

# Examining the Trend in Agarwood Oil Studies for the 5 Recent Years (2019-2023): A Comprehensive Bibliometric Analysis using VOSviewer

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**Abstract**— This bibliometric article investigates the burgeoning research landscape surrounding agarwood oil, derived from the *Aquilaria* tree species. The historical and cultural significance of agarwood, coupled with its diverse applications in perfumery, traditional medicine, and religious practices, has fueled a surge in scientific interest. However, a comprehensive understanding of the current state of agarwood oil research is lacking. This study addresses this gap through a systematic review and bibliometric analysis, utilizing the SCOPUS database as the primary source of scholarly. By employing techniques such as co-citation analysis and keyword co-occurrence, the research aims to quantify patterns, relationships, and collaborations within the literature. The methodology involves a focused exploration of a specified timeframe to capture recent developments, with the anticipation that the outcomes will include the identification of key contributors, thematic clusters, and emerging trends in agarwood oil research. The study is poised to contribute valuable insights for researchers, policymakers, and industry stakeholders, offering a holistic perspective on the interconnectedness of agarwood oil research and guiding future exploration in this dynamic field.

**Index Terms**— Agarwood oil, bibliometric analysis, gaharu, research trend, VOSviewer

## I. INTRODUCTION

The surge in scientific interest and commercial significance of agarwood oil derived from the *Aquilaria* tree species has propelled it to the forefront of research in recent years. This aromatic substance, with deep-rooted cultural, religious, and traditional medicinal value, has witnessed an unprecedented rise in demand across various industries, ranging from perfumery to pharmaceutical [1]–[3]. As an academician deeply

engaged in exploring emerging trends, this bibliometric analysis seeks to comprehensively examine the trajectory of agarwood oil studies within the scholarly landscape [4]. Agarwood's historical importance is underscored by its use in diverse cultural practices and traditional healing systems [5]–[7]. The dynamic relationship between historical significance and modern applications has spurred a multifaceted exploration of agarwood oil's chemical composition, extraction methodologies, and extensive applications. Despite the expanding body of literature on agarwood, there exists a critical gap in our understanding, a comprehensive bibliometric assessment that systematically reviews and analyzes the evolving trends in agarwood oil studies.

The proposed study addresses this gap through a meticulous examination of scholarly databases, employing advanced bibliometric techniques such as co-citation analysis and keyword co-occurrence. By delving into the vast expanse of Agarwood literature within a specified timeframe, this analysis aims to unearth hidden patterns, identify influential contributors, and map the collaborative networks shaping the field. Through the lens of bibliometrics, the study not only promises to provide a panoramic view of the current research landscape but also offers a strategic roadmap for future investigations and applications.

This paper is structured as follows: Section 2 provides a literature review on the significant chemical constituents and applications of agarwood oil. Section 3 discusses the data collection process and bibliometric methods employed, including keyword co-occurrence and co-citation analysis. In Section 4, we present the bibliometric findings, covering research trends, key contributors, and thematic clusters. Section 5 offers a discussion of the results, highlighting the implications for future research and potential applications. Finally, Section 6 concludes the paper by summarizing the key findings and suggesting directions for further

## II. LITERATURE REVIEW

### A. Agarwood Essential Oil

Agarwood, derived from the *Aquilaria* tree species, is a resinous substance highly esteemed for its distinct aroma. It has played a pivotal role in cultural practices across the globe. Throughout history, agarwood has been utilized in religious ceremonies, traditional medicine, and perfumery due to its

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aromatic and therapeutic properties [8]–[10]. The deep cultural roots of agarwood make it a subject of both historical and contemporary interest. Traditional uses have prompted scientific inquiry into its chemical composition and potential applications, revealing a complex matrix of secondary metabolites that contribute to its unique fragrance [11][12][13].

### B. Chemical Composition

Extensive research has delved into the intricate chemical composition of agarwood, uncovering a diverse array of sesquiterpenes, phenolic compounds, and volatile oils that contribute to its therapeutic properties[14][15][16]. Notable examples include  $\alpha$ -agarofuran and  $\beta$ -agarotene among the sesquiterpenes, and eugenol and vanillin among the phenolic compounds. The pharmacological potential of Agarwood has been explored, with studies demonstrating antimicrobial, anti-inflammatory, and antioxidant activities [17][18].

### C. Cultural Significance

The multifaceted nature of agarwood's bioactivity has prompted increased attention from the pharmaceutical and cosmetic industries, to harness its medicinal and aromatic potential for various applications [19]. Agarwood's applications extend beyond traditional uses, encompassing a broad spectrum of industries. Its incorporation into perfumery has been a longstanding practice, with the unique fragrance profile making it a sought-after ingredient in high-end fragrances [10], [12], [20], [21] However, the sustainable production of agarwood presents challenges, as the formation is often induced by external factors such as fungal infections or physical injury to the trees [6][22]. Striking a balance between conservation efforts and meeting the increasing demand for agarwood products poses a significant challenge that requires interdisciplinary solutions. While individual studies have contributed substantially to understanding agarwood, there is a need for a comprehensive overview of the research landscape. A bibliometric analysis of agarwood oil studies would offer [10]:

- 1) With a thorough bibliometric analysis covering the years 2019 to 2023, the paper provides a methodical picture of the changing field of agarwood oil research. The study offers important insights into the trends, major contributors, and developing themes in this field by synthesizing the body of available knowledge.
- 2) The paper consolidates and analyzes research on agarwood oil's chemical composition and pharmacological properties, facilitating a comprehensive understanding of its unique fragrance and potential therapeutic uses.
- 3) The study offers valuable insights for policymakers, conservationists, and industry stakeholders to promote responsible and sustainable approaches to agarwood production.

## III. DATA COLLECTION & METHOD

Bibliometrics involves consolidating, managing, and scrutinizing bibliographic information derived from scientific publications[23]–[26]. In addition to basic descriptive statistics like publishing journals, publication year, and primary author classification[27], it encompasses intricate techniques such as document co-citation analysis. Conducting an effective literature review requires an iterative process that involves the identification of suitable keywords and a literature search. This is followed by a comprehensive analysis to construct a thorough bibliography and produce reliable results [28], [29]. Given these considerations, the study aimed to concentrate on top-tier publications, as they provide valuable insights into the theoretical perspectives shaping the evolution of the research domain. To ensure data reliability, the study relied on the SCOPUS database for data collection due to its extensive coverage of peer-reviewed literature [30][31]. Furthermore, to guarantee the inclusion of high-quality publications, only articles published in rigorously peer-reviewed academic journals were considered, deliberately excluding books and lecture notes[32]. It is worth noting that Elsevier's Scopus, renowned for its extensive coverage, facilitated the collection of publications spanning from 2019 to December 2023 for subsequent analysis.

### A. Data search strategy

The study employed a screening sequence to determine the search terms for article retrieval. Study was initiated by querying Scopus database as shown in Table I and Table II with online TITLE ( agarwood OR Aquilaria ) AND ( LIMIT-TO ( SRCTYPE , "j" ) OR LIMIT-TO ( SRCTYPE , "p" ) ) AND ( LIMIT-TO ( PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) ) AND ( LIMIT-TO ( PUBYEAR , 2019 ) OR LIMIT-TO ( PUBYEAR , 2020 ) OR LIMIT-TO ( PUBYEAR , 2021 ) OR LIMIT-TO ( PUBYEAR , 2022 ) OR LIMIT-TO ( PUBYEAR , 2023 ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) , thereby assembling 1135 articles as shown in Fig. 1 with the latest article identified through the search query was titled 2-(2-Phenylethyl)chromone-enriched extract of Chinese agarwood (*Aquilaria sinensis*) inhibits atherosclerosis progression through endoplasmic reticulum stress-mediated CD36 expression in macrophages by [33] .Meanwhile, Fig. 2 enumerates various document categories. The table shows that the vast majority (83.5%) of the documents are articles. This is to be expected, as articles are the most common type of scientific publication. A smaller number of the documents are conference papers (10.7%), reviews (2.9%), letters (0.7%), notes (0.7%), errata (0.6%), book chapters (0.5%), data papers (0.1%), editorials (0.1%), and short surveys (0.1%). The high proportion of articles suggests that agarwood oil is a well-researched topic. The presence of a few conference papers, reviews, and other document types suggests that there is also interest in disseminating and synthesizing research on agarwood oil. Afterwards, the query string was revised so that the search terms “agarwood OR Aquilaria” and the final search string refinement included 440 articles which were used for bibliometric analysis. As of December 2023, all articles from

Scopus database relating to agarwood and Aquilaria oil, were incorporated in the study.

