
2007	8	405	50.62
2008	10	524	52.4
2009	13	348	26.77
2010	11	270	24.54
2011	25	880	35.20
2012	16	435	27.19

2013	7	160	22.86
2014	15	226	15.07
2015	17	205	12.06
2016	22	201	9.14
2017	22	166	7.54
2018	20	92	4.6
2019	17	52	3.06
2020	21	21	1

Table 2 provides a comprehensive overview of the publication trends concerning *B. serrata* from 1969 to 2020. Initially, research activity on *B. serrata* was limited, with only a solitary publication in 1969 and intermittent publications until 1985. However, from 1986 onward, there was a gradual increase in research output. Notably, certain years stood out due to remarkable contributions, such as 1986, when a publication received an impressive 152 citations, and 1988, when another publication garnered 38 citations. From 1991 to 2000, there was modest growth in the number of publications, with one publication in 1991, two in 1992, and a total of 19 publications throughout the decade. The momentum continued from 2001 to 2010, the number of publications rose to 78. It highlights that 2009 marked a noteworthy year with 13 recorded publications.

This data reflects the evolving research landscape on *B. serrata*, indicating a progressive shift from limited activity to a more significant presence in the scientific community. The following sections delve deeper into the specific trends observed within this timeframe.

From 2011 to 2020, the subsequent decade, we witnessed a significant surge in research output, with 182 publications. The year 2011 stood out with 25 publications, attracting 880 citations. However, the average number of citations per publication gradually declined over the years, indicating a broader distribution of citations across the increasing number of publications.

Overall, the research output encompassed various types of publications, including 260 original research articles, 16 reviews, 6 conference papers, and 2 book chapters. 200 different sources contributed to these publications. Among the top productive sources, Planta Medica and Phytomedicine journals emerged as the leading publishers, with 14 and 13 articles, respectively. For a comprehensive list of the most productive sources, please refer to Table 3.

Notably, there needed to be more research activity in the early years, followed by a gradual increase and a significant surge in research output from 2011 onwards. This trend indicates a growing interest and active research engagement in B. serrata over time.

Table 3. The most productive sources of *B serrata* publication from the Scopus database 1969-2020.

Source Titles	Count	Citations	Impact Factor
Planta Medica	14	817	2.687
Phytomedicine	13	805	4.268
Phytotherapy Research	5	135	4.087
European Review for Medical and Pharmacological Sciences	4	46	3.024

PLoS ONE	4	111	2.87
Asian Journal of Chemistry	3	4	-----
Fitoterapia	3	96	2.527
Indian Journal of Biotechnology	3	26	0.413
Indian Journal of Pharmaceutical Sciences	3	101	0.721
International Immunopharmacology	3	180	3.943
Journal of Ethnopharmacology	3	53	3.690
Natural Products Journal	3	1	----

Table 3 presents the most productive sources of *B. serrata* publications from the Scopus database from 1969 to 2020. The table includes the source titles, the count of publications from each source, the corresponding citations received, and the impact factor of the journals (where available). Planta Medica emerges as the top productive source, with 14 publications on *B. serrata*, accumulating 817 citations. This journal has an impact factor of 2.687, indicating its significance in the field. Following closely is Phytomedicine, which published 13 articles and received 805 citations. Phytomedicine boasts a higher impact factor of 4.268, highlighting its influence in the scientific community.

Other notable sources include Phytotherapy Research, with five publications and 135 citations; European Review for Medical and Pharmacological Sciences, with four publications and 46 citations; and PLoS ONE, with four publications and 111 citations. Although the Asian Journal of Chemistry contributed three publications, it did not provide impact factor information. Fitoterapia, Indian Journal of Biotechnology, Indian Journal of Pharmaceutical Sciences, International Immunopharmacology, Journal of Ethnopharmacology, and Natural Products Journal contributed significantly to *B. serrata* research.

The citation count indicates the attention and recognition received by the publications from these sources. Additionally, the impact factor of the journals provides insight into their reputation and influence within the scientific community.

Overall, these productive sources have played a crucial role in disseminating research on *B. serrata*, attracting citations, and contributing to advancing knowledge in this field. Researchers and readers interested in *B. serrata* can refer to these sources to access valuable studies and insights.

A 10-year period overview in *B. serrata* research during 1969-2020 is presented in Table 4.

Table 4. Analyses of the 10-year periods in *B. serrata* publications.

