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Editorial

A Deeper Insight into Research on Piper betel Essential Oil from 1991-2021: A Critical Bibliometric Analysis based Appraisal

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Abstract:

The objective of this study is to conduct a bibliometric analysis, examine research verticals, and establish a conceptual framework for Piper Betel essential oil. Data was retrieved from SCOPUS database (1991-2021) using the following search terms (keywords): "betle" OR "Piper betle." The data visualisation tools employed in this study included Microsoft Excel 2019, VOS viewer, and Cite Space. The data acquired from Scopus (n=844) was sorted strategically (n=75) and examined using the data analysis programme VOS viewer 1.6.15. This article is expected to ease out the decision-making process for researchers interested in PBEO research.

Key Words: piper betle; essential oil; bibliometric analysis; scopus; vos viewer

Introduction

Essential oils (EO), sometimes referred to as volatile oils are complex combinations of molecules with a low molecular weight that are extracted from aromatic plants by steam distillation (Cassel et al., 2009; Singh Chouhan et al., 2019). Recent years have seen a significant increase in the usage of EO in the pharmaceutical, food & beverage, furniture, flavour& fragrance, and agricultural industries. For the treatment of several illnesses, EO has been eloquently described in Ayurveda and Traditional Chinese Medicine (Bajpai et al., 2010; Das, Parida, Sriram Sandeep, et al., 2016; Jane et al., 2014; Sudjaroen, 2012). The main chemical components that give EOs their distinctive aroma and biological capabilities are terpenoids (monoterpenes, sesquiterpenes, and oxygenated derivatives comprise the greatest category of chemical entities in EOs) and phenylpropanoids (Sendra, 2016). Aromatherapy is recognized as the contemporary form of traditional EO treatment (Meena et al., 2021). EOs are often given as traditional medicine all throughout the globe (Sudjaroen, 2012). According to one of the published statistics, 40,000-60,000 tonnes of EO production per year with an estimated market worth of USD 700 million clearly suggests that EO production and use are expanding globally (Singh Chouhan et al., 2019). In the present situation, however, the essential oil is identified immediately by the name of the parent material, such as betel leaf oil (Chowdhury & Baruah, 2020; Fazal et al., 2014; Karak et al., 2018). Betel leaf (*Piper betel*) is a perennial traditional medicinal plant native to Malaysia that belongs to the Piperaceae family (Madhumita et al., 2019). Over 700 *Piper betel* species have been identified in both the Northern and Southern hemispheres of the planet, and they are extensively produced in most nations, including India, Sri Lanka, Malaysia, Indonesia, the Philippines, and other Southeast Asian and East African countries (Das, Parida, Sriram Sandeep, et al., 2016). This plant is often known as 'Paan' and is extensively farmed and eaten across India. It is an evergreen aquatic root-climbing vine with dorsiventral heart-shaped leaves that a great number of Asians consume on a daily basis. Annually, the crop generates around INR 6000-7000 million for the national

economy, with leaves worth INR 30-40 million exported to foreign nations. Researchers have also performed extensive investigations on different aspects of betel vine, either substantiating different folklore claims, essential oil profiling, and many more (Taukoorah et al., 2016). In the past 30 years, 25 review articles have been published on *Piper betel* majorly highlighting its different biological activities, traditional uses, volatile principles, cultivation practices, and biotechnological interventions. With probably all corners covered, and the existing panoramic literature available makes it almost impossible to find a reason for writing another review article and still being not repetitive. Henceforth, it was thought worthwhile to revisit the literature available to generate a comprehensive overview along with critical analysis and carry out a bibliographic information-driven systematic literature review. The literature on *Piper betel* essential oil (PBEO) is growing at an exponential rate highlighting the necessity to convey fresh insights and research directions in light of the most recent advancements. The following objectives shall be addressed for creating a wider spectrum of understanding, "Who are the prominent authors?" "What is the current publishing trend?", "What are the most important journals?", "Which nations and institutions contribute the most?". Furthermore, what are the major domains that can be inferred upon from which the existing PBEO literature can be categorized, and how can a basic framework to grasp the notion of PBEO be drawn? As a result, the goal of this work is to evaluate the existing literature on PBEO and give ideas for understanding the current occurrence as well as future research approaches. From1991 until September 2021, the data was obtained from the Scopus database. The current article examines 273 publications collected objectively from the Scopus database in order to offer metadata analysis. Emphasis was laid on the participation and collaboration among authors, countries, and journals. This study is expected to deliver a better understanding and prediction of future strategies and the continuous need for interdisciplinary networking and collaborations among researchers.

This article contains descriptive bibliometric based visual representations about important authors, popular journals, institutions, topic areas, influential articles, and the nations that contributed papers on the PBEO literature. In addition, the study provides several findings that might offer an essential route for future cutting-edge research by bringing in more clarity of thoughts among the researchers. The article captures a bird's eye view by visualizing the literature from diverse perspectives and proposes a fresh, straightforward, and simple-to-understand conceptual framework of PBEO with future possibilities.

Material and Methods:

Bibliometrics is the study of how publications and research in a certain area of study are changing over time. It is a quantitative study where author collaboration networks, scientific outputs, their contributions, the effects of researchers' work, institutional collaborations, and national contributions to research are illustratively studied and have been rightly done in this particular review (George et al., 2021). The SCOPUS database was utilized to compile a comprehensive and extensive collection of documents on PBEO, ensuring the inclusion of all relevant data released throughout the years. SCOPUS provides comprehensive publication data with navigation ease and is a widely accepted and frequently used citation-based database for the analysis of scientific publications. The authors have vividly explained the advantages of using SCOPUS for data mining in one of their previously published review article (Kala et al., 2016). Briefly, Scopus provides different searching and browsing options during the data mining and there are different searchable fields which makes the navigation work very easy permitting the user to easily narrow down their searching. The results can even be refined to quickly limit or exclude results by author, source, year, subject area, document type, institutions, countries, funding agencies, and languages. Results are allowed to be printed, e-mailed, or exported to a citation manager. The results may also be reorganized according to the needs of the researcher by simply clicking on the headings of each column. Scopus also allows analysing the results graphically by drawing histograms or charts. All these features improve the personal experience of the researcher through a smoothened navigation procedure. Considering the various advantages and ease of navigation coupled

with accuracy in data mining through the application of user-friendly filters, the authors have performed data mining from SCOPUS for the purpose of writing this critical analysis-based review article.

Data sources

Data mining and extraction was primarily carried out using SCOPUS database. Data retrieval from SCOPUS database took place on September 2, 2022, using the following search terms (keywords): "betle" OR "Piper betle." Studies published between 1991 and 2021 were included. Post-data extraction, the papers were chosen and critically analyzed through a three-stage data filtration and capturing process as mentioned below.

Literature screening criteria

Inclusion criteria

The following eligibility criteria were fixed for article inclusion, (i) Must include involvement of research on PBEO; (ii) Must involve some phytochemical (inclusive of extraction method) or chemical profiling or biological activity studies associated with PBEO; (iii) Records (articles and reviews) available only in English were considered.

Exclusion criteria

The following criteria were fixed for article exclusion. (i) Papers published in language other than English; (ii) Book, book chapters, conference proceedings, editorials were not included; (iii) Papers having no relevance with PBEO.

Data mining & extraction

Stage 1

The first step was the usage of keywords "betle" OR "Piper betle" to generate the master data pool regarding all published works regarding *Piper betle* (n=843). From this master data on *Piper betle* research, articles connected with PBEO research were searched using the option "search within results" using the keyword "essential oil" which resulted in 273 records.

Stage 2

From these 273 records, only articles and reviews published in English were considered. Among the 273 papers that were obtained, the authors in a group of two read the title and abstract for further fine-tuning of the data. During this procedure of screening, records that were not found relevant to research on PBEO were excluded (n=198). A separate team reviewed the discrepant results by reading the full text of the papers, and those who were still not found eligible were excluded (Figure 2).

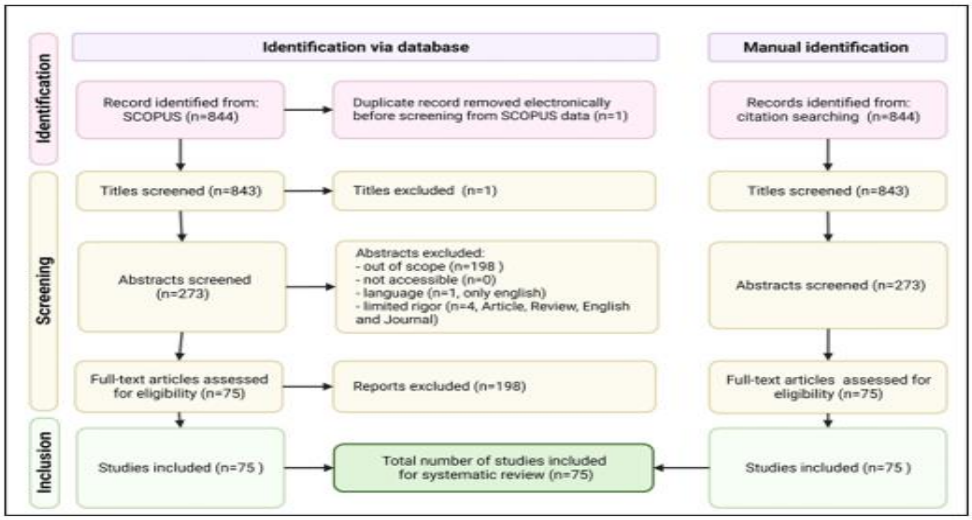


Figure 2: Prisma flowchart depicting the data mining, extraction and sorting method used in this study

Stage 3

A total of 75 records (articles and reviews) were found eligible as per the criteria fixed. This sorted data was then taken up for bibliometric based systematic literature review using the latest VOS viewer 1.6.15 software (Leiden, Netherlands) and critical analysis. The purpose of the systemic literature review was to organize and present a bird's-eye view of PBEO literature published over the tenure of 1991-2021. Another objective of the study was to provide a research mapping for better future research navigation on PBEO and create an ease in decision-making for researchers interested in PBEO research. The following issues were understood closely in light of the critical findings from the published data, (a) "Which authors have mostly investigated *Piper betle* essential oil?" (b) "Where does the bulk of research take place" (c) "Most important *Piper betle* essential oil research area clusters?" (d) "Major thrust areas in *Piper betle* essential oil research" (e) "Current active researchers and collaboration network" (f) "Most often used keywords?".