TABLE I. THE SEARCH STRING

| The Database | The search query                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Scopus       | TITLE ( agarwood OR Aquilaria ) AND ( LIMIT-TO ( SRCTYPE , "j" ) OR LIMIT-TO ( SRCTYPE , "p" ) ) AND ( LIMIT-TO ( PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) ) AND ( LIMIT-TO ( PUBYEAR , 2019 ) OR LIMIT-TO ( PUBYEAR , 2020 ) OR LIMIT-TO ( PUBYEAR , 2021 ) OR LIMIT-TO ( PUBYEAR , 2022 ) OR LIMIT-TO ( PUBYEAR , 2023 ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) |

TABLE II. THE INCLUSION AND EXCLUSION CRITERIA

| Criterion       | Inclusion                        | Exclusion    |
|-----------------|----------------------------------|--------------|
| Language        | English                          | Non-English  |
| Timeline        | 2019-2023                        | <2019        |
| Literature type | Journal (Article) and proceeding | Book, Review |

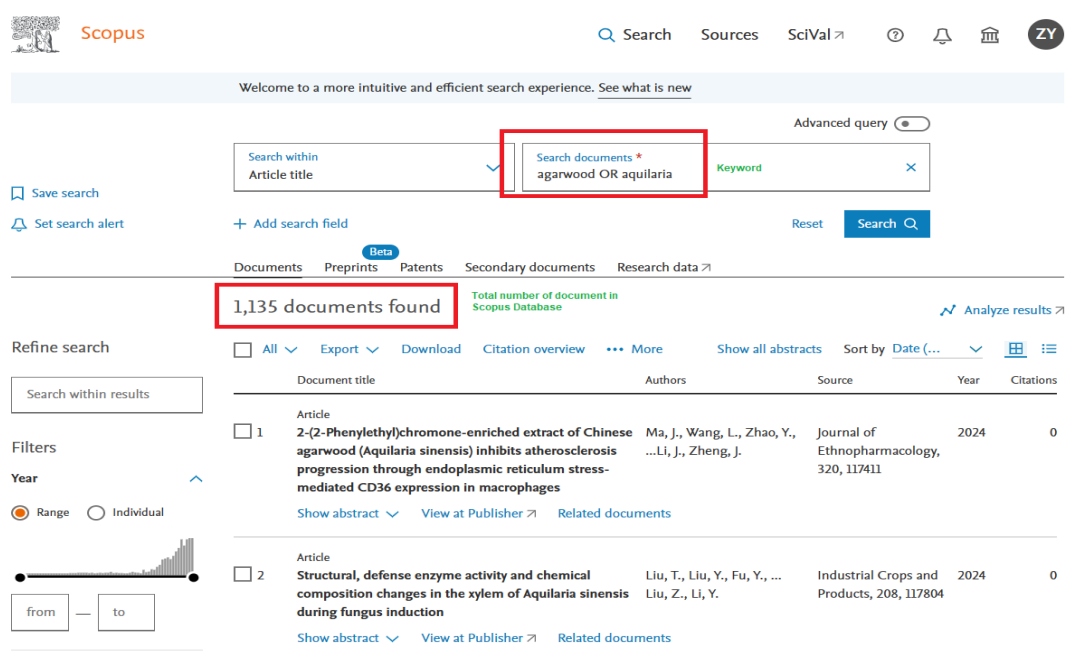


Fig. 1. The keyword is included in the search group on Scopus

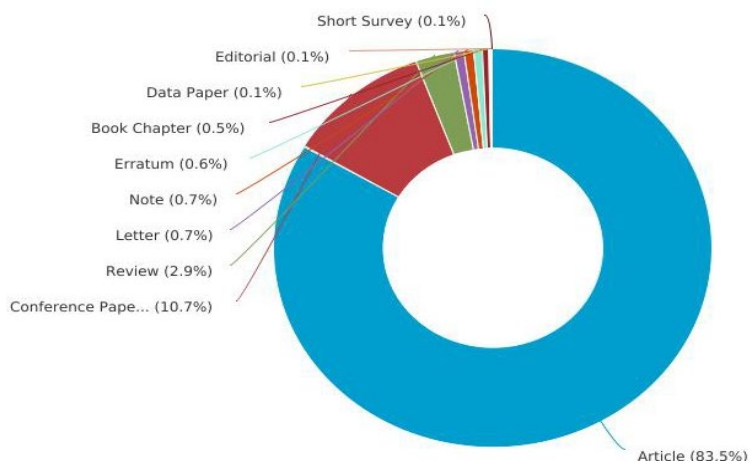


Fig. 2. The bibliometric categories of documents

### B. Data Analysis Data search strategy

Data sets containing the study publication year, publication title, author name, journal, citation, and keyword in PlainText format were acquired from the Scopus Database covering the period 2019 to December 2023 and were analyzed in VOSviewer software version 1.6.19. Using VOS clustering and mapping techniques, this software was used for analysis and map generation. These techniques analyze relationships between different publications or authors by grouping them based on co-citation or co-authorship patterns. An alternative to the Multidimensional Scaling (MDS) approach, VOSViewer is focused on placing items in low-dimensional areas so that the distance between any two items accurately reflects their relatedness and similarity[34]. This approach is similar to the MDS approach in this regard[35]. In contrast to MDS, which focuses on calculating similarity metrics like cosine and Jaccard indices, VOS uses a more appropriate method for normalizing co-occurrence frequencies[36], such as the association strength ( $As_{ij}$ ), which is calculated as in (1) and (2):

$$As_{ij} = \frac{1}{4} C_{ij} \quad (1)$$

$$WiWj \quad (2)$$

which is proportional to the ratio between, on the one hand, the observed number of co-occurrences of  $i$  and  $j$ , and on the other hand, the expected number of co-occurrences of  $i$  and  $j$  under the assumption that co-occurrences of  $i$  and  $j$  are statistically independent. Consequently, employing this index, VOSViewer arranges items into a map by reducing the weighted sum of squared distances between all pairs of items. As highlighted by [35], the LinLog/modularity normalization method was implemented. Additionally, leveraging visualization techniques in VOSViewer for the dataset revealed patterns based on mathematical relationships, facilitating analyses such as keyword co-occurrence, citation analysis, and co-citation analysis. Therefore, utilizing this index, VOSviewer organizes items into a map by minimizing the weighted sum of squared distances between all pairs of items. According to [35], LinLog/modularity normalization was employed to improve the accuracy of the clustering results in the analysis. This method adjusts the weights of edges in the network based on the degree of nodes, helping to enhance the detection of community structures within the data. Employing visualization techniques with VOSviewer on the dataset revealed patterns based on mathematical relationships, leading to analyses such as keyword co-occurrence, citation analysis, and co-citation analysis. The evolution of a research area over time can be examined through keyword co-occurrence analysis[37], which successfully identifies popular topics in various fields [38]. In contrast, citation analysis proves valuable for identifying key research issues, trends, and techniques, as well as exploring the historical relevance of a discipline's primary focus area[39]. Document co-citation analysis is a widely used bibliometric method [28], [32], [35], that relies on network theory to identify the relevant structure of data [32] [40].