Year range	Year of publication	First Author	Journal	Total Citations	Average citations / Year	Research focus
1961-1970	1969	Kar A.,	Life Sciences	17		Analgesic activity.
1981-1990	1986	Singh G.B.,	Agents and Actions	152		Pharmacology of alcoholic extract of salaiguggal
	1988	Sharma M.L.,	Agents and Actions	38		Effect of alcoholic extract of salaiguggal on immune response

1991-2000	1992	Safayhi H.,	Journal of Pharmacology and Experimental Therapeutics	343	11.83	Inhibition of 5-lipoxygenase by Boswellic acids
	1998	Gupta I.,	European journal of medical research	210	9.13	Anti-asthma activity
	1997	Gupta I.,	European journal of medical research	194	8.08	Mitigative effect against Ulcerative colitis
	1991	Ammon H.P.T.,	Planta Medica	169	5.63	Anti-inflammatory activity
	1998	Shao Y.,	Planta Medica	131	5.69	Anti-leukemia activity
2001-2010	2003	Kimmatkar N.,	Phytomedicine	242	13.44	Anti-arthritis activity
	2001	Gupta I.,	Planta Medica	194	9.70	Mitigative effect against chronic colitis
	2009	Pang X.,	Cancer Research	150	12.5	Anti-tumour activity
	2006	Takada Y.,	Journal of Immunology	149	9.93	Apoptotic activity and Anti-osteoclastogenesis
	2002	Liu J.-J.,	Carcinogenesis	147	7.74	Apoptotic activity
2011-2020	2011	Abdel-Tawab M.,	Clinical Pharmacokinetics	156	7.8	Anti-inflammatory mechanism
	2011	Siddiqui M.Z.	Indian Journal of Pharmaceutical Sciences	99	4.95	Phyto constituents and Anti-inflammatory activity
	2012	Kora A.J.,	Process Biochemistry	74	3.89	Biogenic nanoparticles
	2012	Yadav V.R.,	International Journal of Cancer	69	3.63	Inhibition of Colorectal cancer
	2011	Raja A.F.,	BMC Microbiology	67	3.35	Antibacterial activity

Table 4 presents an analysis of the 10-year periods in *B. serrata* publications, highlighting the year of publication, first author, journal, total citations, average citations per year, and research focus of the most cited documents within each period.

From 1961 to 1970, Kar A. published a study in Life Sciences focusing on the analgesic activity of gum resin, which accumulated 17 citations.

During 1981-1990, Singh G.B. and Sharma M.L. were the first authors with publications in the Agents and Actions journal. Their research delved into the pharmacology of the alcoholic extract of salaiguggal and its effect on immune response, respectively. These studies received 152 and 38 citations, respectively.

From 1991-2000, several significant findings emerged. Safayhi H. published a study in the Journal of Pharmacology and Experimental Therapeutics, demonstrating the inhibition of 5-lipoxygenase by Boswellic acids, which garnered 343 citations. Gupta I. published two influential papers in the European Journal of Medical Research, highlighting the anti-asthma activity and the mitigative effect against ulcerative colitis of Boswellia serrata, with 210 and 194 citations, respectively. Ammon H.P.T. contributed to Planta Medica with a study on the anti-inflammatory activity of Boswellia serrata, receiving 169 citations. Shao Y. also published in Planta Medica, elucidating the anti-leukemia activity of Boswellia serrata, earning 131 citations.

Moving 200-2010, 1 emerged in various areas. Kimmatkar N. published a study in Phytomedicine focusing on the anti-arthritis activity of Boswellia serrata, which received 242 citations. Gupta I. contributed to Planta Medica with t n the mitigative effect against chronic colitis, accumulating 194 citations for side rablesurveyoco-researchan of. Pang X. published in Cancer Research, highlighting the anti-tumor activity of Boswellia serrata, with 150 citations. Takada Y. researched apoptotic activity and anti-osteoclastogenesis, which earned 149 citations and was published in the Journal of Immunology. Liu J.-J. explored the apoptotic activity of Boswellia serrata, resulting in 147 citations and published in Carcinogenesis.

Lastly, from 2011-2020, research focused on different aspects of Boswellia serrata. Abdel-Tawab M. published a study in Clinical Pharmacokinetics, elucidating the anti-inflammatory mechanism, which garnered 156 citations. Siddiqui M.Z. contributed to the Indian Journal of Pharmaceutical Sciences, exploring the phytoconstituents and anti-inflammatory activity, accumulating 99 citations. Kora A.J. researched biogenic nanoparticles in Process Biochemistry, earning 74 citations. Yadav V.R. published in the International Journal of Cancer, highlighting the inhibition of colorectal cancer, with 69 citations. Raja A.F. investigated the antibacterial activity of Boswellia serrata, published in BMC Microbiology, and received 67 citations.

These highly cited documents significantly contribute to understanding *B. serrata* and its various therapeutic properties. The research focus shifted across different periods, covering areas such as analgesic activity, anti-inflammatory effects, immune response, inhibition of enzymes, anti-asthma and anti-tumor activities, apoptotic effects, and antibacterial properties.