Data Analysis

The VOS viewer software version 1.6.15 (2020), Leiden, Netherlands, and Microsoft Excel 2019 & Cite space were used to analyse the relevant documents (articles, and reviews) on PBEO research extracted via the Scopus database. VOS viewer specifically was used as the bibliometric analysis software to draw a scientific knowledge map, into which the format files obtained previously were imported to perform various analyses and the results were displayed as overlay/network visualization. The workflow of the research is depicted in Figure 1.

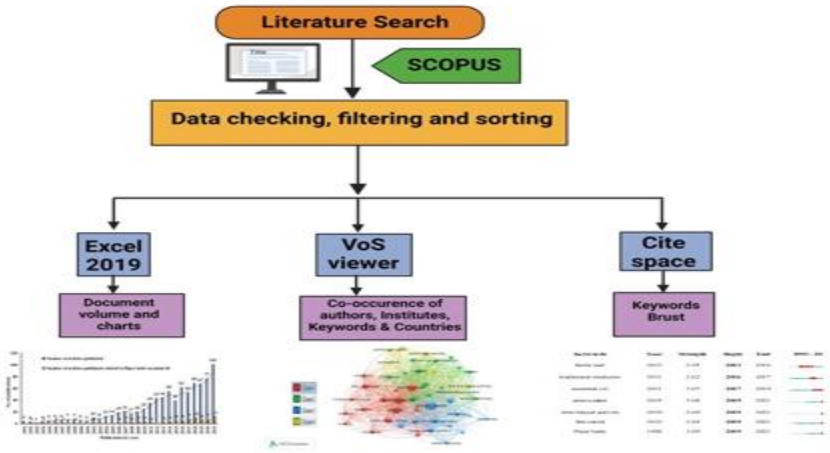


Figure 1: Illustrative representation of workflow of the research

Results and Discussion:

Global Publication trend and relevancy factor

Figure 3. shows the correlation of publication by year between data on *Piper betle* (n=843, unsorted data) and that of actual sorted data (n=75) which has relevance with PBEO research. Data is indicative of the fact that only 8.5% of the total publications (inclusive of only research articles) on *Piper betle* have some relevance with PBEO research taking the relevance factor to 8.5 publications dedicated to PBEO research for per 100 publications on *Piper betle*. This is not at all a bad relevancy because research on EO has very limited verticals. Since EO is mostly used for topical purposes, the biological activities that are commonly investigated are limited to antimicrobial, antioxidant, anti-rheumatic, and anti-inflammatory likely to be intended for use on the skin (Agarwal et al., 2012; Aumeeruddy-Elalfi et al., 2015; Basak & Guha, 2015; Prakash et al., 2010). Other EO research verticals are gas chromatography profiling of volatile principles and chemical profiling-based comparison of different varieties or differences based on geographical occurrences (Khalil et al., 2017). The emergence of publications on PBEO

started in 2011, followed by a steady growth rate. Moreover, the trend line also indicates an increasing pattern, which implies that the literature on PBEO is still growing. The correlation between data extracted on *Piper betle* (unsorted data) and sorted data (data relevant to PBEO research) is also very interesting as the PEARSON coefficient of 0.8 indicates a positive correlation between them. This indicates that whenever there is an increase in research on *Piper betle*, there has been a simultaneous increase in research on PBEO as well. The last 5 years have proved to be very productive both for research on *Piper betle* and PBEO research. Critical analysis of global research trends reflects that 43.5% of the research on *Piper betle* was conducted in the last 5 years itself. The prospect is even far better in PBEO research as 56% of the research has taken place in the last 5 years indicating a late research surge among the researchers which can be mainly attributed to potential cross-field application of *Piper betle* EO and innovations in hyphenated chromatographic techniques. The citation track record is also in tandem with the global publication trend. The total citation counts for all unsorted data (n=843) extracted for the said 30-year period on *Piper betle* research was 7696 whereas, the citation count of the actual qualified record (sorted data, n=75) was found to be 6909. From the above observation, it can be opined about the citation relevancy factor, indicating that for every 100 citations on *Piper betle* research, at least 88 citations belong to PBEO thrust area.

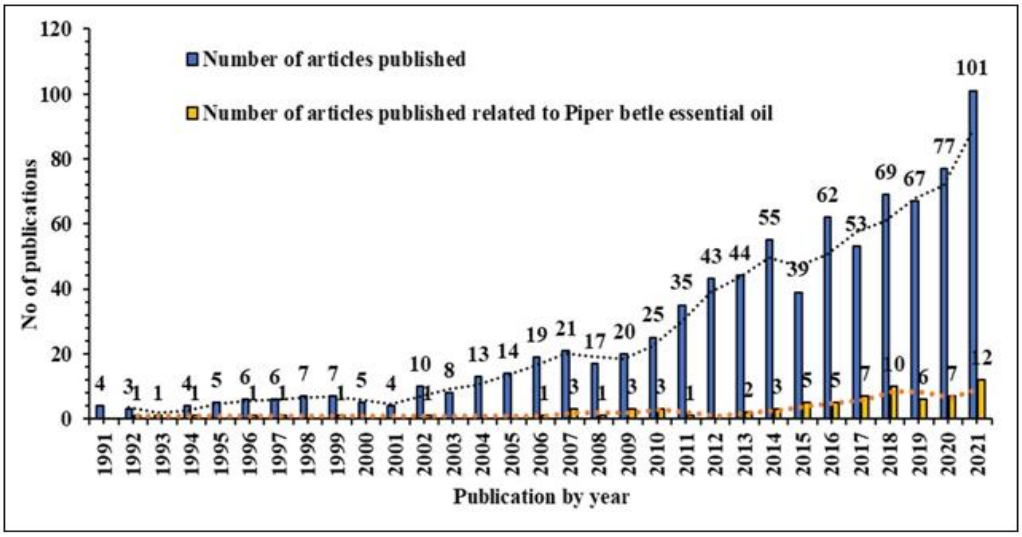


Figure 3: Graphical representation of the correlation of publication by year between

Bibliometric analysis:

The following section presents the bibliometric-based report along with a critical analysis of the sorted data (n=75), and deep insights have been presented based on the content analysis of the sorted records. In the current study, a time frame of 30 years (1991-2021) was selected based on data mining and extraction from SCOPUS database as explained

in the previous section. This section presents the descriptive statistics based on the metadata of 75 papers. In metadata analysis, one paper is counted multiple times even if the paper has multiple authors. For example, if a paper is co-authored by Dr. P. Guha and S. Basak, both earn one publication credit. Similarly, both of their countries and institutes earn one publication credit as well. In some cases, this study does not present the statistics in full list, but rather in a summarized format to increase readability.

Most common words used in the title

Knowledge of using appropriate keywords is vital in conducting data mining and data extraction through scientific databases (such as SCOPUS, WoS, Dimension) which allows navigation through use of keywords. Use of the right keywords shall return appropriate and most relevant search results. At the same time proper usage of keywords shall increase the visibility of the publication which also has a direct bearing on its citation as well. The importance of keywords is reflected in this current work by making an attempt to understand the pattern of keywords being used in PBEO research. A total of 1072 keywords were identified (in the last 30 years) which had been used in publications associated with PBEO research and presented in a network visualization pattern using VOS viewer (Figure 4). Out of these only 48 could meet the threshold value of minimum 5 occurrences (Table 1) and was found to be spread across 4 clusters. The keywords (*Piper betle*, essential oil and eugenol) with link strength above 150 were obvious in nature. Eugenol being the primary volatile constituent responsible for determining the quality of the essential oil has been of prime importance in all research related to PBEO. Whatever may be the objective of the research any work on PBEO must quantitatively determine the eugenol content which is a direct indicator for PBEO quality. Noteworthy, to mention that identification of judicially selected keywords and appropriate usage of words in the title is very important for article citation. The closer are used words with the research theme, the more likely they are going to be captured when searched through any citation-based database like SCOPUS. Based on the findings of keyword analysis, it was revealed that researchers need to pay special attention on the volatile principles present in different varieties and the biological potency of PBEO as well. Explanation of the former has been taken care of in the subsequent sections whereas; in this particular section vital research leads regarding biological potency are presented as consolidated information,

Key words	Total link strength
Piper betle	374
essential oil	322
Eugenol	154
Oils, volatile	147
gas chromatography	120
minimum inhibitory concentration	103
anti-microbial activity	81
anti-fungal activity	77
extraction	63
betel leaf	44

Table 1: Top 10 keywords with minimum 5 publications as threshold value

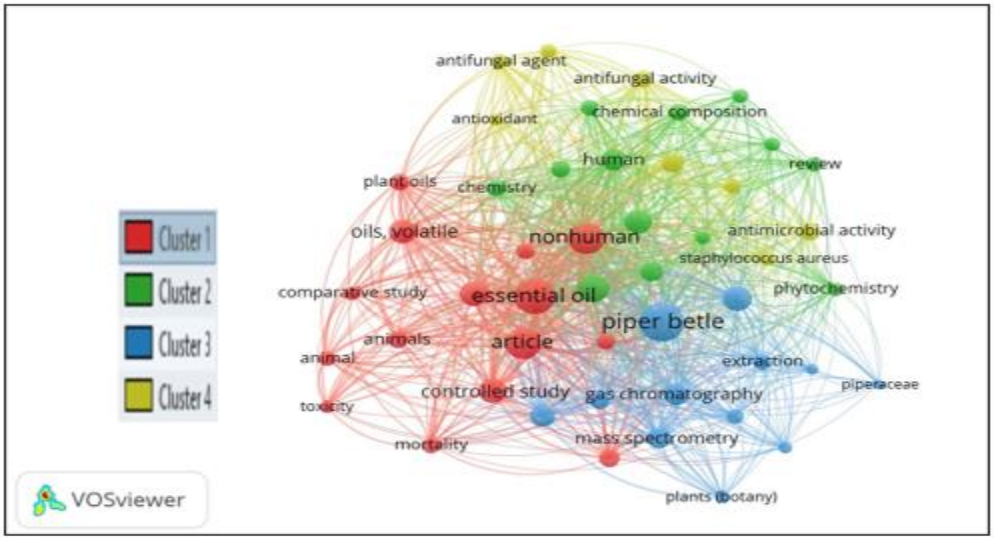


Figure 4: Network visualization of author's keyword with a minimum of 5 co-occurrences