## IV. BIBLIOMETRIC ANALYSIS

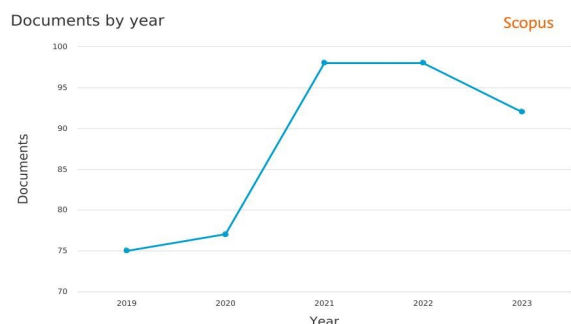
This section will explore the landscape of agarwood research, investigate current trends, examines research trends in agarwood based on the year of publication, identifies authors of the most-cited articles along with their affiliations, delve into the most popular subject areas, rank the top 10 documents by the number of citations, explore the popularity of documents by affiliation, maps the co-authorship network within the agarwood research community, highlights popular keywords related to the study, and provide a comprehensive network mapping with countries.

### A. Research trends in Agarwood according to the year of publication

The data presented in Table III and Fig. 3 provide a comprehensive view of the number of publications over a five-year period. In 2019, there were 75 publications, accounting for 17.05% of the total. The following year, 2020, saw a slight increase to 77 publications, representing 17.50%. Subsequently, 2021 and 2022 exhibited consistency with 98 publications each, constituting 22.27% in both years. The most recent data for 2023 indicates a slight decrease to 92 publications, contributing 20.91% to the total. The percentage distribution reveals that 2021 and 2022 share the highest contribution, each accounting for 22.27%, while 2023, though slightly lower, still maintains a substantial presence with 20.91%. The years 2019 and 2020, with slightly lower percentages, suggest a comparatively smaller contribution during those periods. The analysis indicates a noticeable increase in publications from 2019 to 2020, followed by a plateau in 2021 and 2022, and a slight decrease in 2023. Understanding these trends is crucial for stakeholders, researchers, and policymakers to plan future research strategies, allocate resources effectively, and gain insights into the dynamics of the field over time. Further investigation into the context and factors influencing these trends could provide a more nuanced understanding of the publication landscape.

TABLE III. PERCENTAGES OF RESEARCH TRENDS IN AGARWOOD

| Year | Number of Publication | Percentage (%) |
|------|-----------------------|----------------|
| 2023 | 92                    | 20.91          |
| 2022 | 98                    | 22.27          |
| 2021 | 98                    | 22.27          |
| 2020 | 77                    | 17.50          |
| 2019 | 75                    | 17.05          |



**Fig. 3.** Research trends in agarwood according to the year of publication

### B. The most cited articles

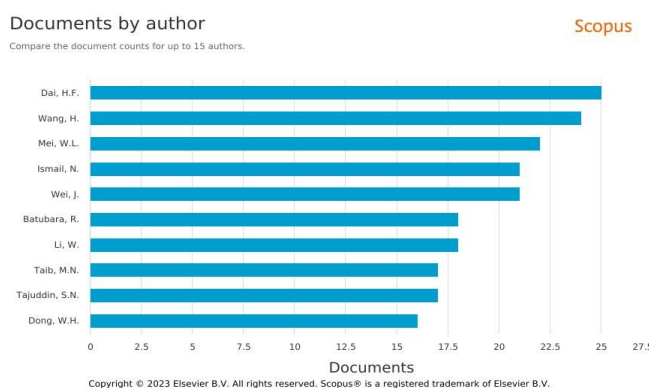
The bibliometric analysis of agarwood oil, as reflected in Fig. 4 and Table IV detailing the number of documents published by authors using Scopus Analyzer, offers a comprehensive overview of the scholarly landscape in this field. It allows researchers to examine publication trends, citation patterns, and the impact of specific articles or authors over time. The data not only highlights prolific authors but also provides a quantitative measure of their individual contributions, expressed as both absolute numbers and percentages. Dai, H.F., emerges as the leading contributor with a substantial 25 documents, representing 2.70% of the total output. His significant percentage indicates a noteworthy influence in the academic discourse surrounding agarwood oil.

Following closely is Wang, H., with 24 documents, contributing 2.59% to the overall body of literature. The combined impact of Dai and Wang suggests a concentrated expertise at the forefront of agarwood oil research. Mei, W.L., Ismail, N., and Wei, J., each with 22 and 21 documents, respectively, contribute significantly, with their percentages (2.38% and 2.27%) underscoring their substantial influence. Their work not only adds depth to the field but also indicates a shared prominence in scholarly contributions. Batubara, R., and Li, W., both with 18 documents, represent 1.95% each, contributing meaningfully to the overall body of literature. Their consistent output suggests a sustained commitment to agarwood oil research, contributing to the diversity of perspectives within the academic community. Taib, M.N., Tajuddin, S.N., and Dong, W.H., each with 17 and 16 documents, contribute 1.84% and 1.73%, respectively. While individually their percentages may be slightly lower, their collective impact is crucial in shaping the multidimensional nature of agarwood oil research. The distribution of percentages among these prolific authors not only highlights their individual contributions but also indicates the relative weight of their impact within the broader context of agarwood oil research.

This information is valuable for researchers and policymakers seeking to understand the key players in the field, foster collaboration and identify potential areas for further exploration. In conclusion, bibliometric analysis, through both absolute document counts and percentages, provides a nuanced understanding of the scholarly contributions of various authors in the agarwood oil domain. This insight serves as a foundation for identifying research trends, influential figures, and potential collaborative opportunities within this specialized field.

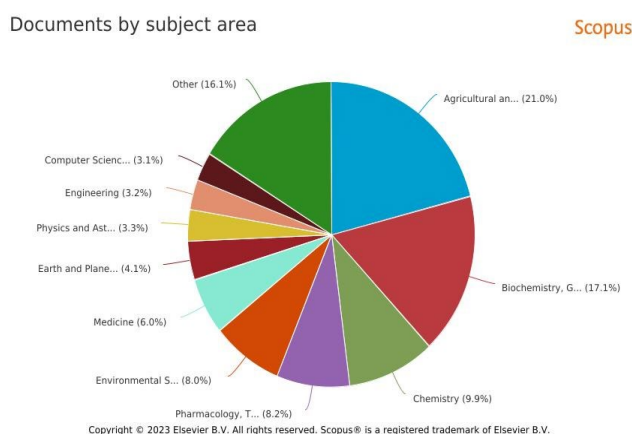
TABLE IV. PERCENTAGE OF DOCUMENTS BY AUTHOR

| Author Name    | Number of Document | Percentage (%) |
|----------------|--------------------|----------------|
| Dai, H.F.      | 25                 | 2.70           |
| Wang, H.       | 24                 | 2.59           |
| Mei, W.L.      | 22                 | 2.38           |
| Ismail, N.     | 21                 | 2.27           |
| Wei, J.        | 21                 | 2.27           |
| Batubara, R.   | 18                 | 1.95           |
| Li, W.         | 18                 | 1.95           |
| Taib, M.N.     | 17                 | 1.84           |
| Tajuddin, S.N. | 17                 | 1.84           |
| Dong, W.H.     | 16                 | 1.73           |



**Fig. 4.** Documents by author

### C. The most popular subject area in this research



**Fig. 5.** Documents by subject area

The bibliometric analysis of documents related to agarwood oil across various subject areas, as presented in Figure 5 utilizing Scopus Analyzer, provides a comprehensive understanding of the multidisciplinary nature of research in this field. The distribution of publications across subject areas not only highlights the diverse facets of agarwood oil exploration but also underscores its significance in a broad spectrum of scientific disciplines.