Furthermore, the analysis reveals the involvement of multiple authors, with the number ranging from 1 to 16. Notably, Mehta M. and Niphadkar S. emerged as the most frequent top first

Table 5. Frequent first authors and coauthors contributed to the publications during 1969-2020.

Frequent Author	Name	Incidence
First Author	Mehta M	5
	Niphadkar S	5
	Ahmed H.H	4
	Al-Yasiry A.R	4
	Sengupta K	4
	Bhushan S	3
	Divisha R	3
	Gupta I	3
	Jalili C	3
	Kiczorowska B	3
	Riva A	3
	Safayhi H	3
Coauthor	Schubert-Zsilavecz M	12
	Abdel-Tawab M	11
	Ammon H.P	10
	Safayhi H	9
	Taneja S.C	9
	Aggarwal B.B	7
	Badmaev V	7
	Krishnaraju A.V	7
	Kumar A	7
	Samolińska W	7
	Singh J	7
	Büchele B	6
	Sengupta K	6
	Singh S	6
	Sung B	6
	Werz O	6
	Chopra A	5
	Garg M	5
	Golakoti T	5
	Hingirani L	5
	Khajuria A	5
	Qazi G.N	5
	Sadeghnia H.R	5
	Simmet T	5
	Eggenhoffner R	4

	Fricker G	4
	Giacomelli L	4
	Ho C.T	4
	Khan I.A	4
	Kiczorowska B	4
	Rathod V.K	4
	Raychaudhuri S.P	4
	Togni S	4
	Andotra S.S	3
	Belcaro G	3
	Bhakuni R.S	3
	Dodda S	3
	Esfandiari E	3
	Franceschi F	3
	Goel A	3
	Harwalkar J.A	3
	Johri R.K	3
	Lee J.H	3
	Liu Y	3
	Lüdtke R	3
	Malik F	3
	Meins J	3
	Mondhe D.M	3
	Moradi S	3
	Parihar A	3
	Poeckel D	3
	Purohit S.D	3
	Satija S	3
	Saxena A.K	3
	Singh G.B	3
	Singh S.K	3
	Thawani V	3
	Trimurtulu G	3
	Zhang Y	3

50 Best-cited publications on *Boswellia serrata*

Table 5 provides information about the frequent first authors and coauthors who contributed significantly to the *B serrata* publications from 1969 to 2020.

Among the first authors, Mehta M and Niphadkar S were the most frequent, with five publications each. They were followed by Ahmed H.H, Al-Yasiry A.R, Sengupta K, Bhushan S, Divisha R, Gupta I, Jalili C, Kiczorowska B, Riva A, and Safayhi H, who all had three publications each.

Regarding coauthors, Schubert-Zsilavecz M had the highest incidence with 12 publications, followed by Abdel-Tawab M with 11 publications, and Ammon H.P with 10 publications. Other notable coauthors included Safayhi H, Taneja S.C, Aggarwal B.B, Badmaev V, Krishnaraju A.V, Kumar A, Samolińska W, Singh J, Büchele B, Sengupta K, Singh S, Sung B, Werz O, Chopra A, Garg M, Golakoti T, Hingirani L, Khajuria A, Qazi G.N, Sadeghnia H.R, Simmet T, Eggenhoffner R, Fricker G, Giacomelli L, Ho C.T, Khan I.A, Kiczorowska B, Rathod V.K, Raychaudhuri S.P, Togni S, Andotra S.S, Belcaro G, Bhakuni R.S, Dodda S, Esfandiari E, Franceschi F, Goel A, Harwalkar J.A, Johri R.K, Lee J.H, Liu Y, Lüdtke R, Malik F, Meins J, Mondhe D.M, Moradi S, Parihar A, Poeckel D, Purohit S.D, Satija S, Saxena A.K, Singh G.B, Singh S.K, Thawani V, Trimurtulu G, and Zhang Y, each with three to seven publications.

These frequent authors and coauthors have contributed significantly to *B. serrata* research, collaborating on numerous publications and advancing our understanding of the plant's properties and applications.

Additionally, the search on the most extensive database, Scopus, identified 856 articles on Boswellia serrata from 1969 to November 2020. After applying inclusion criteria, 284 documents were selected for analysis, and the 50 best-cited articles were examined using scientometrics. Table 6 provides detailed information about these 50 highly cited articles.