- Vietnamese piper betle essential oil was found to be effective in the treatment of Malassezia-associated illnesses due to the presence of predominant constituents namely, eugenol acetate (38.66%) and m-eugenol (30.28%)(Thanh et al., 1997).
- The Thailand *Piper betle* variety essential oil was reported to kill acaroids, because of the presence of phenylpropanoids and aromatic compounds, including up to 40% eugenol, carvacrol, and chavicol (Chaimanee et al., 2021).
- Research by Subaharan et al. (2021) says that the essential oil from *Piper betle* L. has several important parts, such as safrole, eugenol, β-caryophyllene, β-selinene, α-selinene, and eugenol acetate. According to the results, one of the parts, eugenol, was 4.5 times more effective at killing adult houseflies (Musca domestica) and was also more toxic to them as a fumigant (LC50 88.38 mg/dm3) (Subaharan et al., 2021).
- According to the findings of Prakash et al. (2010), the essential oil extracted from betel leaf (Magahi variety) mostly consists of eugenol (63.39%) and acetyl-eugenol (14.05%). These two components have been identified as the key contributors to the antifungal properties (0.7µl/ml minimum inhibitory concentration against *A. Flavus*) (Prakash et al., 2010).
- Antimicrobial activity of cured leaf essential oil at a concentration of 0.5 mL was found considerably greater against *M. smegmatis* (multidrug-resistant strain) when compared to fresh leaf EO at a concentration of 1 ml. This difference in antimicrobial activity can be attributed to the higher presence of linalool in cured PBEO, which has been identified as a potent antibacterial agent (Madhumita et al., 2019).
- *Piper betle* essential oil has also been investigated as a potential treatment for the arthropod-transmitted disease *Aedes aegypti*. The findings of the study indicate that the adulticide activity of PBEO was shown to be highly efficient at a concentration of 2.5 µl/ml, resulting in complete mortality within a time frame of 15–30 minutes (Hao et al., 2018).
- *Piper betle* essential oil was also found effective in killing storage insect pests like S. zeamai, C. maculatus, and R. donicia (Martianasari & Hamid, 2019).
- Indian varieties like 'Bangla, Bagerhati, Manikdanga, Meetha, Kalibangla, and Ghanagete' exhibited significant acetylcholinesterase activity primarily due to the presence of eugenol (Karak et al., 2018).

Publications by journals and relevance factor:

Data indicates that journal LWT and Industrial crops and products published the highest number of articles (4), which is around 5.33% of the total 75 papers (Figure 5).

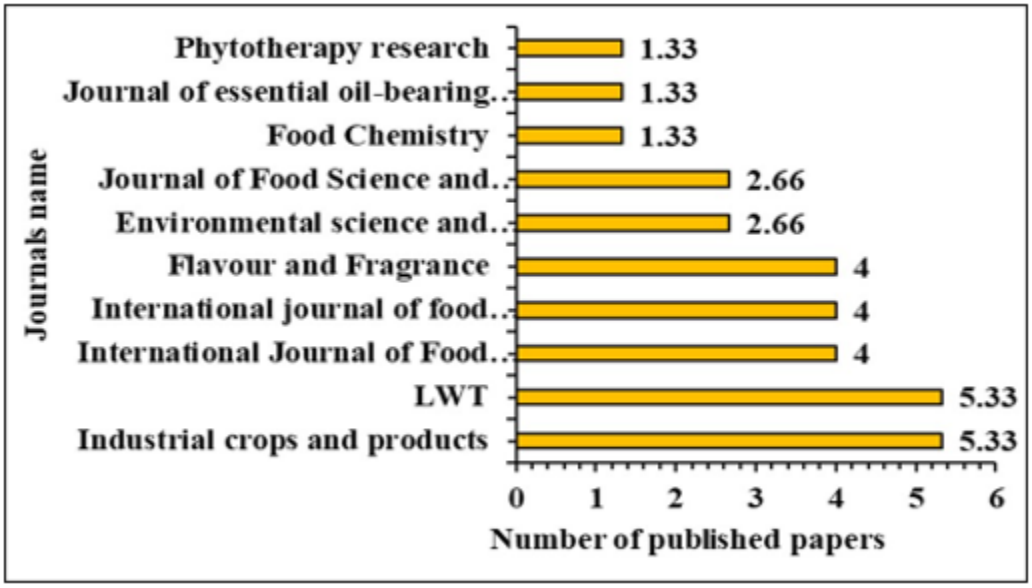


Figure 5: Publications by Top 10 journals publishing on PBEO

A relevancy factor of 1:425 was observed for LWT journal indicating that for every 425 papers published in the said journal, one paper is dedicated to PBEO research (Table 2). The relevance factor, in this case, is indicated by the fact that for the appearance of every single paper on PBEO research, how many articles on EO need to be published in that particular journal? The relevance factor will indicate in this case the degree of likeliness of choosing a particular journal by the researcher for publishing the findings associated with PBEO research. The lowest is the relevance factor, the highest is the likeliness of preferring the journal by any researcher. Having said this, according to relevancy factor the most preferred Journal for PBEO research is International Journal of Food Properties which has a relevancy factor of 1:83. Journals according to relevancy factor are shown in Table 2. Phytotherapy Research (7219) which had produced only 1 paper showed the highest relevance factor. However, relevance factor is only an indicator for finding journals for publishing articles related to PBEO. Noteworthy, to mention that the journal Phytotherapy research even though has a poor relevancy factor but was found as the most preferred journal for publishing articles on essential oil research as indicated by its 7219 publications on essential from 1991-2021.

Journals name	Number of articles published on essential oil (1991-2021)	SCImago rank	Impact Factor (2021)	Number of articles published on PBEO	Relevance Factor
International Journal of Food Properties	250	0.164	3.46	3	83.33
International journal of food processing and preservation	539	0.494	2.609	3	179.66
LWT	1699	1.173	6.056	4	425
Journal of Food Science and Technology	1019	0.666	3.177	2	509.5
Industrial crops and products	2812	0.897	6.4	4	703
Flavour and Fragrance	2532	0.451	2.5	3	844
Environmental science and pollution research	2516	0.944	4.88	2	1258
Journal of essential oil-bearing plants	2259	0.459	1.699	1	2259
Food Chemistry	3665	1.624	9.231	1	3665
Phytotherapy research	7219	1.073	5.878	1	7219

Table 2 List of top ten journals publishing on PBEO research

Publications by authors:

Figure 6 shows the ranking of the top ten authors based on the percent contribution to the knowledge of PBEO research. Results are indicative of the fact that all authors featured in this list belong to India which is not surprising, taking into account the volume of cultivation of *Piper betle* in India and the significant amount of commerce and trade involved with *Piper betle*. Findings indicate that P. Guha published the highest number of papers on PBEO (11 out of 75) indicating the highest contribution. The authors have devised a new model for tracing the most productive author in the field of PBEO research which is an integration of relevance factor, and citation factor. The productivity of the author cannot be judged just based on the total number of publications. The relevance factor indicates the total number of papers a particular author consumes to publish one paper relevant to PBEO. The lower the relevance factor the higher the authors involvement intensity in PBEO and productivity as well.

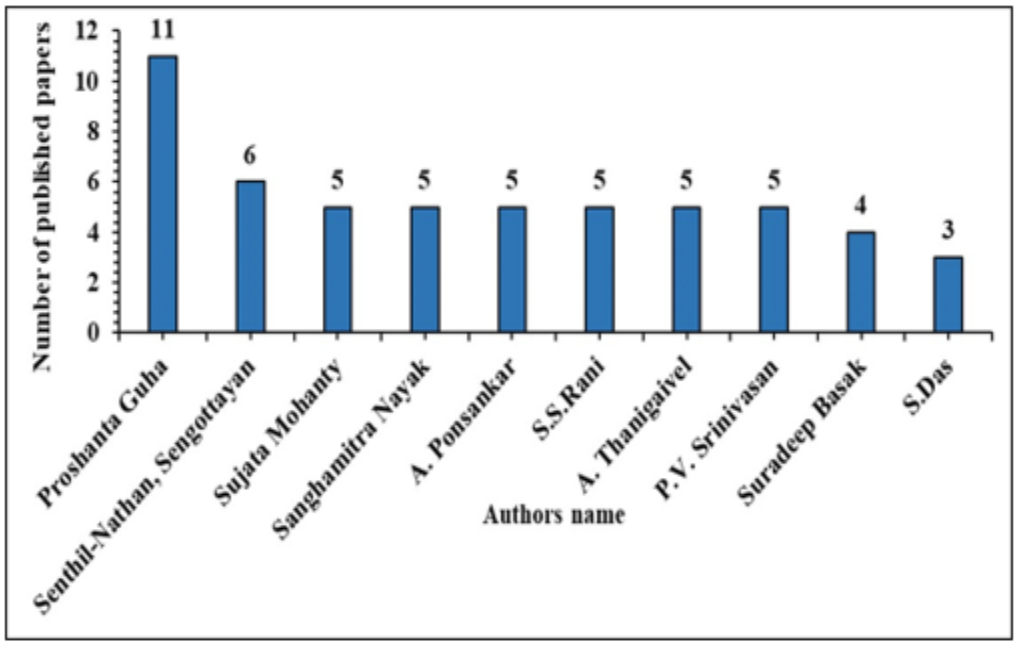


Figure 6: Publications by Top ten Authors publishing on PBEO

The citation factor is the percentage of citations dedicated to PBEO as against the total citation of the author excluding self-citation. Considering the above integration of the two factors so mentioned, Prasanta Guha (IIT, Kharagpur, India), Suradeep Basak (Pondicherry University, India) and Suryasnata Das (SOA University, India) can be considered the most productive in terms of lower publication consumption for producing one paper on PBEO and their citations on PBEO is 50% of their total citations (Table 3). Identification of productive authors helps in targeted network building and increases the possibility of finding better productive collaborating partners.