Agricultural and Biological Sciences emerge as the dominant subject area, with a substantial 178 publications, constituting an impressive 20.97% of the total output. This prominence suggests a strong emphasis on the biological and agricultural aspects of agarwood, potentially exploring its cultivation, biological properties, and ecological impact. The categories of Biochemistry, Genetics, and Molecular Biology closely follow with 145 publications, representing 17.08%. This indicates a substantial focus on the molecular and genetic aspects of agarwood, reflecting a keen interest in understanding the biochemical processes underlying its formation and properties. Chemistry, with 84 publications at 9.89%, signifies a significant contribution to the chemical characterization and analysis of agarwood. The emphasis on chemistry suggests a concentrated effort to unravel the complex chemical composition of agarwood, contributing to its applications and uses. Pharmacology, Toxicology, and Pharmaceuticals, with 70 publications (8.24%), reflect a growing interest in understanding the pharmacological properties of agarwood, potentially exploring its applications in medicine and pharmaceuticals. Environmental Science and Medicine contribute significantly, with 68 and 51 publications, representing 8.01% and 6.01%, respectively. This underscores the broader implications of agarwood oil, not only in terms of its ecological impact but also in its potential medicinal applications. Earth and Planetary Sciences, Physics and Astronomy, Engineering, and Computer Science collectively contribute to the interdisciplinary nature of agarwood research, with each subject area accounting for a smaller yet significant percentage of publications.

The diverse distribution of publications across these subject areas highlights the interconnectedness of agarwood oil research with various scientific disciplines. This cross-disciplinary engagement is crucial for comprehensively understanding the various facets of agarwood, from its biological and chemical aspects to its potential applications in medicine and environmental science.

#### D. Top 10 number of citations by research

The bibliometric analysis of the top 10 most-cited research articles related to Agarwood oil as tabulated in Table V, as indicated by Scopus Analyzer, sheds light on the seminal contributions that have garnered significant attention within the academic community. These highly cited works span a range of topics, from the chemical composition of agarwood to its molecular biology and medicinal properties. The article by Yang et al. [41] stands out as the most cited, with 39 citations. The research focuses on sesquiterpenoids and 2-(2-phenylethyl)chromones found in agarwood, showcasing their dual role as  $\alpha$ -glucosidase and tyrosinase inhibitors. This work is instrumental in understanding the pharmacological potential of agarwood compounds. Ding et al. [42] follow closely with 33 citations, presenting the first chromosome-level draft genome of the agarwood tree *Aquilaria sinensis*. This groundbreaking genomic study opens avenues for further genetic research and manipulation, providing a valuable resource for the scientific community.

TABLE V. TOP 10 NUMBER OF CITATIONS BY RESEARCH

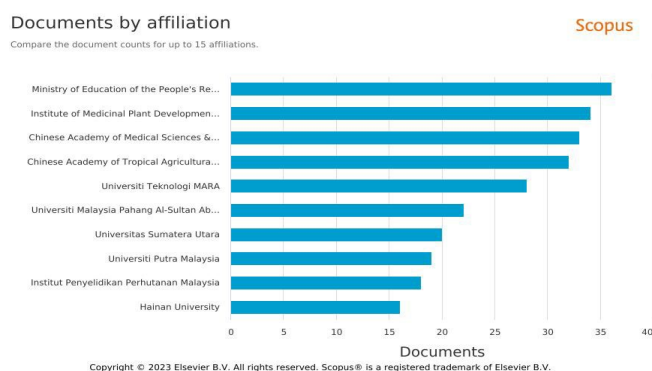
| Authors                                | Title                                                                                                                                                             | Year | Source title                                         | Cited by |
|----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------------------------------------------------------|----------|
| Yang et al. [41]                       | Sesquiterpenoids and 2-(2-phenylethyl)chromones respectively acting as $\alpha$ -glucosidase and tyrosinase inhibitors from agarwood of an <i>Aquilaria</i> plant | 2019 | Journal of Enzyme Inhibition and Medicinal Chemistry | 39       |
| Ding et al. [42]                       | Genome sequence of the agarwood tree <i>Aquilaria sinensis</i> (Lour.) Spreng: the first chromosome-level draft genome in the Thymelaeaceae family                | 2020 | GigaScience                                          | 33       |
| Lv et al. [43]                         | Hydrogen peroxide burst triggers accumulation of jasmonates and salicylic acid inducing sesquiterpene biosynthesis in wounded <i>Aquilaria sinensis</i>           | 2019 | Journal of Plant Physiology                          | 32       |
| Sun et al. [7]                         | WRKY44 represses expression of the wound-induced sesquiterpene biosynthetic gene ASS1 in <i>Aquilaria sinensis</i>                                                | 2020 | Journal of Experimental Botany                       | 31       |
| Liu et al. [44]                        | Interxylary phloem and xylem rays are the structural foundation of agarwood resin formation in the stems of <i>Aquilaria sinensis</i>                             | 2019 | Trees - Structure and Function                       | 30       |
| Thuy et al. [2]                        | Isolation process and compound identification of agarwood essential oils from <i>Aquilaria crassna</i> cultivated at three different locations in Vietnam         | 2019 | Processes                                            | 29       |
| Huo et al. [45]                        | LC-MS-guided isolation of anti-inflammatory 2-(2-phenylethyl)chromone dimers from Chinese agarwood ( <i>Aquilaria sinensis</i> )                                  | 2019 | Phytochemistry                                       | 28       |
| Yu et al. [46]                         | Anti-inflammatory 5,6,7,8-tetrahydro-2-(2-phenylethyl)chromones from agarwood of <i>Aquilaria sinensis</i>                                                        | 2020 | Bioorganic Chemistry                                 | 25       |
| Kuo T.-H.; Huang H.-C.; Hsu C.-C. [47] | Mass spectrometry imaging guided molecular networking to expedite discovery and structural analysis of agarwood natural products                                  | 2019 | Analytica Chimica Acta                               | 25       |
| Wang et al. [1]                        | Identification of a diarylpentanoid-producing polyketide synthase revealing an unusual biosynthetic pathway of 2-(2-phenylethyl)chromones in agarwood             | 2022 | Nature Communications                                | 24       |



Lv et al. [43] explore the molecular mechanisms behind agarwood resin formation, earning 32 citations. Their study delves into the hydrogen peroxide burst triggering the accumulation of jasmonates and salicylic acid, elucidating the intricate pathways leading to sesquiterpene biosynthesis. Investigating the role of WRKY44 in repressing the expression of the wound-induced sesquiterpene biosynthetic gene ASS1 in *Aquilaria sinensis* was studied by Sun et al. [7]. This research, with 31 citations, contributes to the understanding of gene regulation in agarwood formation. Next, Liu et al [44] provide structural insights into agarwood resin formation, specifically focusing on the interxylary phloem and xylem rays. This anatomical study, with 30 citations, establishes the structural foundation for resin production in the stems of *Aquilaria sinensis*.

Thuy et al. contribute to the exploration of agarwood essential oils, earning 29 citations for their work on the isolation process and compound identification from *Aquilaria crassna* cultivated in Vietnam [2]. Other notable works include studies on anti-inflammatory compounds isolated from agarwood, such as 2-(2-phenylethyl)chromone dimers [45], 5,6,7,8-tetrahydro-2-(2-phenylethyl)chromones [46], and the identification of diarylpentanoid-producing polyketide synthase [1]. Additionally, mass spectrometry imaging is explored as a tool for the discovery and structural analysis of agarwood natural products [47], highlighting the importance of advanced analytical techniques in agarwood research. These highly cited articles collectively contribute to the growing body of knowledge on agarwood, covering diverse aspects such as its chemical constituents, genomic makeup, pharmacological properties, and applications. The significant citation counts signify the impact and influence of these studies within the scientific community, making them pivotal references in the field of agarwood oil research.