Table 6. 50 Best cited articles on *B. serrata* (1969-2020)

S.No	Article	Journal	Total Citations	Average citations/Year	Research Focus
1	Safayhi H, et al. 1992 [5]	Journal of Pharmacology and Experimental Therapeutics	343	11.83	Anti-inflammatory activity
2	Kimmatkar N, et al. 2003 [6]	Phytomedicine	242	13.44	Anti-arthritic activity
3	Gupta I, et al. 1998 [7]	European journal of medical research	210	9.13	Anti-asthmatic effect
4	Gupta I, et al. 2001 [8]	Planta Medica	194	9.7	Anti-inflammatory activity: Chronic colitis
5	Gupta I, et al. 1997 [9]	European journal of medical research	194	8.08	Anti-inflammatory activity: Ulcerative colitis
6	Ammon HPT, et al. 1991 [10]	Planta Medica	169	5.63	Anti-inflammatory activity

7	Abdel-Tawab M, et al. 2011[11]	Clinical Pharmacokinetics	156	15.6	Mechanism of action
8	Singh G.B and Atal C.K. 1986 [12]	Agents and Actions	152	4.34	Anti-inflammatory activity
9	Pang X, et al. 2009 [13]	Cancer Research	150	12.5	Anti-tumor activity
10	Takada Y, et al.2006 [14]	Journal of Immunology	149	9.93	Anti-osteoclastogenesis
11	Liu J J, et al. 2002[15]	Carcinogenesis	147	7.74	Anti-proliferative and apoptotic activity
12	Shao Y, et al. 1998[16]	Planta Medica	131	5.69	Anti-tumor activity
13	Sengupta K, et al.2008 [17]	Arthritis Research and Therapy	120	9.23	Anti-arthritic activity
14	Gayathri B, et al.2007 [18]	International Immuno pharmacology	118	8.43	Anti-inflammatory activity
15	Singh S, et al. 2008[19]	Phytomedicine	108	8.31	Anti-ulcer activity
16	Ammon HPT.2010 [20]	Phytomedicine	107	9.73	Modulation of the immune system
17	Siddiqui MZ. 2011 [21]	Indian Journal of Pharmaceutical Sciences	99	9.9	Anti-inflammatory activity
18	Bhushan S, et al. 2007 [22]	Apoptosis	97	6.93	Apoptotic activity
19	Hostanska K, et al. 2002 [23]	Anti-cancer Research	96	5.05	Cytotoxic, cytostatic and apoptotic activity
20	Huang M.-T, et al. 2000[24]	BioFactors	91	4.33	Anti-tumor and anti-carcinogenic activity
21	Krieglstein C F, et al. 2001 [26]	International Journal of Colorectal Disease	87	4.35	Anti-inflammatory activity
22	Kiela P R, et al. 2005 [27]	American Journal of Physiology - Gastrointestinal and Liver Physiology	80	5	Colitis

23	Liu J J, et al.2002 [28]	International journal of molecular medicine	76	4	Anti-proliferative and apoptotic activity
24	Kora A.J, et al. 2012 [29]	Process Biochemistry	74	8.22	Biogenic silver nanoparticles
25	Krüger P, et al. 2008 [30]	Drug Metabolism and Disposition	73	5.61	Enhancing efficacy of *Boswelliaserrata*
26	Yadav V R, et al. 2012 [31]	International Journal of Cancer	69	7.67	Inhibition of growth and metastasis in human colorectal cancer
27	Singh S, et al. 2008 [32]	Phytomedicine	69	5.31	Anti-inflammatory effect
28	Madisch A, et al.2007 [33]	International Journal of Colorectal Disease	69	4.93	Treatment of collagenous colitis
29	Sharma S, et al. 2004 [34]	Phytomedicine	68	4	Pharmacokinetics study of 11-Keto β-Boswellic acid
30	Raja A F, et al. 2011 [35]	BMC Microbiology	67	6.7	Anti-bacterial activity
31	Hartmann R M, et al. 2012 [36]	Digestive Diseases and Sciences	66	7.33	Antioxidant activity
32	Ding Y, et al. 2015 [37]	Molecular Neurobiology	64	10.67	Neuroprotection
33	Sterk V, et al. 2004 [38]	Planta Medica	64	3.76	Food intake and bioavailabilty of boswellic acids
34	Safayhi H, et al.2000 [39]	Planta Medica	64	3.05	Anti-inflammatory activity
35	Borrelli F, et al.2006 [40]	British Journal of Pharmacology	63	4.2	Anti-diarrheal activity
36	TakahashI M, et al. 2012 [41]	Carcinogenesis	61	6.78	Anti-tumour effect
37	Ernst E. 2008 [42]	BMJ	60	4.61	Effectiveness of extracts.
38	Hüsch J, et al. 2013 [43]	Fitoterapia	59	7.38	Bioavailability of Casperome™ and corresponding extract
39	Umar S, et al. 2014 [44]	Phytomedicine	58	8.28	Antioxidant and anti-arthritic activity

