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A Bibliometric Analysis of Agarwood Research, 1959-2021

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ABSTRACT

Agarwood is a fragrant resinous wood unique due to its peculiarity of being formed and harvested only from diseased trees of a certain genus of Thymelaeaceae. It has survived years of history and established itself in the modern agarwood value chain. Therefore, it is only logical that the progress has been fueled by scientific research carried out over the years. This current review is the first bibliometric study to uncover the agarwood research trend across many themes. Bibliometric data were extracted from the Scopus database in March 2021 using the search term 'agarwood' from 1959 to 2021. A total of 513 records were analysed using VosViewer and Publish or Perish software. Collectively, the articles were cited 6216 times with citations per year of 100.26 and an H-index of 42. The top-contributing countries were China, Malaysia, Japan and Indonesia. Most publications were in agricultural and biological sciences; biochemistry, genetics and molecular biology; chemistry; and pharmacology/pharmaceutics. The early years of agarwood research was focused on chemical compounds, followed by studies on biological effects before the themes became varied in the last ten years. Critical knowledge gaps identified include the safety of agarwood and its related materials, the translational link between proof of concept and clinical applications, and the role of agarwood in a nation's socioeconomic development. Altogether, this work could be used as a landscape to chart future research that leverages agarwood-producing trees as economic plant species towards progressive yet sustainable socioeconomic development and benefit humanity.

Keywords: agarwood, bibliometric, chromone, ecopharmacognosy, ethnopharmacology, sesquiterpene

INTRODUCTION

Agarwood has been present in various cultures in the world since thousands of years ago due to its widespread use for medicinal, aromatic and religious purposes. This also lends to its many names across cultures including 'oud' in Arabic, 'gaharu' in Malay and Indonesian language, 'jin-koh' in Japanese, 'chen xiang or chen hsiang' in

Chinese, 'agar' in Hindi (from Sanskrit 'aguru'), 'chim-hyuang' in Korea, 'tram huong' in Vietnamese language, 'kritsana noi' in Thai, and 'bols d'agle', 'bols d'aloes', 'calambac' or calambour' in French (Burkill 1935; Ng et al., 1997; Sidiyasa et al., 1986). The term 'agarwood' or its names in other languages normally refers to the heavy, dense and fragrant resinous wood (some authors use heartwood or stembark to mean wood interchangeably) that is formed in the trees of Aquilaria, Gonystylus and Gyrinops of the Thymelaeaceae family (Hashim et al., 2016). Agarwood is also referred to as aloeswood or eaglewood (López-Sampson and Page, 2018). This aromatic resinous wood has been traded since 2000 years ago through traditional trade routes (Hou and Steenis, 1960).

Interestingly, traditional high demand came from the non-growing area of agarwood, particularly the Middle East where agarwood is being used in daily cultural and religious purposes of the Arab community. While the Middle East is still the top consumer, followed by East Asia, in recent years; the high demand also came from the western countries where agarwood oil is used as base notes in luxury perfumes. The choice of agarwood oil in the blend of fragrances are due to the rich aroma and low volatility rendering the oil to have the characteristics of a fixative that holds many different notes and the ability to extend the longevity of fragrances (Lias et al. 2016). In more recent reports, Hai et al. (2021a, b) showed that agarwood oil is a good and effective fixative in blending fragrance aromatherapy.

Agarwood tree is a type of non-timber forest tree that can reach 40 m in height and 60 cm in diameter (Blanchette and van Beek, 2005). The natural habitat of agarwood trees is distinctive to South East Asia, some parts of China and the Indian subcontinent (Persoon and van Beek, 2008). The uniqueness of agarwood is attributed to the formation of the aromatic resinous wood of which it is only formed in stressed or diseased trees. This peculiarity has not only led agarwood to be regarded as the finest and the most expensive type of wood but also resulted in the overharvesting of wild trees in the forest.

In response to the threat of the sustainability of agarwood trees in the wild, two major resolutions emerged, one is the listing of Aquilaria species under CITES (CITES Trade Database 2021) and the Red List of the IUCN (IUCN Red List of Threatened Species 2021); and two is the establishment of agarwood plantations in many countries including Malaysia.