### E. The most popular documents by affiliation



**Fig. 6.** Documents by affiliations

The top 10 affiliations by the number of publications as shown in Fig. 6 underscore the global nature of Agarwood research, with prominent representation from institutions in China and Southeast Asia. The Ministry of Education of the People's Republic of China emerges as the leading contributor with 36 publications, showcasing a robust commitment to Agarwood research. Following closely are the Institute of Medicinal Plant Development, Chinese Academy of Medical Sciences & Peking Union Medical College, and the Chinese

Academy of Medical Sciences & Peking Union Medical College with 34 and 33 publications, respectively. These affiliations, both prestigious in the medical sciences domain, demonstrate a sustained interest and investment in understanding the medicinal and therapeutic aspects of Agarwood oil. Notably, the Chinese Academy of Tropical Agricultural Sciences, with 32 publications, reflects the intersection of agricultural and medical research, emphasizing the multidisciplinary nature of Agarwood studies. This trend is further supported by the presence of Universiti Teknologi MARA, Universiti Malaysia Pahang Al-Sultan Abdullah, and Universitas Sumatera Utara, representing institutions from Malaysia and Indonesia, where Agarwood cultivation and traditional uses have deep cultural roots. The inclusion of Universiti Putra Malaysia, Institut Penyelidikan Perhutanan Malaysia, and Hainan University in the top 10 highlights the diversity of research perspectives. Universiti Putra Malaysia and Institut Penyelidikan Perhutanan Malaysia underscore the role of Malaysian institutions in contributing to the global discourse on Agarwood.

This analysis suggests a collaborative and global effort in Agarwood research, with institutions from China and Southeast Asia playing pivotal roles. The diverse affiliations in the top 10 signify a broad range of expertise, from medicinal plant development to tropical agricultural sciences, contributing to a holistic understanding of Agarwood oil. As the field continues to evolve, these findings provide valuable insights into the collaborative networks and geographic distribution of research efforts, paving the way for future interdisciplinary collaboration and knowledge exchange.

### F. Top journal publishing work on the subject area

Table VI shows the results obtained from the Scopus Analyzer and reveals the top journals contributing to the subject area. It presents key information, including the source title, the number of publications, and the respective percentage of contribution. Notably, the IOP Conference Series Earth and Environmental Science emerges as a prominent contributor with 30 publications, constituting 6.79% of the total. Following closely are journals such as *Molecules*, *AIP Conference Proceedings*, and *Biodiversitas*, each making significant contributions to the field. The list showcases a diverse range of journals, from *Fitoterapia* to *Industrial Crops and Products*, indicating the interdisciplinary nature of research on agarwood oil. Additionally, journals like the *Journal of Tropical Forest Science* and *Forests* underscore the importance of forestry-related publications in this domain. The findings suggest a varied landscape of scholarly output, with *Chemistry of Natural Compounds*, *Phytochemistry Letters*, and other specialized journals contributing significantly. Furthermore, the analysis reveals the international scope of research, with journals like *Mitochondrial DNA Part B Resources* and the *Indonesian Journal of Electrical Engineering and Computer Science* making noteworthy contributions. The distribution of publications across different journals emphasizes the collaborative and multidisciplinary nature of agarwood oil research.

TABLE VI. TOP JOURNAL PUBLISHING WORK ON THE SUBJECT AREA

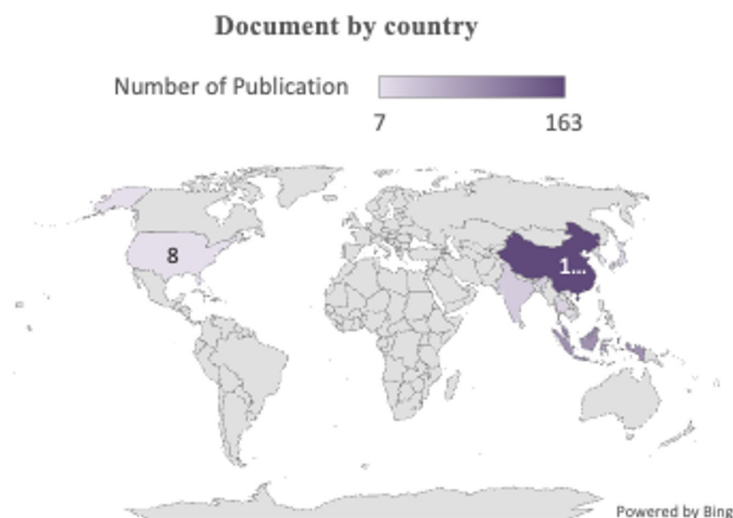
| Source Title                                                      | Number of publications | Percentage (%) |
|-------------------------------------------------------------------|------------------------|----------------|
| Iop Conference Series Earth and Environmental Science             | 30                     | 6.79           |
| Molecules                                                         | 17                     | 3.85           |
| Aip Conference Proceedings                                        | 14                     | 3.17           |
| Biodiversitas                                                     | 14                     | 3.17           |
| Fitoterapia                                                       | 12                     | 2.71           |
| Journal Of Tropical Forest Science                                | 12                     | 2.71           |
| Industrial Crops and Products                                     | 10                     | 2.26           |
| Forests                                                           | 9                      | 2.04           |
| Chemistry Of Natural Compounds                                    | 6                      | 1.36           |
| Indonesian Journal Of Electrical Engineering And Computer Science | 6                      | 1.36           |
| Mitochondrial DNA Part B Resources                                | 6                      | 1.36           |
| Phytochemistry Letters                                            | 6                      | 1.36           |
| Journal Of Natural Medicines                                      | 5                      | 1.13           |
| Phytochemistry                                                    | 5                      | 1.13           |
| IAWA Journal                                                      | 4                      | 0.90           |
| International Journal of Biological Macromolecules                | 4                      | 0.90           |
| Journal Of Asian Natural Products Research                        | 4                      | 0.90           |
| Journal Of Forestry Research                                      | 4                      | 0.90           |
| Natural Product Research                                          | 4                      | 0.90           |
| Bioresources                                                      | 3                      | 0.68           |

### G. Top Country Contributed to the Subject Area

The examination of the top countries contributing to the subject area reveals significant patterns, as shown in Fig. 7. Table VII presents crucial data, including the number of publications and the respective percentage contributions from each country or territory. China emerges as the leading contributor with a substantial 163 publications, constituting a remarkable 36.88% of the total output. Following closely are Malaysia and Indonesia, with 101 and 89 publications, respectively, showcasing their robust contributions at 22.85% and 20.14% of the total. This distribution underscores the substantial engagement of Asian countries in agarwood oil research. India, Thailand, and Japan contribute significantly, with 29, 22, and 20 publications, respectively. While India

represents 6.56% of the total output, Thailand and Japan contribute 4.98% and 4.52%, respectively. The collaborative efforts of these countries indicate a shared interest and involvement in advancing research in the field. Vietnam, Taiwan, the United States, and South Korea also make noteworthy contributions, each with a distinct percentage share ranging from 2.71% to 1.58%. This global distribution highlights the international collaboration and diverse perspectives in agarwood oil research. The dominance of China, coupled with significant contributions from Malaysia and Indonesia, reflects the concentrated regional interest in this subject area. The varied participation of other countries, including those outside Asia, further emphasizes the global relevance and collaborative nature of research on agarwood oil.