Authors name	Affiliation	Total publication (1991-2021)	Total citation (2021)	Author-h index (2021)
Proshanta Guha	Indian Institute of Technology, Kharagpur	26 (*Piper betle* = 11) **Relevance factor (RF) = 2.36**	304 (289) **Citation percent earned on PBEO research = 95%**	10
Senthil-Nathan, Sengottayan	University Tirunelveli India	146 (*Piper betle* = 6) **RF = 24.3**	2330(68) **Citation percent earned on PBEO research = 2.9%**	34
Sujata Mohanty	Rama Devi Women's University, Bhuban eswar, India	57 (*Piper betle* = 5) **RF = 11.4**	510(53) **Citation percent earned on PBEO research = 10.39%**	15
Sanghamitra Nayak	Siksha O Anusandhan (Deemed to be University), Bhuban eswar, India	168 (*Piper betle* = 5) **RF = 33.6**	1425(53) **Citation percent earned on PBEO research = 3.7%**	24
Athirstam Ponsankar	Sri Paramakalyani College, Tirunelveli , India	30 (*Piper betle* = 5) **RF = 6**	486(67) **Citation percent earned on PBEO research = 13.7%**	16

Selvaraj Selin-Rani	Manonmaniam Sundaranar University, Tirunelveli, India	18 (Piper betle=5) **RF = 3.6**	390(67) **Citation percent earned on PBEO research = 17.1%**	15
Annamalai Thanigaivel	Manonmaniam Sundaranar University, Tirunelveli, India	37 (*Piper betle* = 5) **RF = 7.4**	579(14) **Citation percent earned on PBEO research = 2.4%**	17
P. Vasantha-Srinivasan	Saveetha Institute of Medical and Technical Sciences, Chennai, India	51 (*Piper betle* = 5) **RF = 10.2**	664(67) **10%**	17
Suradeep Basak	Pondicherry University, Puducherry, India	10 (*Piper betle* = 4) **RF = 2.5**	137(70) **51%**	7
Suryasnata Das	Siksha O Anusandhan (Deemed to be University), Centre for Biotechnology, Bhubaneswar, India	8 (*Piper betle* = 3) **RF = 2.6**	83(47) **56%**	6

Table 3 Citation and relevance factor of top ten authors

Figure 7 represents the co-authorship analysis using VOS viewer (1.6.15 version, Leiden, Netherlands) which provides vital leads on the average number of publication years and active years (in terms of research on PBEO) for a particular author. Results indicate 6 clusters with 25 items (researchers). The most active researchers are indicated by yellow circles which in this case are an integrated collaboration from P. Guha, Madhumita M, S. Basak from IIT, Kharagpur (India) with total link strength of 15. This particular group have continuously published articles in PBEO research from 2015-2019, thus gaining the status of most active research group. This particular finding is in tandem with the model proposed for finding the most productive researcher in the area of PBEO research. The authors with light blue to purple dots are not actively publishing research on PBEO with cumulative link strength of only 12. The biggest cluster is represented by green circles with Senthil-Nathan S. as the prime researcher to whom various co-authors (10 numbers) are linked, displaying a link strength of 30 (Table 4).

Authors Name	**Documents**	**Total link strength**
Edwin, Edward Sam	5	30
Kalaivani, Kandasamy	5	30
Ponsankar athirstam	5	30
Selin-Rani, Selvaraj	5	30
Senthil-nathan, sengottayan	6	30
Thanigaivel Annamalai	5	30
Basak, Suradeep	9	5
Guha, Proshanta	10	5
Mohanty, Sujata	5	5
Nayak, Sanghamitra	5	5

Table 4 Top 10 Co-authors with a minimum of 5 publications as the threshold value

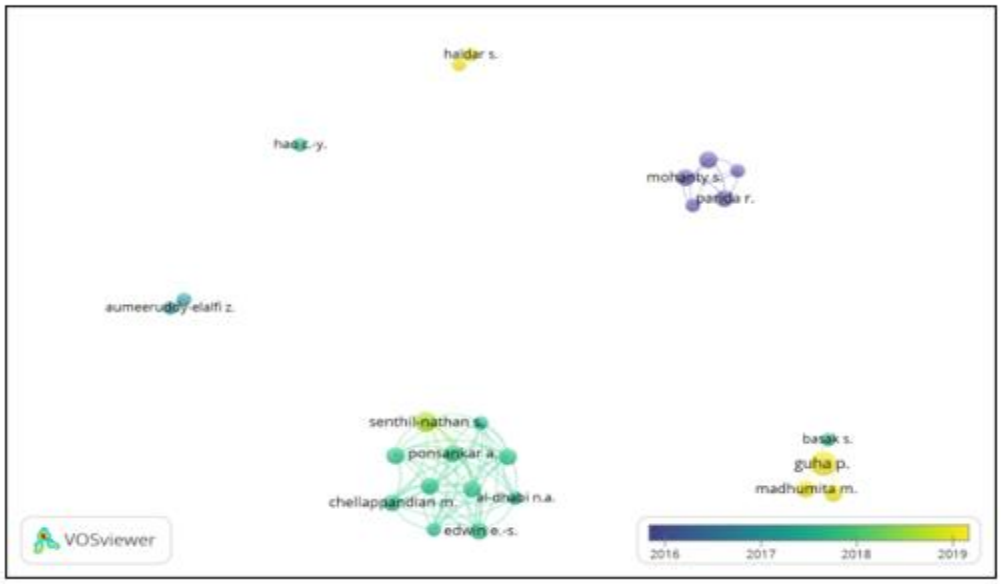


Figure 7: Overlay visualization of co-authorship network on PBEO

Publications by countries:

The overlay visualization (analysed through VOS viewer) of the co-authorship network map of countries is shown in Figure 8. The individual countries are represented in circles whereby; the size of the circles is directly proportional to the output. The assembly of circles forms a cluster which is interconnected with lines representing the networking between the countries and their strength. Strength is indicated by the thickness of the interconnecting lines which is based on authorship and citations. A clear dominance of productivity is indicated by India, making it as the centre of attraction for PBEO research. The thickness of all interconnecting lines (which depends upon the link strength), that connects other countries with India shows the intensity of international collaboration network. Thicker lines as determined by the link strength shall indicate high international collaboration network with India. Such early identification shall definitely help in building collaborating network with productive countries and sharing each other expertise for more productive output. Countries with low collaborating network need to identify their more productive international partners and join hands with them. In light of the above explanation, Figure 8 indicates 4 clusters with total of 49 countries (represented by circles). In the first cluster there are 6 countries namely, Iran, Malaysia, Pakistan, South Korea, and Bangladesh with a total link strength of 60. In the second cluster there are 5 countries namely, Sri Lanka, Indonesia, Thailand, Vietnam, and France with a total link strength of 60. India and Saudia Arabia are placed together placed in cluster 4 with a total link strength of 36 with India being the most productive country both in terms of number of publications and international collaborating partners (Table 5).

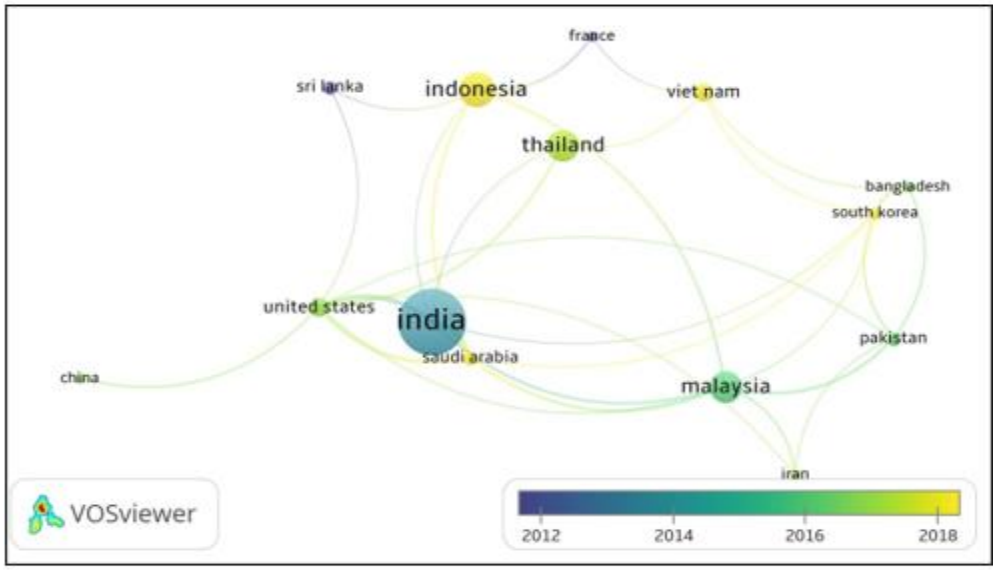


Figure 8: Overlay visualization of Collaboration network of countries on PBEO

Country Names	Documents	Total Link Strength
India	111	19
United States	15	19
Saudi Arabia	8	17
Malaysia	33	14
Pakisthan	8	9
Indonesia	38	8
Bangladesh	5	6
Thailand	33	4
Vietnam	13	4
China	5	2

Table 5 List of top collaborative countries with minimum5 publications on PBEO research as threshold value

It is surprising to see Saudi Arabia as one of the productive performers despite being a desert country which shows their deep research interest in PBEO particularly in areas of food, beverages, spa, relaxation, cleaning purpose etc. Third cluster has countries namely, the United States and China with total link strength of 21. China was found to have the lowest link strength indicating that their international collaboration network with other productive countries is low. China in particular despite being world leaders in traditional medicine need to establish more international collaboration linkage with productive countries such as India, USA, Malaysia, and Saudi Arabia. This observation implies that the allocation of resources for study was not consistently maintained, maybe indicating limitations in financial support or levels of interest.

It has become clear that South Asia, and, South East Asia dominate the PBEO research segment. It is interesting to note that 33% of the publications (without repeat count) on PBEO research have been produced by India and its neighbouring countries with whom it shares its international borders. Such fact could be interesting both in terms of commercial and academic point of view. Increased research on PBEO in such countries might be due to the utilization of betel leaves in producing modern-commercial goods which could increase the economy of local farmers, specifically in Asia. The dominance of Asian countries, particularly India can also be explained by the fact that such countries are agriculture oriented with climate ambient to production of *Piper betle*. Moreover, these countries do not experience snowfall throughout territory thus favouring agriculture. Government of these countries, particularly India is committed to empowering the farmers and to increase their profit margin and hence concept of contract farming is very popular in India. India's dominance also indicates that India and its other Asian neighbours have very well utilized their geographical advantage in their favour and channelized their research movement keeping in view their geographical advantage.