More subtle but nonetheless imperative responses following the above resolutions include technology advancement in areas of agronomic practices for agarwood plantation, plant tissue culture techniques, genetic tools for identification of agarwood species, technology innovation of inoculation or inducement methods and formulations for resin formation, new and improved methods for extraction of agarwood oil, modern technology to detect the resin in agarwood tree, modern techniques for profiling and grading agarwood, bioprospecting of materials from agarwood tree beyond the fragrant resinous wood and development of downstream products. This is in agreement with Khairuddin et al. (2017), who argued that science and technology must cut a whole spectrum of agarwood industry to solve problems and spur innovation. On a bigger scale, these scenarios feed into a circular economic model that values agarwood as a potential sustainable commodity that can provide a real positive socioeconomic impact to the nation.

It is only logical that the development in the agarwood value chain is fuelled by the exploration or investigations performed by the agarwood research fraternity. Akin to the vastness of the agarwood industry, themes of agarwood research also cover a broad subject area or discipline. While there have been reviews on agarwood in specific areas such as phytochemistry and secondary metabolites, pharmacology and biological activities, induction methods and historical aspects of agarwood; to the best of our knowledge this present study is the first attempt to look at agarwood research as a whole. This study also appears to be the first to adopt bibliometric analysis to uncover the trend of agarwood research across the many sub-disciplines or themes of the agarwood field.

Authors adopted a bibliometric and network analysis approach to examine 513 peer-reviewed journal articles drawn from the Scopus database. Taking advantage of the ability to comprehend Malay and Indonesian (the authors' native language), the articles in these languages are also included in the analysis.

Bibliometric analysis has increasingly been used to investigate and deduce the evolution of research areas of interest and project future trends. This is because it can systematically and elegantly acquire information from published literature through statistical and visualization tools (Ahmi and Mohamad, 2019). One team of researchers attributed their decision to use bibliometric analysis in their work to i) the ability of bibliometric analysis to efficiently handle a large number of articles, ii) the ability to capture comprehensive information, and iii) the visualisation of information that enables more practical interpretation of findings (Omar et al., 2020).

In natural products and ethnopharmacology areas, bibliometric approach has been undertaken to understand the research theme surrounding a topic and its future research trend. For example, Yeung et al. (2020) used a bibliometric approach to identify natural products and research directions of the major contributors of academic journals in the area of diabetic therapy. In another example, bibliometric analysis on curcumin research revealed that drug delivery, bioavailability and nanoparticles are the emerging trend in the field (Yeung et al., 2019). Meanwhile, in 2018, Yeung et al. identified important drivers and research trends in the field of ethnopharmacology including the emerging importance in the context of disease prevention (food science) alongside the conventional link of ethnopharmacology to traditional medicinal knowledge, drug discovery and pharmacology (Yeung et al., 2018).

This work aims to quantitatively evaluate the scholarly research on agarwood over time and investigate the evolution and research theme. Through bibliometric analysis, important questions including the most productive authors, affiliations and countries, can be answered. In addition, data on the most impactful articles based on citation is also obtained. Taken together, the information can assist in identifying gaps in the agarwood research landscape and forecasting future work towards sustainable use of this natural resource not only for research purposes but more importantly the translational impact to a progressive socioeconomic development and benefit to mankind.

SEARCH STRATEGY

This study involved data extraction from records in Scopus in the area of agarwood research. As the ultimate aim of the study was to identify the research gaps and potential future directions in the diverse area of agarwood research, the search was not limited to any specific scope. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were adopted to assist the systematic analysis of the data (Moher et al., 2010). The selected records were then analysed using bibliometric and network analysis.

Data sources

This study employed the Scopus database as a source of data. Scopus is one of the largest scholarly databases comprising science and social science (Falagas et al., 2008; Vieira and Gomes, 2009; Mongeon and Paul-Hus, 2016).

In March 2021, the authors searched the Scopus database to identify articles with the term “agarwood" that appear in their title, abstract, and or keyword. No limitation was set for the publication year. NMS performed the initial extraction of 596 records. Three researchers (NMS, YZH-YH and UAMT) screened the records and assessed for their eligibility to be included in the study. Records in foreign languages (other than English, Malay and Indonesian) and records with incomplete title, erratum and technical error were excluded, leaving 513 records relevant to the study. The search result containing 513 manuscripts was then exported into Research Information System (RIS) format to enable further bibliographic analysis.