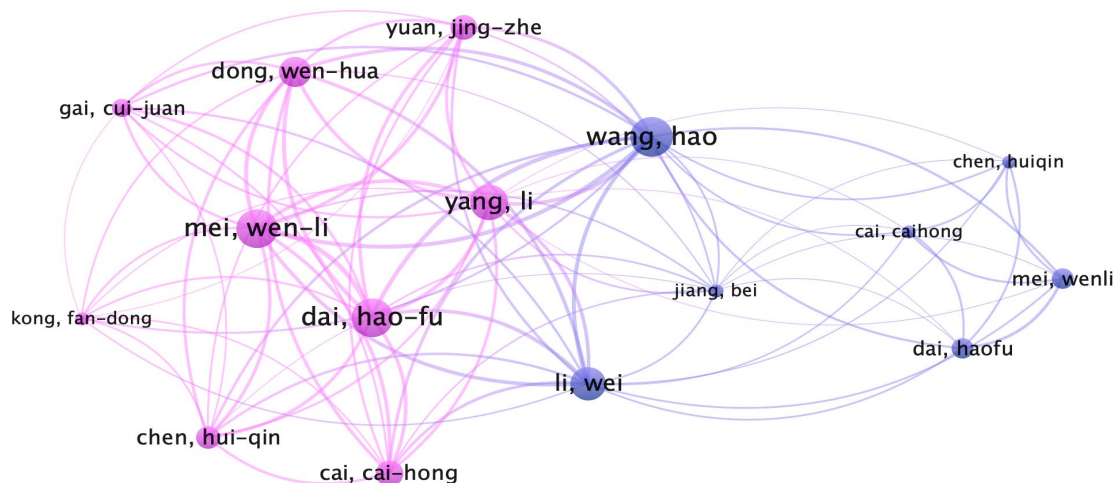
**Fig. 7.** Top Country Contributed to the Subject Area

**TABLE VII.** TOP COUNTRY CONTRIBUTOR TO THE SUBJECT AREA

| Country/Territory | Number of Publication | Percentage (%) |
|-------------------|-----------------------|----------------|
| China             | 163                   | 36.88          |
| Malaysia          | 101                   | 22.85          |
| Indonesia         | 89                    | 20.14          |
| India             | 29                    | 6.56           |
| Thailand          | 22                    | 4.98           |
| Japan             | 20                    | 4.52           |
| Viet Nam          | 12                    | 2.71           |
| Taiwan            | 11                    | 2.49           |
| United States     | 8                     | 1.81           |
| South Korea       | 7                     | 1.58           |

#### *H. The map of Co-Authorship about Agarwood*

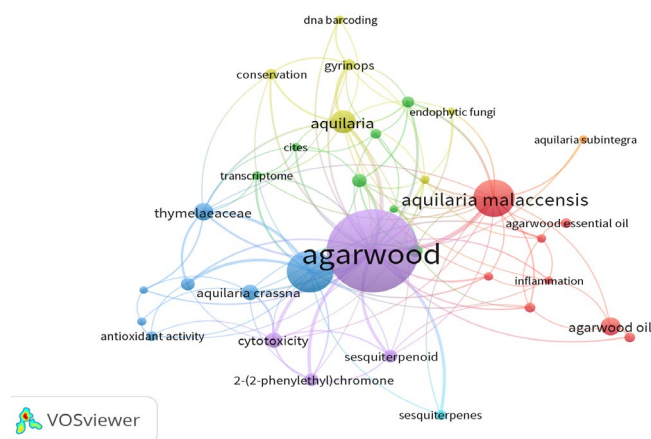
The map in Fig. 8 shows the relationships between different researchers who have co-authored papers about agarwood oil. The size of the nodes represents the number of papers that an author has co-authored, and the thickness of the edges between nodes represents the strength of the co-authorship relationship. The central nodes in the map are Yuan, Jing-zhe and Dong, Wen-hua, who have co-authored the most papers about agarwood oil together. They are followed by Gai, Cui-juan, Wang, Hao, and Chen, Huiqin. These researchers have all made significant contributions to the field of agarwood oil research. The map also shows some interesting collaborations between researchers from different countries. For example, Yuan, Jing-Zhe from China has co-authored papers with Dong, Wen-Hua from Taiwan, Wang, Hao from China, and Chen, Huiqin from China. This suggests that there is a strong international collaboration in agarwood oil research.



**Fig. 8.** Network visualization map of Co-Authorship

### I. The popular keywords related to the study

Fig. 9 shows the relationships between different keywords that appear frequently together in papers about agarwood oil. The size of the nodes represents the frequency of the keyword, and the thickness of the edges between nodes represents the strength of the co-occurrence relationship. The central node in the map is "agarwood oil," which is not surprising given that it is the main topic of the paper. The other nodes that are most closely connected to "agarwood oil" include "agarwood," "sesquiterpenes," "aquilaria malaccensis," "agarwood essential oil," and "cytotoxicity." These keywords all represent important aspects of agarwood oil, such as its chemical composition, biological properties, and potential uses. The map also shows some interesting relationships between other keywords. For example, "agarwood" is connected to "thymelaeaceae," which is the family of plants that agarwood comes from. "Agarwood essential oil" is connected to "2-(2-phenylethyl) chromone," which is a major component of agarwood essential oil. And "cytotoxicity" is connected to "inflammation," which suggests that agarwood oil may have anti-inflammatory properties. Overall, the network visualization map provides a helpful overview of the main topics that are covered in the literature on agarwood oil. It can also be used to identify new research questions by looking for keywords that are not well-connected to others.



**Fig. 9.** Network Visualization Map of Keywords Co-occurrence

### J. Network mapping with countries



**Fig. 10.** Network mapping with countries

Fig. 10 shows a network map with several countries as nodes and connecting lines between them. The thickness of the lines represents the strength of collaboration between the countries. The countries with the most collaboration are:

Malaysia, Thailand, Vietnam, China, and Egypt. These countries are likely the leading producers or researchers of agarwood oil, as they have the most frequent collaborations with other countries on the topic.

## V. DISCUSSION IN THE SUBJECT AREA

### A. Keyword summary on Agarwood, Chemical Compounds and Sesquiterpenes

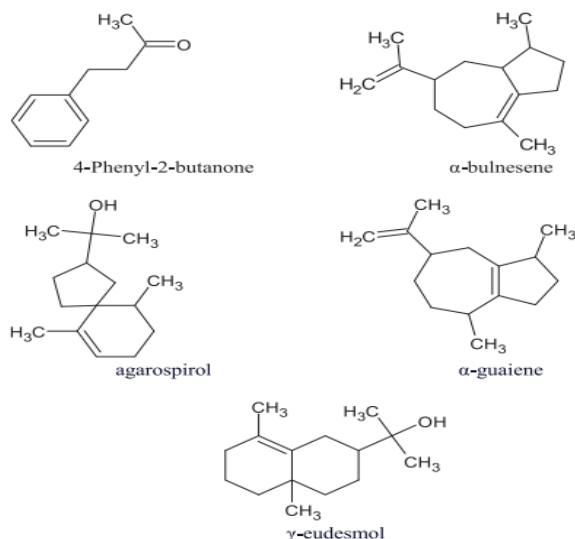
Agarwood oil, derived from the resin of *Aquilaria* trees, is a valuable and expensive product in the global market due to its numerous benefits and applications in perfumery, cosmetics, and traditional medicine. The chemical composition of agarwood oil plays a crucial role in determining its quality and potential applications. Agarwood oil is composed of various chemical compounds, with the most prominent being  $\beta$ -agarofuran,  $\alpha$ -agarofuran, 10-epi- $\beta$ -agarofuran, and  $\gamma$ -eudesmol [48], [49].