Publications by Institutions:

The institutional participation in PBEO research is dominated by Indian institution which is mainly due to geographical advantage of India and considering the immense amount of trade and commerce associated with *Piper betle* in India and Asia as well (Table 6).

Name of Institution	Country	Total publication (1991-2021)	Total citation
Indian Institute of Technology Kharagpur	India	14	336
Siksha O Anusandhan (Deemed to be University), Bhubaneswar,	India	8	100
Manonmaniam Sundaranar UniversityTirunelveli	India	6	68
Sri Paramakalyani College, Tirunelveli,	India	5	67
Manonmaniam Sundaranar University, Tirunelveli	India	5	67
Rama Devi Women's University, Bhubaneswar,	India	5	53
Manonmaniam Sundaranar University, Tirunelveli	India	5	14
Saveetha Institute of Medical and Technical Sciences, Chennai	India	5	67

Table 6 List of top institutions with at least 5 publications on PBEO

Figure 9 represents the overlay visualization indicating the involvement of various institutions and their activeness in PBEO research. A total of 25 institutions were selected by the software based on their minimum citation and link strength as per the software algorithm, institutes with no citation resulting in zero link strength were not taken up by the software for this overlay visualization analysis. Institutes with yellow colour are still actively working on the said topic and there exists only 4 such institutes among those selected by the software having minimum link strength. A total of 10 institutes were found to have stopped working on PBEO by the end of year 2018. A total of 11 institutes were active on PBEO research for only a brief time span ranging from 2014-2015. Results indicate that 84% of the selected institutes with significant contribution in PBEO worked only between 2014-2018. The drop in research interest on PBEO after 2018 as evident from the

involvement of lesser number of institutes after the said tenure could be an indicative of attaining a level of saturation in the field of PBEO research. Research in essential oil as stated earlier has only limited verticals or domains, the major being biological activity evaluation and volatile principal profiling. However, it's time to re-think on the subject matter and create new verticals in PBEO research. One such vertical could be designing of green extraction methods for extraction of PBEO with significant advantage on time and yield when compared to traditional distillation.

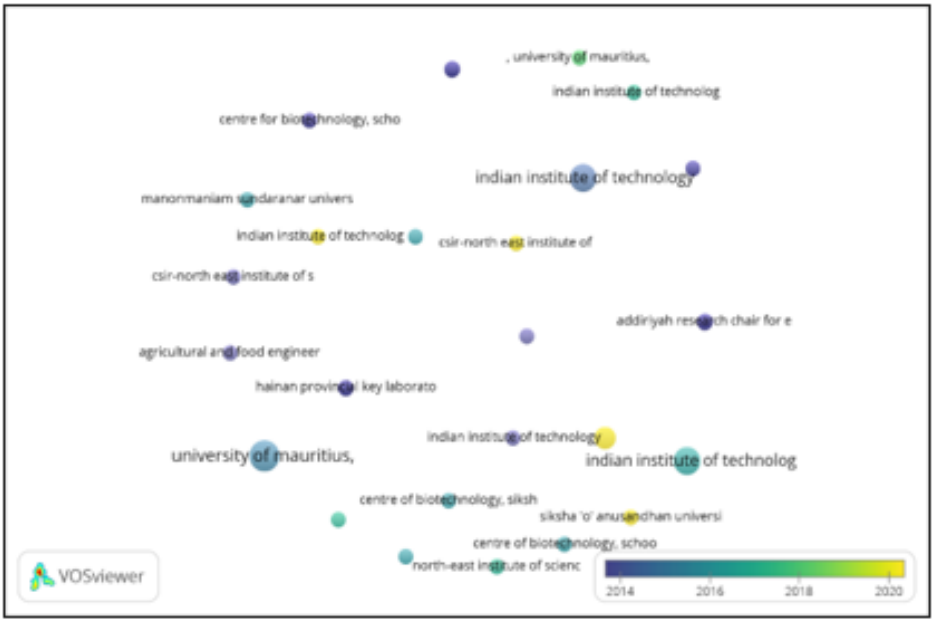
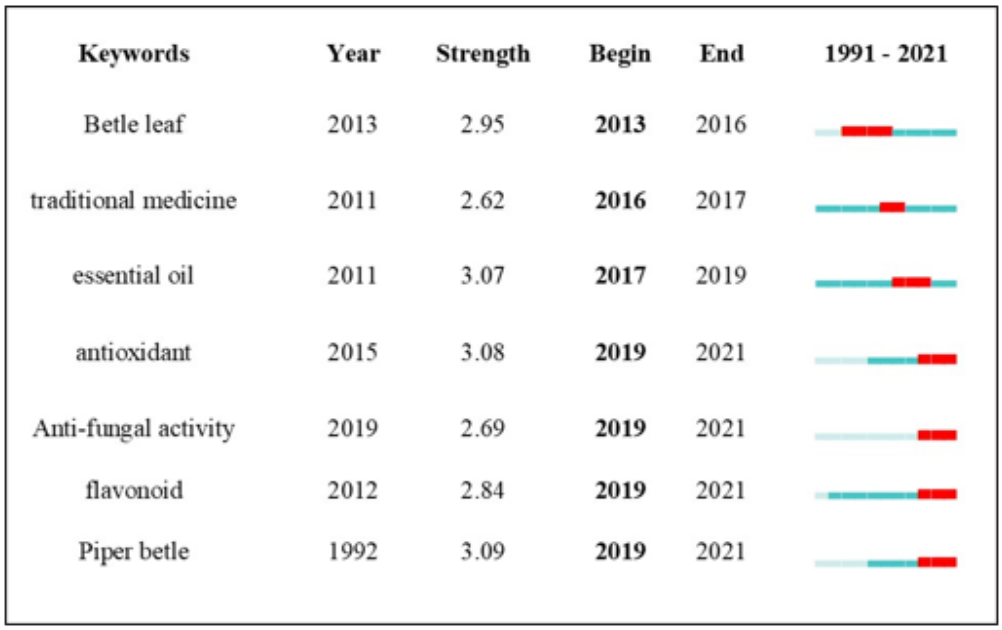


Figure 9: Overlay visualization of the institute network map on PBEO research

Keywords with strongest Citation burst analysis

Cite Space, a scientometric analysis software programme (6.1.R6 Basic version), was used to do the citation burst study (Figure 10). Cite Space, among other things, allows for the examination of keywords that had a citation burst, which is a rapid spike in the number of citations in a certain time and research area. Burst Keywords shall be indicators of emerging trends and shows increases attention of scholars. The citation burst study revealed that six keywords had a sudden surge in citations between 1991 and 2021 (Figure 10). The findings of the bibliometric network analysis were validated, indicating the relevance of essential oil in *Piper betle* scientific study across time. Throughout the years of research, keywords like essential oil, flavonoid, and antioxidant were found more significant. Between 2013 and 2016, the term "betle leaf" underwent a citation explosion, indicating that the scientific community was more attracted towards betle leaf after which a decline or reduction in active participation could be possible which is also in tandem with the bibliometric analysis presented in the earlier section. Furthermore, according to the overlay visualisation of the co-occurrence analysis of keywords, the citation burst analysis highlights the recent interest in scientific research on *Piper betle* for pharmaceutical, food, and flavouring purposes, as well as the recent increase in studies dealing with the essential oil in India.



Keywords	Year	Strength	Begin	End	1991 - 2021
Betle leaf	2013	2.95	**2013**	2016	
traditional medicine	2011	2.62	**2016**	2017	
essential oil	2011	3.07	**2017**	2019	
antioxidant	2015	3.08	**2019**	2021	
Anti-fungal activity	2019	2.69	**2019**	2021	
flavonoid	2012	2.84	**2019**	2021	
Piper betle	1992	3.09	**2019**	2021	

Figure 10: Top 6 keywords with the strongest citation burst. A strong citation burst indicates that a variable undergoes a great change in a short period of time. Red bars indicate the duration of bursts

Traditional uses of Piper betle: Global perspective:

This section provides a vivid picture of the traditional practices associated with Piper betle with special emphasis on Asian countries. The tutelage presented in this section shall set the tone of article as it will throw light on the immense ethnic practices associated with the said plant, making it an ideal research hotspot.

It was observed that people in Bangladesh, Burma, China, India, Indonesia, Malaysia, Nepal, Pakistan, the Philippines, South Africa, Sri Lanka, Thailand, and other places have used betel leaf for a long time as a chewing gum and a medicine for many health disorders. The utilisation of betel leaf, either in isolation or in combination with other botanicals, is a common practice seen in Ayurvedic literature dating back to 1,400 BC. This approach is believed to potentially enhance the therapeutic outcomes of these formulations. According to reports, betel leaves are said to contain aphrodisiac effects and are referenced in Vatsyayan's Kamasutra, an ancient Sanskrit Indian literature that focuses on sexual behaviour and instruction. The consumption of betel leaf is believed to possess numerous medical properties, including enhancing vocalisation, strengthening gum tissue, preserving dental health, freshening breath, and mitigating halitosis. The emphasis on its efficacy as an anti-inflammatory and antibacterial agent is seen in multiple instances. In instances of painful infection and night blindness, the juice derived from the leaves is removed and administered to the eyes. The use of essential oil derived from the leaves of this plant has been documented in the treatment of respiratory catarrhs and as an antiseptic. Additionally, the fruit of this plant is commonly combined with honey to create a cough medicine. Indian traditional and folk medicine have shown that certain leaves can cure wounds, are beneficial in treating bronchitis, and aid in the digestive process. It relieves flatulence, drives out worms, is fragrant, warming, antibacterial, reduces fat, and, when chewed after meals, acts as a mild digestive enhancer. The leaf juice is administered systemically to children to alleviate dyspepsia and cough. Additionally, the leaves are applied as a counterirritant to stop milk from being secreted from breast abscesses. Applied topically or gargled with, the oil is an effective local stimulant that helps relieve coughs and respiratory catarrhs. The traditional medicinal practices of Sri Lanka and the countries of Southeast Asia likewise heavily rely on betel leaf (Kumar et al., 2010; Pradhan et al., 2013). They treat joint pain, arthritis, headaches, and dental issues in Malaysia. China's Guangdong province, Yunnan province, and Guangxi province are home to large populations of piper betles. The traditional Chinese medical system uses *Piper betle* leaves to treat rheumatic osteodynia, cold coughs, detumescence, and as an antipruritic. Some parts of China employ betel leaves in their cuisine. Chewing betel nuts is a custom in several parts of China, especially the southern provinces. It is common practice to wrap betel nuts in betel leaves and chew them either alone or with other substances like tobacco and slaked lime. This custom is comparable to other Asian regions betel quid chewing customs.