40	Roy S, et al. 2005 [45]	DNA and Cell Biology	58	3.62	Genetic basis of the anti-inflammatory activity
41	Kirste S, et al. 2011 [46]	Cancer	55	5.5	Reduction of cerebral edema
42	Yong S.P, et al. 2002 [47]	Planta Medica	55	2.89	Cytotoxic activity of acetyl-11-keto-β-boswellic acid
43	Tausch L, et al. 2009 [48]	Journal of Immunology	54	4.5	Cathepsin G target of boswellic acids
44	Sharma M L, et al. 1996 [49]	Phytotherapy Research	54	2.16	Immunomodulatory activity
45	Park B, et al. 2011 [50]	PLoS ONE	53	5.3	Inhibition of growth and metastasis in human pancreatic tumours
46	Pandey R.S, et al. 2005 [51]	Indian Journal of Experimental Biology	53	3.31	Inhibition of LPS induced NO production
47	Holtmeier W, et al. 2011 [52]	Inflammatory Bowel Diseases	52	5.2	Crohn's disease
48	Reising K, et al.2005 [53]	Analytical Chemistry	52	3.25	Determination of Boswellic acids in brain and plasma
49	Agrawal S S, et al. 2011 [54]	Food and Chemical Toxicology	50	5	Anti-tumour activity
50	Sengupta K, et al. 2010 [55]	International Journal of Medical Sciences	50	4.54	Anti-arthritis

Table 6 lists the 50 best-cited articles on *B. serrata* from 1969 to 2020. These articles were selected based on their total citation count, annual average citations, and research focus. The range of citations for these articles varied from 50 to 343, with an average of 99 citations per paper.

The research focus of these articles covered various aspects of *B. serrata*, including its anti-inflammatory activity, anti-arthritic activity, anti-asthmatic effect, anti-tumor and anti-carcinogenic activity, anti-osteoclastogenesis, anti-proliferative and apoptotic activity, anti-ulcer activity, immunomodulatory activity, cytotoxic and cytostatic activity, antibacterial activity, antioxidant activity, anti-diarrheal activity, anti-tumor effect, neuroprotection, pharmacokinetics, biogenic antibacterial nanoparticles, metabolism, the bioavailability of standardized extracts, the genetic basis of anti-inflammatory activity, the cytotoxic activity of bioactive components, and the inhibition of growth and metastasis in colorectal and pancreatic tumors.

The most highly cited paper (343 citations) by Safayhi et al., published in the Journal of Pharmacology and Experimental Therapeutics in 1992, discussed the 5-lipoxygenase inhibitors found in boswellic acids. The second most highly cited paper (242 citations) by Kimmatkar et al., published in Phytomedicine in 2003, demonstrated the

anti-arthritic activity of B. serrata extract on knee osteoarthritis patients, showing significant improvement in knee joint swelling, pain reduction, increased knee flexion, and walking distance.

The third most highly cited publication (210 citations) by Gupta et al., published in the European Journal of Medical Research in 1998, presented a clinical study on 40 bronchial asthma patients. The study showed that B. serrata gum extract, when administered at a dosage of 300 mg thrice daily, resulted in significant improvement in asthma symptoms and signs.

The selected articles were published in reputable journals, with Phytomedicine and Planta Medica having the highest number of articles (6 each) and total citations of 652 and 677, respectively. Other journals had one or two articles among the top 50.

Additionally, the interpretation mentioned that citations reflect the usage and influence of published articles, indicating the impact of academic research. Furthermore, Table 7 was introduced to showcase the top 10 articles based on their average citation per year.

Table 7. Top 10 best articles with best average citations per year

Rank	Articles	Average no of citations per year
1	Abdel-Tawab M, et al. 2011	15.6
2	Kimmatkar N, et al. 2003	13.44
3	Pang X, et al. 2009	12.5
4	Safayhi H, et al. 1992	11.83
5	Ding Y, et al. 2015	10.67
6	Takada Y, et al. 2006	9.93
7	Siddiqui M.Z. 2011	9.9
8	Ammon H.P.T. 2010	9.73
9	Gupta I, et al. 2001	9.7
10	Sengupta K, et al. 2008	9.23

Ranking first is the article by Abdel-Tawab M et al., published in 2011, with an average of 15.6 citations per year. This study has been highly influential in its respective field. The second-ranked article is by Kimmatkar N et al. (2003), with an average of 13.44 citations per year, focusing on the anti-arthritic activity of B. serrata extract in knee osteoarthritis patients.

Pang X et al.'s article (2009) secured the third position, receiving an average of 12.5 citations annually. Their study explored the anti-tumor activity of B. serrata. Safayhi H et al.'s publication from 1992, ranking fourth, has an average of 11.83 citations per year. This influential work investigated the inhibition of 5-lipoxygenase by boswellic acids.