Other significant compounds include aromadendrane,  $\alpha$ -guaiene, 4-phenyl-2-butanone,  $\alpha$ -elemol,  $\alpha$ -muurolene, selina-3,11-dien-9-ol, and selina-4,11-dien-14-al [14], [50]. These compounds contribute to the unique aroma and therapeutic properties of agarwood oil. The chemical composition plays an important factor in determining its quality and potential applications in various industries, including perfumery, cosmetics, and traditional medicine.

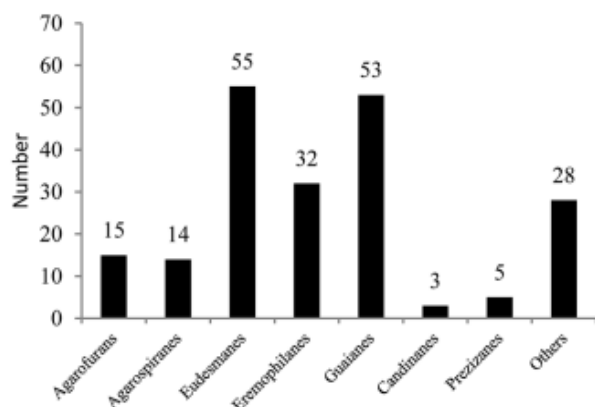
The current method of determining the quality of agarwood oil relies solely on human perception, which has several limitations. Firstly, human perception can be affected by the presence of multiple oils, making it difficult to accurately determine the quality of a sample. Secondly, the process is time-consuming and expensive, as it requires trained graders to evaluate the physical properties of the oil, such as color, odor, and long-lasting aroma. Thirdly, the human sensory system can be affected, particularly the eyes and nose, leading to inaccurate results [51]–[54]. The use of advanced analytical techniques, such as gas chromatography-mass spectrometry (GC-MS) and solid-phase microextraction (SPME) combined with GC-MS, has enabled the identification and quantification of these chemical compounds, providing valuable insights into the quality and classification of agarwood oil [55]–[60].

Sesquiterpenes are a class of compounds found in agarwood essential oil known for their therapeutic properties and distinct scent. Almost all types of sesquiterpenes can be found in the following four agarwood species: *A. sinensis*, *A. malaccensis*, *A. crassna*, and *A. subintegra*; however, there are significant differences among the sesquiterpenes of these species [61][2], [48], [54], [62]. Agarwood contains at least 210 sesquiterpenes, which vary in the type of skeleton, including eudesmanes, eremophilanes, guaianes, agarospiroanones, acoranes, cadinanes, prezizaanones, zizaanones, and humulanones. The sesquiterpenes isolated from agarwood exhibit various types, including acoranes (A), agarospiroanones (B), cadinanes (C), eudesmanes (D), eremophilanes (E), guaianes (F), humulanones (G), prezizaanones (H), and zizaanones (I). The complex composition of agarwood makes sesquiterpenes and chromone derivatives crucial for quality control analysis [48]. Fig. 11 displays the various types of sesquiterpenes in agarwood. Fig. 12 shows the percentage of each type of sesquiterpene found in agarwood

resin. The most abundant types of sesquiterpene are eudesmanes (55%), guaianes (53%) and eremophilanes (32%) of the resin. Other common types of sesquiterpenes include agarofurans (15%), agarospiroans (14%), and candinanes (3%).



**Fig. 11.** Some chemical constituents of Agarwood oil [54]



**Fig. 12.** Various types of sesquiterpenes in agarwood [48]

The presence of these different types of sesquiterpenes contributes to the unique aroma of agarwood. Guaianes are known for their woody, musky scent, while agarofurans have a sweet, floral aroma. Eudesmanes and eremophilanes have spicier, peppery scents. The relative abundance of these different sesquiterpenes can vary depending on the species of *Aquilaria* tree, the part of the tree that the resin comes from, and how the resin was formed. For example, agarwood that is formed in response to infection or injury tends to have higher levels of agarofurans, while agarwood that is formed naturally has higher levels of guaianes. The different types of sesquiterpenes in agarwood also have different medicinal properties. For example, guaianes have anti-inflammatory and anti-tumor effects, while agarofurans have anti-depressant and anti-anxiety effects [63]–[66].

There are several methods for extracting sesquiterpenes from agarwood, which contribute to the unique aroma and therapeutic properties of agarwood oil. The main extraction methods include the following:

- 1) Hydro distillation: This is the most common technique for extracting agarwood oil. It involves heating agarwood in steam, causing the essential oil to be released. The oil is then collected and purified for analysis [2].
- 2) Supercritical Fluid Extraction: This method involves using a supercritical fluid, typically carbon dioxide, to extract the essential oil from agarwood. This technique is less common than hydrodistillation but has been used in some studies to compare the extraction efficiency of the two methods [9], [67], [68].
- 3) Soxhlet Extraction: This technique involves heating the agarwood in a solvent, which causes the essential oil to be released and collected [69]–[71].

The choice of extraction method depends on factors such as the species of agarwood, the desired yield of essential oil, and the specific compounds of interest. Regardless of the extraction method used, the resulting essential oil will contain a variety of compounds, including sesquiterpenes, which can be further analyzed and isolated for study.

Several studies have investigated the medicinal properties of agarwood oil in relation to the different types of sesquiterpenes. These studies have explored various properties, including:

- 1) Anti-inflammatory properties: Sesquiterpenes like β-agarofuran and aromadendrene have been found to exhibit anti-inflammatory effects, which may be beneficial in treating inflammation and related conditions [72].
- 2) Analgesic properties: Sesquiterpenes in agarwood oil, such as β-agarofuran and agarospirol, have been suggested to exhibit analgesic effects, potentially making them useful in traditional medicine for pain management [58], [73].
- 3) Neuroprotective properties: Agarospirol, has been associated with potential neuroprotective properties, that may be beneficial in treating neurological disorders [49], [73].
- 4) Anti-tumor properties: Demonstrated anti-tumor effects, making them potential candidates for the development of anti-cancer therapies [58], [67].
- 5) Anti-bacterial properties: shown anti-bacterial properties, which can be useful in the development of antimicrobial agents [58].
- 6) Gastrointestinal regulation: relieve gastric problems, coughs, and high fever, and sesquiterpenes may contribute to these effects [43], [59].

#### B. The Agarwood Oil Forecast

Fig. 13 shows the Agarwood Oil Market: Global Industry Analysis and Forecast (2023-2029) [74]. The global agarwood oil market is expected to reach nearly US\$424.1 million by 2029, with a CAGR of 5.42% during the forecast period. This indicates steady growth in the market, driven by factors such as

increasing demand for natural and organic products, rising disposable incomes, and growing awareness of the health benefits of agarwood oil, as shown in Table IX. The Asia Pacific region is the largest market for agarwood oil, accounting for over 60% of the global market share in 2022. This is due to the strong presence of agarwood trees in the region, as well as the growing demand for agarwood oil in countries like China, Japan, and India. Europe and North America are the next largest markets, followed by the Middle East & Africa and South America. The market in these regions is expected to grow at a steady pace in the coming years, driven by factors such as increasing consumer interest in luxury goods and rising awareness of the therapeutic properties of agarwood oil.