Research Overview:

Bibliometric-based analysis of research trend clearly indicates that research on *Piper betle* was stagnant from 1991-2001 with no significant growth observed during this period. From 2002 to 2021 a major surge in research on *Piper betle* took place whereby, the number of publications has increased by tenfold. The authors are of the opinion that this surge in research may be due to technological advancements taking place in the field of chromatography with special emphasis on hyphenated techniques that have made the detection of volatile principles present in essential oil more accurate and precise. Proper keyword usage is the key to success in getting increased citations. The earlier section have vividly presented the various keywords used using VOS viewer which shall ease out the job of the researchers intending to work on PBEO. Identification of active collaborative partners have also been shown through network overlay visualization which shall help future researchers interested in PBEO research to identify active collaborating partners with good relevance factor at an early stage.

Research Hotspots:

The use of various disciplines in the PBEO literature demonstrates its importance and acceptance in the academic field. Certain important verticals in PBEO research have been identified along with their contribution (in terms of number of publications in the identified theme) after critical analysis of the qualified articles (Figure 11). Evaluations of biological activity particularly for those diseases where essential oil can be used externally and application of gas chromatography-based chemical profiling of volatile principles are the major verticals with highest percent contribution. In the earlier sections, it was observed that only a few researchers and institutions are still actively working on PBEO research. The question which needs to be answered is whether, has the saturation been achieved in the case of PBEO

research. Identification of new verticals and research dimensions can further result in research surge in PBEO. Designing of new green extraction tools, preparation of PBEO based formulations for commercial use could be some outcome-based research dimensions. Enough literature is available on various biological activities and volatile principles present in PBEO and based on such robust data-driven understanding, it is high time that researchers should use this as a strong foundation and build further on it. In order to facilitate researchers in their decision-making process in terms of research on PBEO, the authors are furnishing a directory of volatile principles detected and reported so far in different varieties of *Piper betle*.

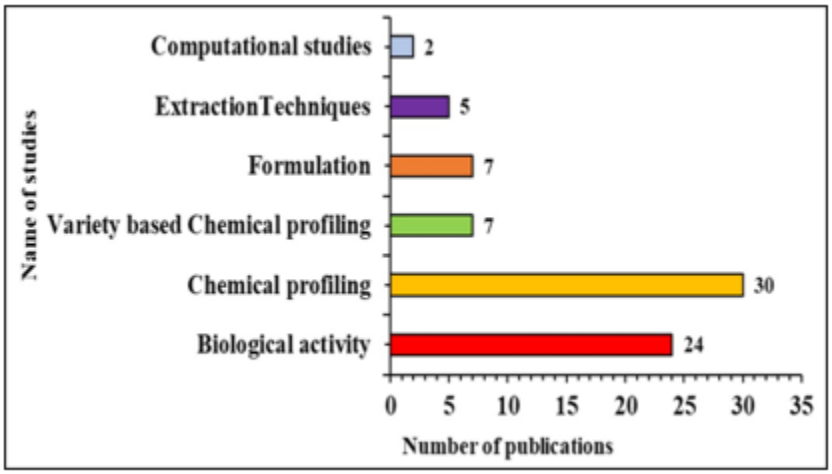


Figure 11: Graphical representation of contribution by subject area on PBEO research

Composition of Meetha leaf (Conventional hydrodistillation method)

Eucalyptol, Linalool, Chavicol, γ elemene, Eugenol, Caryophyllene, Germacrene D, β-elemene, α- cadinene, Globulol, α- cadinol, Caryophyllene oxide (Valle et al., 2016).

Composition of kapoori leaf (Conventional hydrodistillation method)

Gamma terpinene, Linalool, 4-terpineol, Beta elemene, α-ylangene,Eugenol,Caryophyllene, Aromandrene, Germacrene-D, Humulene, Gamma cadinene, Beta-ylangene, Globulol, α- cadinol (Jadhav et al., 2022).

Unknown variety of PBEO (Magnetic string method)

1-menthol, δ-cadinol, caryophyllenol II, α-bisabolol, α-muurolene, δ-cadinene, caryophyllene oxide, 12-oxabicyclo [9.1.0] dodeca3,7-diene, 6,10,14-trimethyl-2- pentadecanone, hexadecanoic acid, 1-octadecanol, trans-2-methoxy-4- propenylphenol, methyl eugenol, phytol, 2-propenamide, 3-phenylN2-propenyl, diphenylamine (Yoonus et al., 2020).

Composition of Paradeep variety (Conventional hydrodistillation method)

Artemisia triene, Beta-cis-ocimene, Linalool, Acetyleugenol, Isoeugenol, trans-isoeugenol, alpha-copaene, Beta-cubebene, Allylpyrocatecholdiacetate, Caryophyllene, Beta-Humulene, Alpha caryophyllene, Alloaromadendrene, delta-muurolone, delta-Gurjunene, alpha-Muurolone, alpha-selinene, Germacrene-D, delta-cadinene, Cada 1,4 diene, alpha-Selinene, Ledene, alpha-Elemene (Srinivasan et al., 2016).

Composition of Birikuli variety (Conventional hydrodistillation method)

Artemisia triene, Cis-ocimene, Linalool, Acetyl eugenol, Eugenol, Isoeugenol, trans-isoeugenol, alpha-cubebene, Beta-cubebene, Allylpyrocatecholdiacetate, Beta-caryophyllene, Alpha caryophyllene, Alloaromadendrene, delta-muurolone, alpha-Muurolone, alpha-selinene, Germacrene-D, Bicyclogermacrene, delta-cadinene, alpha-Selinene, alpha-Elemene, Muurolol (Kurnia et al., 2020).

Composition of Mataiali variety (Conventional hydrodistillation method)

Alpha-phellandrene, cis-ocimene, Acetyl eugenol, Iso-eugenol, Methyl eugenol, Allylpyrocatecholdiacetate, Gamma-Muurolone, Gamma-Gurjunene, valencene, Germacrene-D, Gamma-cadinene, Delta cadinene, isoeugenol acetate, delta-muurolol, Ledene, alpha-elemene (Verma et al., 2016).

Composition of Sachi variety (Conventional hydrodistillation method)

Acetyl eugenol, Iso eugenol, Beta-elemene, Allyl pyrocatechol diacetate, Caryophyllene, Beta-humulene, Delta-muurolane, Delta-gurjurene, alpha-muurolone, valencene, Germacrene-D, Delta-cadinene, Delta-muurolol (Nayaka et al., 2021).

Composition of Kali Bangla variety (Conventional hydrodistillation method)

Chavicol acetate, Chavicol, Acetyl eugenol, Beta-cubebene, Allyl pyrocatechol diacetate, Caryophyllene, Alpha caryophyllene, Gamma-Muurolone, alpha-muurolone, Germacrene-D, Beta-cadinene, Cada 1,4 diene, Delta-muurolol (Waghmode et al., 2017).

Unknown variety of PBEO (Steam distillation method)

Alpha-pinene, Bicyclo [2,2,1] heptane,7,7-dimethyl-2-methylene, Eucalyptol, 3-octen-5yene,2,7 -dimethyl-[E], Cyclohexene,1-methyl-4-[1-methyethylidene], Linalool, 5-caranol, 2-isopropenyl-5-methylcyclohexanol, Nitrosothymol, Naphthalene, Globulol, 1-Napthol, Phytol (Periyanayagam et al., 2012).

Composition of Chandrakala variety (Conventional hydrodistillation method)

Eugenol, 2-picoline, n-(4-Aminophenyl)-maleimide, 1-Hexanamine, n-(phenylmethyl ether), 4(3H)-Quinazolinone, 2-Aminocarbonylbenzoic acid, 4-Amino benzofuran, 4-tert-Butylbenzamide, 2-Indolinone, 4-Hydroxy-3-methoxyphenylaceto, Cadinene, Eugenol acetate, B-Elemene, Terpinolene, Terpinolene (Ali et al., 2018).

Composition of Karpada variety (Conventional hydrodistillation method)

Eugenol, 2-Methoxybenzaldehyde, m-Toluidine Benzaldehyde,4-(diethylamino), n-(4-Aminophenyl)-maleimide9 1-Hexanamine, n-(phenylmethylether), 4(3H)-Quinazolinone, 2-Pyridine propanol, -tert-Butyl pyridine, Formamide, 4-Diethylaminobenzaldehyde (Kaypetch & Thaweboon, 2018).

Composition of Godibalunga variety (Conventional hydrodistillsation method)

Eugenol, Alloaromandendrene, Cadinene, Eugenol acetate B-Elemene, Caryophyllene 4-Allylcatechol diacetate, γ-Himachalene, 4-Allylcatechol diacetate Caryophyllene (Jubeh et al., 2020).

Composition of Nahua variety (Conventional hydrodistillation method)

Eugenol, 3-Carene, 3-Allyl-6-methoxy phenol, Alloaromandendrene, Cadinene, β-Guaiene, Eugenol acetate, 4-Allylcatechol diacetate, γ-Himachalene, 4-Allylcatechol diacetate, Caryophyllene

Composition of Balia variety (Conventional hydrodistillation method)

2-Pyridinepropanol, 2 2-Methoxybenzaldehyde, m-Toluidine, Eugenol, Benzaldehyde,4-(diethylamino), 2-Picoline, 1-Benzosuberone, n-(4-Aminophenyl)-maleimide,1-Hexanamine, n-(phenylmethyl ether), Methyl vanillyl ketone, n-(p-Methoxyphenyl) maleimide, 2-Aminocarbonylbenzoic acid, 1,3-Dimethyl-6-phenylpiperidin, 2-Indolinone, Alloaromandendrene, Cadinene, β-Guaiene, Eugenol acetate, γ-Himachalene, 4-Allylcatechol diacetate, γ-Terpinene, Longifolene.

Composition of Desi Bangla variety (Conventional hydrodistillation method)

Eugenol, 2-picoline, n-(p-Methoxyphenyl) maleimide, 4(3H)-Quinazolinone, n-(p-Methoxyphenyl) maleimide, 2-Aminocarbonylbenzoic acid, 1,3-Dimethyl-6-phenylpiperidin, 2-Indolinone, Cadinene, β-Guaiene, Eugenol acetate, 4-Aminobenzofuran, Isophthalic acid dihydrazide.