Ding Y et al. (2015) secured the fifth position with an average of 10.67 citations annually. Their research focused on neuroprotection. Takada Y et al. (2006) ranked sixth with an average of 9.93 citations per year, studying the anti-

osteoclastogenesis properties of B. serrata. Siddiqui M.Z.'s article from 2011 is ranked seventh, receiving an average of 9.9 citations per year, and explores the anti-inflammatory activity of B. serrata.

Ammon H.P.T.'s article from 2010 holds the eighth position, with an average of 9.73 citations per year. Their study examined the modulation of the immune system. Gupta I et al.'s publication from 2001 ranks ninth, receiving an average of 9.7 citations per year, and focuses on the anti-inflammatory activity of B. serrata in chronic colitis. Sengupta K et al.'s article from 2008 secures the tenth position, with an average of 9.23 citations per year, exploring the anti-arthritic activity of B. serrata.

The distribution of the best-cited articles indicates that a significant number of them were published between 2001 and 2010 (27 articles), followed by 2011 to 2020 (14 articles), 1991 to 2000 (8 articles), and 1981 to 1990 (1 article), as depicted in Figure 1.

Figure 1 illustrates the distribution of the best-cited articles across different periods.

The impact factors of the journals in which the 50 best-cited articles were published range from 0.721 to 9.727, as presented in Table 8. This information demonstrates the prestige and influence of the journals in which these influential articles.

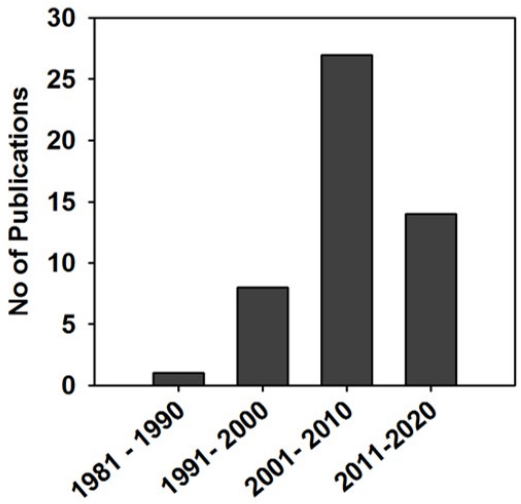

Figure 1. The best-cited articles distributed across different time periods.

The impact factor varied between 0.721-9.727, as presented in Table 8.

Table 8. The Journals information and the Impact factor of the 50 best-cited articles

Journal	Impact factor
Journal of Pharmacology and Experimental Therapeutics	3.65
Phytomedicine	4.268
European Journal of Medical research	1.826#
Planta Medica	2.687
Clinical Pharmacokinetics	4.604
Agents and Actions	3.174

Cancer Research	9.727
Journal of Immunology	4.886#
Carcinogenesis	4.603
Arthritis Research and Therapy	4.103#
International Immunopharmacology	3.943
Indian Journal of Pharmaceutical Sciences	0.721
Apoptosis	4.543
Anti-cancer Research	1.994
BioFactors	4.734
International Journal of Colorectal Disease	2.108
American Journal of Physiology - Gastrointestinal and Liver Physiology	3.76
International Journal of Molecular medicine	3.098
Process Biochemistry	2.952
Drug Metabolism and Disposition	3.4
International Journal of Cancer	5.145
BMC Microbiology	2.989#
Digestive Diseases and Sciences	2.751
Molecular Neurobiology	4.5
British Journal of Pharmacology	7.73
BMJ	5.48
Fitoterapia	2.527
DNA and Cell Biology	3.314
Cancer	5.742
Phytotherapy Research	4.087
PLoS ONE	2.87
Indian Journal of Experimental Biology	0.783
Inflammatory Bowel Diseases	4.261
Analytical Chemistry	6.785
Food and Chemical Toxicology	4.679
International Journal of Medical Sciences	2.523

2 Year Impact Factor

24 percent of best-cited articles were published in Phytomedicine and Planta Medica. The journal Phytomedicine (Impact factor: 4.268) is a therapy-oriented journal with 10734 total documents published and with citations of 249190 (2006-2020); Planta Medica (Impact factor: 2.687) is a medicinal plant and natural product research-oriented journal with 4759 total documents published and with citations of 121105 (2006-2020).

A total of 47 articles are contributed by multiple authors and 03 articles by a single author. The number of authors varied between 01-16 and the average number of authors was 6. The most frequent first author was Gupta I. Table 9 presents the most frequent first author and coauthors having more than two publications of the 50 best-cited articles.

Table 9. Frequent authors and coauthors are contributing to the 50 best-cited articles.