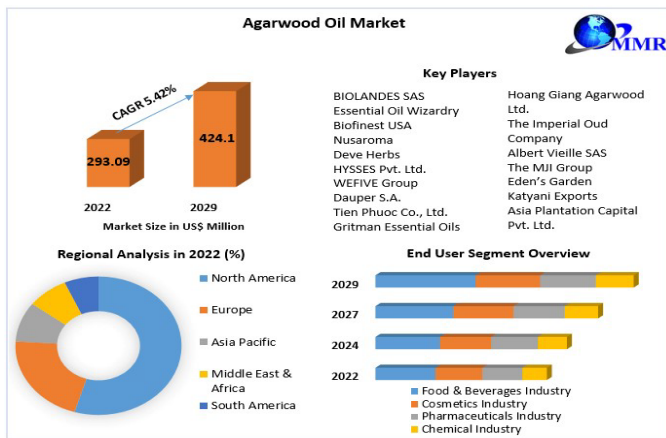


Fig. 13. The Agarwood Forecast

TABLE IX. THE MAJOR FACTORS DRIVING THE GROWTH OF THE AGARWOOD OIL MARKET INCLUDE

| Factor                                   | Description                                                                                                                                                                                                                                                                                                                               |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Unique Aroma and Therapeutic Properties  | Agarwood oil is highly sought after due to its unique aroma and therapeutic properties, making it a valuable commodity in the global market.                                                                                                                                                                                              |
| Increasing Demand in Various Industries: | The growing demand for agarwood oil in industries such as perfumery, cosmetics, and traditional medicine is a significant driver of market growth.                                                                                                                                                                                        |
| High Economic Value                      | The predominant amount of aromatic compounds in agarwood oil contributes to its high economic value, further fuelling its demand and market growth.                                                                                                                                                                                       |
| Lack of Standard Grading Method:         | The absence of a standard grading method for agarwood oil has led to the development of intelligent models for grading its quality, indicating a potential for market growth through improved quality classification.                                                                                                                     |
| Advancements in Analytical Techniques:   | The application of advanced analytical techniques, such as gas chromatography-mass spectrometry (GC-MS) and solid-phase microextraction (SPME) combined with GC-MS, has enabled the identification and quantification of the chemical compounds in agarwood oil, providing valuable insights into its quality and potential applications. |

The agarwood oil market is fragmented, with a number of small and medium-sized players. Some of the key players include Biolandes SAS, Nusaroma Company, Deve Herbs, Albert Vieille SAS, HYSSES Pvt. Ltd., WEFIVE Group, Eden's Garden, Dauper S.A., Katayani Exports, and Asia Plantation Capital. These players are involved in various stages

of the agarwood oil value chain, from cultivation and harvesting of agarwood trees to distillation and extraction of the oil, and distribution and marketing of the finished product.

The agarwood oil market is driven by a variety of end user segments, including the cosmetics and personal care industry, the food and beverage industry, the pharmaceutical industry, and the chemical industry. The cosmetics and personal care industry is the largest user of agarwood oil, accounting for over 40% of the global market. Agarwood oil is used in a variety of cosmetic products, such as perfumes, fragrances, soaps, and lotions, due to its pleasant aroma and perceived medicinal properties. The food and beverage industry is another important user of agarwood oil. Agarwood oil is used as a flavoring agent in a variety of food and beverage products, such as ice cream, cakes, and candy. The pharmaceutical industry is also increasingly interested in agarwood oil for its potential medicinal properties. Agarwood oil is being studied for its potential use in the treatment of a variety of conditions, such as cancer, anxiety, and depression.

The agarwood oil market faces a number of challenges, such as the unsustainable harvesting of agarwood trees, the lack of standardization in the industry, and the high price of the oil. However, there are also a number of opportunities for the agarwood oil market, such as the growing demand for natural and organic products, the increasing awareness of the health benefits of agarwood oil, and the development of new technologies for the cultivation and extraction of the oil.

## VI. CONCLUSION

The most recent data for 2023 indicates a slight decrease to 92 publications, contributing 20.91% to the total. The percentage distribution reveals that 2021 and 2022 share the highest contribution, each accounting for 22.27%, while 2023, though slightly lower, still maintains a substantial presence with 20.91%. The bibliometric analysis of agarwood oil, as reflected in the provided Table 3 detailing the number of documents published by authors using ScopusAnalyzer, offers a comprehensive overview of the scholarly landscape in this field. Dai, H.F., emerges as the leading contributor with a substantial 25 documents, representing 2.70% of the total output. The combined impact of Dai and Wang suggests a concentrated expertise at the forefront of agarwood oil research. Mei, W.L., Ismail, N., and Wei, J., each with 22 and 21 documents, respectively, contribute significantly, with their percentages (2.38% and 2.27%) underscoring their substantial influence. Batubara, R., and Li, W., both with 18 documents, represent 1.95% each, contributing meaningfully to the overall body of literature. The distribution of percentages among these prolific authors not only highlights their individual contributions but also indicates the relative weight of their impact within the broader context of agarwood oil research.

The bibliometric analysis of documents related to agarwood oil across various subject areas, as presented in the table utilizing ScopusAnalyzer, provides a comprehensive understanding of the multidisciplinary nature of research in this field. The distribution of publications across subject areas not only highlights the diverse facets of agarwood oil exploration but also underscores



its significance in a broad spectrum of scientific disciplines. Agricultural and Biological Sciences emerge as the dominant subject area, with a substantial 178 publications, constituting an impressive 20.97% of the total output. The categories of Biochemistry, Genetics, and Molecular Biology closely follow with 145 publications, representing 17.08%. Chemistry, with 84 publications at 9.89%, signifies a significant contribution to the chemical characterization and analysis of agarwood. The emphasis on chemistry suggests a concentrated effort to unravel the complex chemical composition of agarwood, contributing to its applications and uses. Environmental Science and Medicine contribute significantly, with 68 and 51 publications, representing 8.01% and 6.01%, respectively.

The diverse distribution of publications across these subject areas highlights the interconnectedness of agarwood oil research with various scientific disciplines. The bibliometric analysis of the top 10 most-cited research articles related to agarwood oil, as indicated by ScopusAnalyzer, sheds light on the seminal contributions that have garnered significant attention within the academic community. The article by Yang et al. Sun et al. Thuy et al. These highly cited articles collectively contribute to the growing body of knowledge on agarwood, covering diverse aspects such as its chemical constituents, genomic makeup, pharmacological properties, and applications. The significant citation counts signify the impact and influence of these studies within the scientific community, making them pivotal references in the field of agarwood oil research.

The co-authorship network analysis illustrates strong collaboration between researchers, with notable international partnerships. Yuan, Jing-zhe, and Dong, Wen-hua emerge as central figures, indicating their pivotal role in connecting researchers across different countries. This international collaboration suggests a shared commitment to advancing agarwood oil research on a global scale. The keyword co-occurrence network highlights the interconnectedness of key terms related to agarwood oil. "Agarwood oil" serves as the central node, with closely associated terms like "sesquiterpenes," "agarwood essential oil," and "cytotoxicity." This network provides a visual representation of the main topics covered in the literature and can guide future research directions. The collaboration network among countries reveals the leading contributors to agarwood oil research. Malaysia, Thailand, Vietnam, China, and Egypt stand out as key players, demonstrating strong collaborative ties. These collaborations may be driven by shared research interests, access to resources, or complementary expertise.

Agarwood oil holds immense value in the global market due to its numerous benefits and applications. The chemical composition of agarwood oil, particularly sesquiterpenes, plays a vital role in determining its quality and therapeutic properties. Despite challenges such as unsustainable harvesting practices and a lack of standardization, the market for agarwood oil is expected to grow steadily due to increasing demand for natural and organic products. Efforts to promote responsible harvesting practices and establish certification systems are crucial for the conservation and sustainability of agarwood-producing trees.

In conclusion, the bibliometric analysis offers a comprehensive overview of agarwood oil research, encompassing trends over time, influential authors, subject areas of focus, highly cited articles, co-authorship networks,

keyword relationships, and international collaborations. This information is invaluable for stakeholders, researchers, and policymakers in planning future research strategies, identifying collaboration opportunities, and gaining insights into the multidimensional nature of agarwood oil. As the field continues to evolve, ongoing bibliometric analyses will be essential to track emerging trends and guide the direction of future research.

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