Composition of Dada-balunga variety (Conventional hydrodistillation method)

Eugenol, Benzaldehyde,4-(diethylamino), 2-Picoline, 4(3H)-Quinazolinone, Quinazolin-4(3H)-one, Methyl vanillyl ketone, 2-Aminocarbonylbenzoic acid, 1,3-Dimethyl-6-phenylpiperidin, Cadinene, β-Guaiene, Eugenol acetate, Cyclene.

Composition of Maghai variety (Conventional hydrodistillation method)

2-Pyridinepropanol, 2-Methoxybenzaldehyde, m-Toluidine, Eugenol.

Composition of Mauritius variety (Conventional hydrodistillation method)

Alpha-pinene, Beta-myrcene, Sabinene, Alpha-3-carene, 1,4-cineol, Camphor, Alpha-elemene, Beta-caryophyllene, Eugenol, Acetyl eugenol, Safrole.

Composition of Tamluk Mitha variety (hydrodistillation method)

α-Pinene ,Camphene , Undecane , β-Terpinene , β-Phellandrene , L-β-pinene , D-Limonene , Eucalyptol ,β-trans-ocimene , γ-Terpinene, m-xylene, Allo-Ocimene, δ-elemene , α-Cubebene, β-Bourbonene, (+)epi-bicyclosesquiphellandrene, Linalool, β-elemene, Caryophyllene, Aciphyllene, Epizonarene, Estragole, γ-Muurolene, Virdiflorene, β-Cubebene, Elixene, δ-Cadinene, α-Cadinene, Eugenol, Anethole, Seychellene, Isosafrole, 4-Allylphenyl acetate, Methyl eugenol, Carotol, Cubenol, (−)-Globulol, Hexadecamethyl-cyclooctasioxane, Spathulenol, Epizonarene, Chavibetol, α-Cadinol,Chavicol

Composition of Bangla desi variety (hydrodistillation method)

β-Phellandrene, β-ocimene, γ-Terpinene, Terpinolene, Terpineol-4, Safrole, Eugenol, β-Bourbonene, Beta-elemene, Methyl eugenol, Caryophyllene, Aromadendrene, Beta-Farnesene, Methyl isoeugenol, Germacerene-D, Beta-selinene, Alpha-selinene, Alpha-farnesene, Cubebol, Hydroxy cavicol, Eugenol acetate, α-Cadinene, Germacerene-B, E-Nerolidol, Spathulenol, Beta-caryophyllene oxide, Globulol.

Composition of Deswari variety (hydrodistillation method)

α-Pinene, Camphene, Sabinene, Myrcene, Terpinene, β-Phellandrene, β-Ocimene, γ-Terpinene, Terpinolene, Cis-sabinene hydrate, Terpineol-4, Safrole, Eugenol, Iso-safrole, β-Bourbonene, β-Elemene, Methyl Eugenol, Caryophyllene, Aromadendrene, β-Farnesene, Alpha-humulene, Methyl isoeugenol, Germacerene-D, β-Selinene, α-Selinene, α-Farnesene, Cubebol, Hydroxy chavicol, Eugenol acetate, α-Cadinene, Germacerene-B, E-Nerolidol, Spathulenol, β -Caryophyllene oxide, Globulol

Composition of khasia variety (hydrodistillation method)

Dehydro-cineole, 4-d-carene, c-terpinene, (E)-verbenol, p-cymen-8-ol, 4-allylphenyl acetate and Beta-sapthulenol

Composition of Bari variety (hydrodistillation method)

eugenol, b-caryophyllene, chavicol, valencene, and alpha-hemulene

Composition of Bagerhati variety (hydrodistillation method)

α-Pinene, Camphene, Eucalyptol, β-Ocimene, Linalool, Chavicol, Eugenol, Delta-elemene, Chavicol acetate, Beta-elemene, Methyl eugenol, Beta-caryophyllene, Beta-copaene, Alpha-humulene, Gamma-Muurolene, Germacrene-D, Beta-salinene,

Composition of Manikdanga variety (hydrodistillation method)

Eucalyptol, Terpinolene, Linalool, Delta-elemene, Chavicol acetate, Eugenol

Composition of Ghanagete variety (hydrodistillation method)

Viridifloral, Cubenol, Palustrol, Spathulenol, Eucalyptol, Terpinolene, Linalool, Delta-elemene, Chavicol acetate, Eugenol

The authors have taken a holistic approach in identifying some major research hotspots which can be explored further. Below mentioned are some vital observations of the author along with critical analysis which can serve as a future roadmap

Identified research hotspots (scope for future exploration)

- Exploring the variability of the volatile principles involved with the different varieties of *Piper betle* is an important research hotspot. A critical analysis of the findings associated with the above-mentioned agenda is presented below. Various distillation procedures have been employed to extract *Piper betle* essential oil, including hydro distillation, steam distillation, microwave-assisted hydro-distillation, ultrasound-assisted hydro-distillation, and vacuum distillation (Arambewela et al., 2006; Das, Parida, Sriram Sandeep, et al., 2016; Saxena et al., 2014). Hydro-distillation has emerged as the predominant technique, with certain modifications observed in the context of ultrasonic pre-treatment (Jadhav et al., 2022). The yield of betel leaf essential oil often ranges from 0.09% to 0.80% on a fresh weight basis. The yield percentage differs considerably between piper cultivars and geographical areas. The Piper cultivars obtained from West Bengal (India) exhibit comparatively higher yield percentages in comparison to those obtained from other places. Interestingly, there are sporadic reports where high yields beyond 2% have been reported. Rayaguru et al reported in 2007 that ‘Godi Bangla’, a variety originating from Odisha (India), can produce a yield of 9.52% on a dry weight basis. Nevertheless, other researchers have raised concerns regarding this

reporting on yield and have stated that further investigations are required before the data is finally validated. Guha et al in 2007 reported that 'Ramnagar Mitha variety', belonging to West Bengal (India), can produce a yield of 2% through hydrodistillation. The Malaysian cultivar originating from Malaysia exhibits a significantly elevated yield of 5.1% based on dry weight and obtained through hydrodistillation. In certain varieties obtained from Lucknow (India), it is observed that Mitha has a comparatively superior yield of 0.85%, while Kapoori and Desawari displayed lower yields of 0.11% and 0.12%, respectively(Guha, 2006).

- Adopting green extraction techniques capable of producing high yields of PBEO can be a profitable area that the researchers may have missed so far. In this regard attempting solvent-free microwave extraction can be a wise option for extraction of PBEO. An array of green extraction techniques is presented in Figure 12 which can be taken up for investigation in the near future. A detailed description of all these techniques have been vividly explained by the authors in their previous publications (Bhushan et al., 2023; Mukherjee et al., 2022).

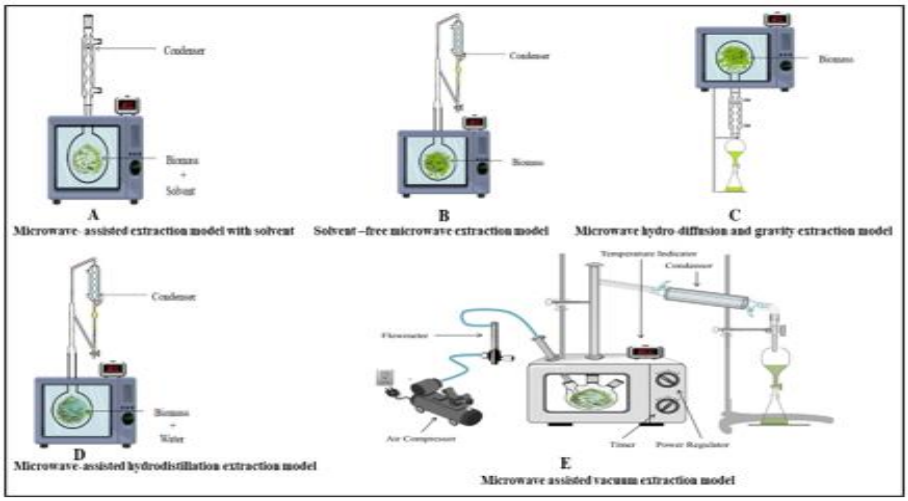


Figure 12: Proposed various extraction models that can be investigated for PBEO extraction

- Sample pretreatment prior to steam distillation can also be seen as a viable option subjected to experimental validation. Yadav et al 2020, reported the exposure of acoustic waves prior to hydrodistillation of two samples obtained from Mumbai (India), specifically Kapoori variety and the Mitha variety. The outcome of this process led to marginally increased yields in comparison to their counterparts that underwent conventional hydrodistillation. However, surprisingly the same authors reported an antagonistic effect for the above two varieties where prior exposure to acoustic waves led to decreased yield when compared to the usual hydrodistillation duration of 180 min (Jadhav et al., 2022).
- Exploring the potentiality of 'cured betle leaves': There is a singular piper variety known as 'Bangla', which produces different yields in two different states - fresh and cured. 'Cured' leaves are those leaves that have been exposed to smoke at a temperature of 50ºC in a closed room for 6 h followed by cooling at room temperature for 12 h. The leaves are then incubated for 15-20 days at room temperature which converts the green betel leaves into yellow colour leaves with better organoleptic properties along with some stimulating and refreshing effects. This practice is being carried out by the local farmers of West Bengal (India) in an effort to tackle the surplus production of betle leaves as it is believed that cured leaves have a longer shelf life. This process of producing cured leaves was first attempted with the "Varanasi" variety. It was reported by the authors that the state of the plant material could potentially affect the quantity of essential oil produced. Fresh leaves upon 140 min and 360 min of hydrodistillation produced a yield (on a dry weight basis) of 0.35% and 0.18% respectively. On the other hand, with cured leaves, the yield observed was found to be 0.48% and 0.22% for the said duration of extraction. It is worth mentioning that the curing of leaves resulted in an increase in oil production. This increase can be attributed to the reduction in various components, such as nonreducing sugar (decreased from 1.30% to 0.29%), starch (decreased from 3.10% to 1.44%), tannin (decreased from 2.05% to 1.8%), and ether extract (decreased from 15.7% to 13.5%). These reductions collectively decreased the overall weight of the leaves, leading to a proportional increase in oil yield compared to fresh leaves. Under conditions of darkness, along with the presence of heat and smoke, particularly carbon monoxide (CO) and carbon dioxide (CO_2), the chlorophyll within the leaves undergoes a progressive reduction, resulting in a light yellow or whitish coloration. This alteration in pigmentation contributes to an extended shelf life for the betel leaves (Madhumita et al., 2019).
- Exploring climate-induced variations: According to Monomodally et al. (2019), in the instance of the 'Mauritius variety' *Piper betel*, it was observed that the yield of PBEO is much higher in the months of May and August compared to other months. This finding can be attributed to the fact that October and May serve as transitional periods between seasons in Mauritius. The average summer temperature is recorded as 24.7°C, while the average winter temperature is measured at 20.4°C. The months of July and August are considered to be the coolest, as seen by the average night low temperatures, which decrease to 16.4ºC. Consequently, there is an enhancement in nutrient absorption, leading to the leaves reaching their maximum vegetative state, thereby facilitating the generation of a greater quantity of essential oil (Aumeeruddy-Elalfi et al., 2015).
- Exploring the variations existing among landraces and identification of unique chemicals which can serve as potential marker for that particular variety. Some studies identify unique chemicals or chemical profiles for specific betel leaf varieties. For example, the presence of oxophorone and 9-epi-b-caryophyllene exclusively in Bangla betel leaves can serve as markers for distinguishing this variety from others (Guha, 2006).
- Drying method-induced variations: The method of drying betle leaves can have a severe bearing on the yield of the oil. Meena et al reported extraction efficiency obtained from fresh betel leaves to be 2.1% on a dry weight basis. The resulting yield exhibited a