Frequent Author	Name	Incidence
First Author	Gupta I.,	03
Frequent Coauthor	Safayhi H.	06
	Badmaev V.,	05
	Schubert-Zsilavecz M.,	04
	Sung B.,	04
	Taneja S.C.,	04
	Khajuria A.,	03
	Lüdtke R.,	03
	Parihar A.,	03
	Qazi G.N.,	03
	Singh G.B.,	03
	Singh J.,	03

Safayhi H. has authored 08 publications, and the author is the top of the 50 best-cited publications. Many authors have contributed to the research of *B. serrata* as first author, coauthor, and corresponding author. These 50 best-cited articles originated from 09 countries and their contributions are Germany (n=17), India (n=15), United States (n=11), Sweden (n=2), Brazil (n=1), China (n=1), Italy (n=1), Switzerland (n=1) and United Kingdom (n=1) are shown in the Figure 2.

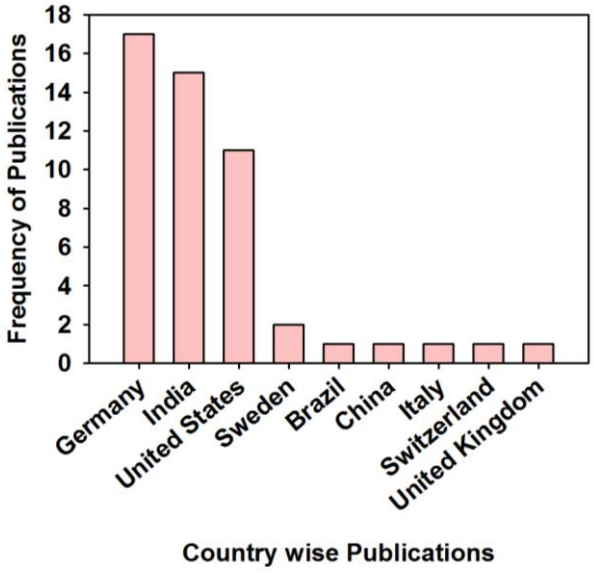

Figure 2. The countries of origin of the corresponding authors of the 50 best-cited articles.

There is a greater interest in medicinal research in countries like Germany and India, reflected by their articles' contributions. Germany contributed 17 articles with the average citation per year (117.76) and India, with 15 articles having an average citation per year (90.6). The majority of the articles were original research, and a very few were review articles. The research of these best-cited documents plays a vital role for future research. The h-index varied from 7-160; Aggarwal B B has the highest h-Index of 160. The affiliation details and h-index of the corresponding authors of the 50 best-cited articles are represented in Table 10.

Table 10. The affiliation details of the corresponding authors and their h-Index

Corresponding Author	Affiliation	h-Index
Abdel-Tawab, M.	Central Laboratory of German Pharmacists, Carl-Mannich-Str. 20, D-65760 Eschborn, Germany	14
Aggarwal, B. B.	Cytokine Research Laboratory, Department of Experimental Therapeutics, University of Texas M. D. Anderson Cancer Center, 1515 Holcombe Boulevard, Houston, TX 77030, United States	160
Agrawal, S.S.	Genome Research Laboratory, Delhi Institute of Pharmaceutical Sciences and Research, PushpVihar Sec-3, M B Road, New Delhi 110017, India	13
Ammon, H.P.T	Department of Pharmacy, Institute of Pharmaceutical Sciences, University of Tübingen, Auf der Morgenstelle 8, 72076 Tübingen, Germany	39
Borrelli, F.	Department of Experimental Pharmacology, University of Naples Federico II, Via D. Montesano 49, 80131 Naples, Italy	48
Duan, R.-D.	Cell Biology B, Biomedical Center, Lund University, Lund, Sweden	36
Ernst, E.	Complementary Medicine, Peninsula Medical School, Universities of Exeter and Plymouth, Exeter EX2 4NT, United Kingdom	105
Goel, A.	GI Cancer Research Laboratory, Baylor University Medical Center, 3500 Gaston Avenue, 250 Hoblitzelle, Dallas, TX 75246, United States	68
Golubic, M.	Cleveland Clinic Foundation, Department of Neurosurgery, 9500 Euclid Avenue/ND4-52A, Cleveland, OH 44195, United States	18
Ho, C.-T.	Department of Food Science, Cook College, State University of New Jersey, New Brunswick, NJ 08903, United States	90
Holtmeier, W.;	Department of Gastroenterology Diabetes and Internal Medicine, Hospital Porz Am Rhein, 51149 Köln-Porz, Germany	23
Hostanska, K.	Department of Internal Medicine, University Hospital Zürich, Rämistrasse 100, 8091 Zürich, Switzerland	21
Huang, M.-T.	Laboratory for Cancer Research, College of Pharmacy, Rutgers, State University of New Jersey, Piscataway, NJ 08854-8020, United States	57
Khan, H.A.	Department of Medical Elementology and Toxicology, JamiaHamdard (Hamdard University), New Delhi 110062, India	18
Kiela, P.R.	Dept. of Pediatrics, Children's Research Center, Univ. of Arizona, 1501 N. Campbell Ave., Tucson, AZ 85724, United States	31
Krieglstein, C.F.	Department of General Surgery, Westfalian Wilhelm's University, Waldeyerstrasse 1, 48149 Münster, Germany	25
Lakshmi, B.S.	Centre for Biotechnology, Anna University, Chennai, India	23
Li, Y.W.	Department of Pharmacy, Xijing Hospital, Fourth Military Medical University, China	16
Liu, J.J.	Biomedical Center, Lund University, Lund, S-22184, Sweden	85

Liu, M.	Institute of Biosciences and Technology, Department of Molecular and Cellular Medicine, Texas A and M University Health Science Center, Houston, TX, United States	55
Madisch, A.	Medical Department I, Technical University Hospital, Fetscherstrasse 74, 01307 Dresden, Germany	26
Marroni, N.P.	Programa de Pós-GraduaçãoemMedicina: CiênciasMédicas, Universidade Federal Do Rio Grande Do sul, Rua José KananAranha no 102, Porto Alegre, Rio Grande do Sul CEP.: 91760-470, Brazil	15
Momm, F.	Department of Radiation Oncology, University Hospital Freiburg, Robert-Koch-Str. 3, 79106 Freiburg, Germany	16
Raychaudhuri, S. P.	Department of Medicine, Division of Rheumatology, Allergy and Immunology, School of Medicine, Hospital Way, Mather, CA 95655, United States/ Laila Impex R and D Center, JawaharAutonagar, Vijayawada, 520 007, India	38
Safayhi, H.	Institute of Pharmaceutical Sciences, Department of Pharmacology, Auf der Morgenstelle 8, 72076 Tubingen, Germany	27
Sashidhar, R.B.	Department of Biochemistry, University College of Science, Osmania University, Hyderabad 500007, India	28
Sen, C.K.	513 Davis Heart and Lung Res. Inst., Ohio State University Medical Center, 473 W. 12th Avenue, Columbus, OH 43210, United States	76
Sharma, M.L.	Department of Pharmacology, Regional Research Laboratory, Canal Road, Jammu-Tawi 180 001, India	17
Shawl, A. S.	Microbiology Unit, Indian Institute of Integrative Medicine (CSIR), Sanatnagar, Srinagar, 190005, India	23
Siddiqui, M.Z.	Processing and Product Development Division, Indian Institute of Natural Resins and Gums, Namkum, Ranchi-834 010, India	7
Simmet, T.	Dept. Pharmacol. Nat. Prod. Clin. P., University of Ulm, Helmholtzstr. 20, 89081 Ulm, Germany	50
Singh, G.B.	Pharmacology Department Regional Research Laboratory, Jammu-Tawi, 180 001, India	10
Singh, J.	Division of Pharmacology, Indian Institute of Integrative Medicine, Canal Road, Jammu 180001, India	33
Singh, S.	Department of Pharmacology, Indian Institute of Integrative Medicine (CSIR), Canal Road Jammu Tawi, J and K 180001, India	11
Thawani, V.	Department of Pharmacology, Government Medical College, Nagpur, India, 14-A, JeevanJyoti, Clarke Town, Nagpur 440 004, India	8
Tripathi, Y.B.	Department of Medicinal Chemistry, Institute of Medical Sciences, Banaras Hindu University, Varanasi 221005, India	28
Werz, O.	Department of Pharmaceutical Analytics, Pharmaceutical Institute, Eberhard-Karls-University Tuebingen, Auf der Morgenstelle 8, 72076 Tuebingen, Germany	53

CONCLUSION

This study conducted a scientometric assessment to analyze the research output on *Boswellia serrata* from 1969 to 2020. The assessment revealed that the Boswellia serrata research is ongoing and published in elite journals. The current research on *Boswellia serrata* is mainly focused on its pharmacological potential. However, there is a need for sustainable gum resin production, highlighting the importance of conservation and improved production methods. Additionally, the research on nanoparticles in *Boswellia serrata* is at an early stage, and further research is required to explore its potential applications.

The study also revealed that in silico research, which predicts the therapeutic activities of *Boswellia serrata* against different pathologies, is limited. Therefore, there is a need for in silico studies on the active constituents of *Boswellia serrata* and their potential therapeutic uses, along with experimental studies. Overall, this study sheds light on the research activities on *Boswellia serrata* and provides direction for future research. The findings of this study help funding agencies prioritize their funding and aid in developing better-quality research in this area. The research on *Boswellia serrata* is crucial for improving the quality of life, and further research is needed to achieve significant results. Therefore, this study is a foundational step toward advancing the understanding of *Boswellia serrata* and its potential benefits.

Declaration - All authors declare that there is no conflict of interest.

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