reduction to 1.5% (dry basis) for both the shade drying and freeze-drying methods, with even lower yields observed for hot air oven drying (1%, dry basis) and vacuum drying (0.8%, dry basis). The rationale for this phenomenon can be elucidated by examining the variations in drying conditions among the chosen drying techniques. In the instances of hot air drying and hoover drying, the temperature was consistently maintained at 60°C (Meena et al., 2021).

Research concentrates:

Certain vital research leads presented as concentrate from this bibliometric-based review are presented below. This research concentrate is expected to provide key highlights related to PBEO research,

- The yield of betel leaf essential oil varies a lot, from 0.09% to 9.52%. This is because of factors like piper cultivars, geographical regions, extraction techniques, seasonal changes, pre-treatment of the raw materials, and how long the raw materials were stored before they were extracted.
- In general, West Bengal (India) piper types provide better yields.
- It is also possible to store the extracted piper betle oil at room temperature for more than three years, but some volatile components may be lost without a noticeable loss of fragrance.
- The amount of essential oil in betel leaf increased from 1.23% to 4.20% after curing. Madhumita et al. (2019) investigated the extraction of essential oil from the bangla type of Piper betle leaves, both fresh and cured, and identified its bioactive components. This analysis revealed that the discovered volatile chemicals had a high degree of similarity in both leaves, but in varying proportions. The eugenol content in fresh leaf is found to be greater (46.02%) compared to that in cured leaf (44.14%). The essential oil derived from cured betel leaves has been observed to possess higher concentrations of estragole (17.12%), linalool (13.25%), and anethole (2.65%) compared to the essential oil obtained from fresh leaves. The rationale for these modifications may be attributed to the use of smoke and heat treatment during the curing procedure (Madhumita et al., 2019).
- Different forms of terpenes and phenols, such as carvacrol, caryophyllene, chavicol, eugenol, limonene, methyl eugenol, pinene, safrole, and some sterols (α-cardinol, linalool, β-sitosterol, etc.), are thought to be the active ingredients that kill microbes.
- Eugenol and chavicol primarily determine the quality of PBEO.
- In a study by S. C. Garg et al. (1992), they found that chavicol made up about 48.78% of the oil that was extracted from the fresh leaves of the sagar bangla variety of piper betle (Garg & Jain, 1992).
- According to a study conducted by Ibrahim bin et al. (1994), it was shown that Chavibetol (69.0%) is the predominant volatile constituent in the essential oil of the Malaysian type of piper betle (Ibrahim et al., 2020).
- Le Thanh et al. (1997) found that α-cadinol (26.2%) and ε-cadinene (11.7%) are the main volatile components of Vietnam variant piper betle rhizome oil (Thanh et al., 1997).
- According to a study conducted by Leopold et al. (1999), the chemical composition of the essential oil extracted from the leaves of piper betle originating from south India exhibits notable significance. This unique composition was not observed in any other essential oil derived from piper betle sourced from different regions (Perino & Chemat, 2019).
- According to a study done by Bhanu Prakash et al. in 2010, the magahi variety of Piper betle essential oil was mostly made up of eugenol (63.39%) and acetyl eugenol (14.05%) (Prakash et al., 2010).
- Das et al. (2016) looked at the essential oil composition in eight important landraces of betel vine: Balia, Chandrakala, Dandabalunga, Desibangla, Godibangla, Karpada local, Maghai, and Nahua. The study revealed that the major component, eugenol, was present in varying percentages across different P. betle landraces. Specifically, Chandrakala exhibited a percentage of 34.61%, Karpada local had 39.845%, Godibangla contained 44.04%, Nahua had 44.96%, Balia contained 45.85%, Desibangla exhibited 46.47%, Dandabalunga contained 55.49%, and Maghai had the highest percentage at 71.87%. The Maghai Pan variety exhibited the highest concentration of eugenol, whereas the Chandrakala variety demonstrated the lowest eugenol level (Das, Parida, Sandeep, et al., 2016).
- In a study conducted by Md Atikul Islam et al. (2020), the researchers investigated the identification and quantification of volatile compounds present in five varieties of Piper betle, namely Bangla Paan, Sanchi Paan, Misti Paan, Khasia Paan, and BARI Paan, originating from Bangladesh. The presence of two specific chemicals, oxophorone and 9-epi-b-caryophyllene, was exclusively observed in Bangla betel leaves, thus establishing a distinguishing characteristic of this variety in comparison to others. The chemical known as 1-H-indole possesses distinctive characteristics that make it a potential marker for the identification of Sanchi pan. The presence of four distinct volatile chemicals, namely pogostol, α-thujene, terpene-4-ol, and dimethylallyl acetate, has been documented in Misti betel leaves, distinguishing them from other types. The Khasia variety exhibited a higher abundance of distinct chemicals, such as dehydrocineole, 4-d-carene, c-terpinene, (E)-verbenol, p-cymen-8-ol, 4-allylphenyl acetate, and β-sapthulenol, in comparison to the remaining betel leaf kinds. The analysis of BARI Paan revealed the presence of four distinct chemicals, namely (Z)2-pentenyl acetate, (E)-ocimene, n-decyl acetate, and undecane-2-one. These compounds were found to be absent in the other types under investigation (Islam et al., 2020).
- Selecting an appropriate drying technique is crucial for extracting the essential oil from the piper betle.
- Hydro-distillation and steam-distillation are among the commonly used distillation techniques used to extract Piper betle essential oil. Microwave-assisted hydro-distillation, ultrasound-assisted hydro-distillation, and solvent-free microwave extraction needs to be explored for better results.

Conclusion:

The major purpose of this article is to present scientific leads in the form of consolidated scientific information to understand the past and predict the future of PBEO research. This article shall serve as a one stop destination for all requirements related to PBEO. The article is expected to be research guide for researchers to understand the global trend in PBEO and shall help in looking out for active collaborating research partners and also in global research networking. Thirty years of SCPUS data has been presented under one roof with critical inputs on different varieties of *Piper betle* and the variations in chemical composition of PBEO associated with these varieties. Various research hotspots with future scope of scientific exploration has also been highlighted which shall be like gold dust for researchers. A Complete dashboard-based information on PBEO research has been produced to create a single window visualization of all numeric data based on PBEO research (Figure 13). Such data shall help in early detection of research work already conducted so that their further replication may be avoided by researchers. This is the first attempt of presenting the research findings of PBEO from 1991-2021 through a bibliometric analysis based comprehensive review. This article is proposed

as a bibliometric data driven consolidated analysis report for the work done so far and the road ahead. This article shall ease out the decision-making process for researchers interested in PBEO research. Although significant research on PBEO has taken place, there could be many other promising areas of untapped potential that needs to be identified and explored. Hence, it would be wise to understand the past and present research trends, find research gaps and propose future research roadmaps comprehensively and systematically. This study is a sincere attempt in that direction.

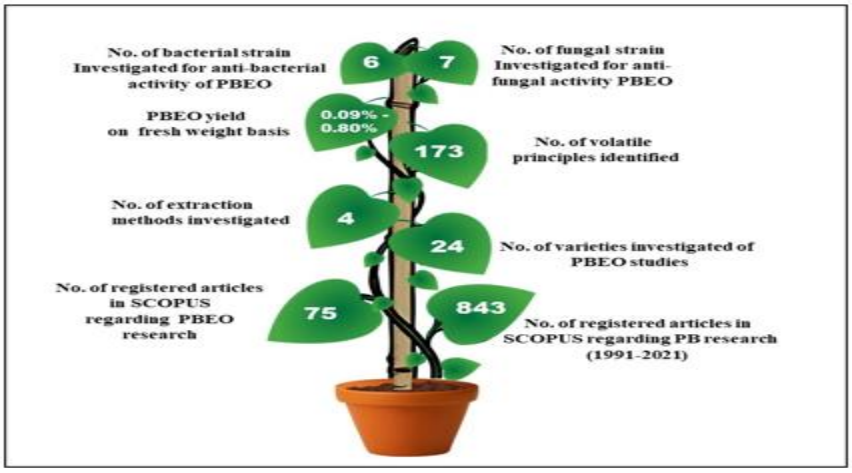


Figure 13: *Piper betle* dash board

Author Contributions:

SM: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing - review & editing. KBC: Formal analysis, Supporting, Methodology, Writing – review. HSK: Data curation, Supporting, Investigation, Supporting, Software - Supporting MD: Conceptualization, Supporting, Methodology, Supporting, Writing – original draft. MSA: Conceptualization, Supporting, Data curation. VM: Conceptualization, Lead, Data curation, Formal analysis, Lead Equal Writing – original draft, Equal, Writing – review & editing.

Conflicts of Interest:

The authors declare that there is no conflict of interest associated with this article.

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