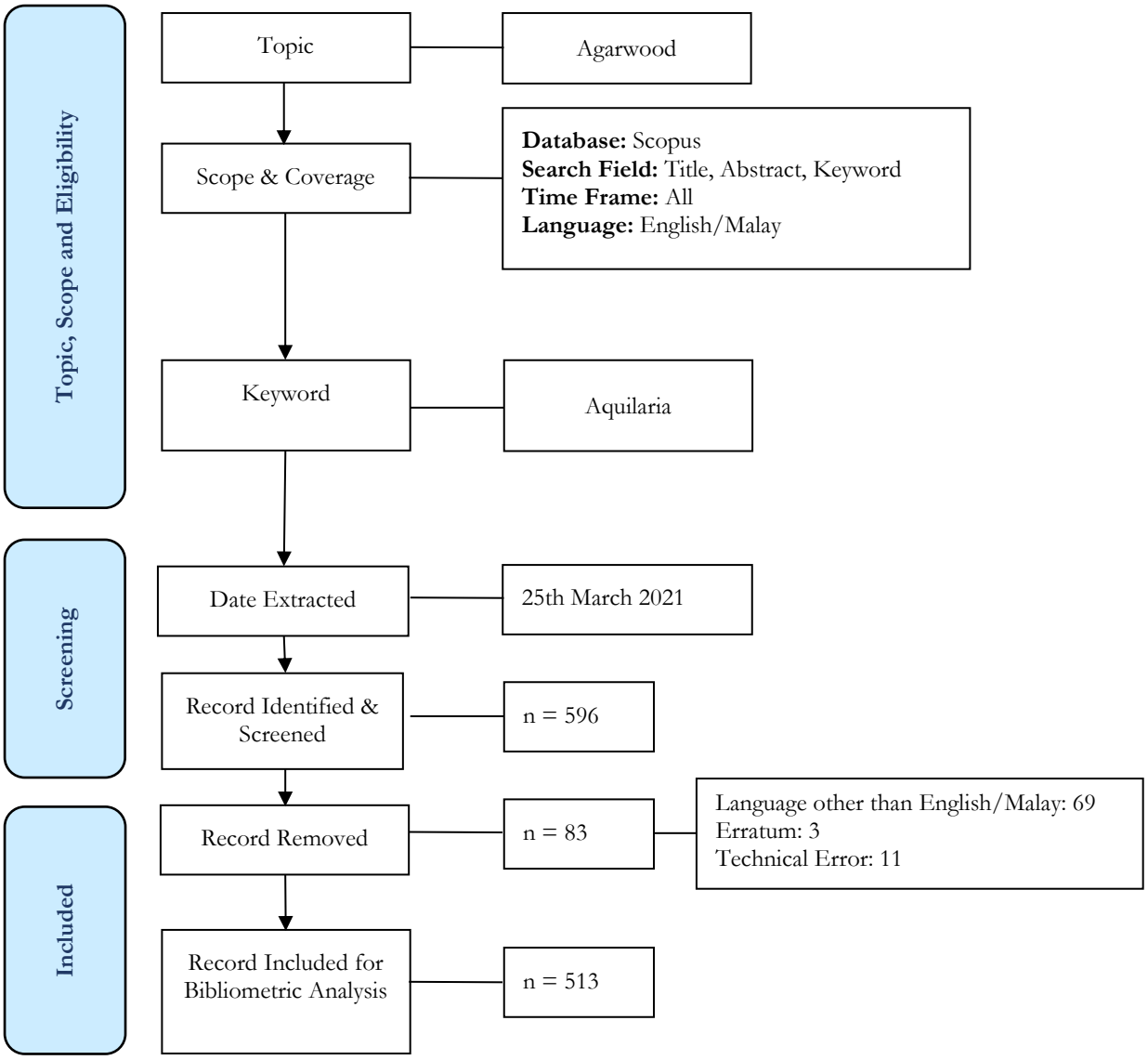


Fig. 1. Flow diagram of the search strategy. Modified from PRISMA (Moher et al. 2009)

Bibliometric and network analysis

The bibliometric analysis focused on answering the research questions by analysing publication growth, keywords, authors, affiliation, and citation patterns. VOSviewer software 1.6.13 was used to visualize the network or interrelationship of several indicators. Publish and Perish v7 was used to analyse data related to citation metrics.

RESULTS AND DISCUSSION

Document types

Table 1 shows that most documents published on agarwood in Scopus database are of article type (80.12%). Conference papers make up 14.82 %, while review type of papers only makes up 2.73% of total documents. Other types of documents represented less than 2.5 % of the total documents. Interestingly, researchers in agarwood have started to share datasets in line with the open science movement in recent years. In this instance,

Abdul Kadir et al. (2020) published the datasets of essential oils from naturally formed and synthetically induced agarwood. It is observed that a deficient proportion of review types of documents were published despite the considerably long history of use of agarwood in both classic and modern era. For example, the earliest review type of document was published by Ito (2008) in the Journal of Natural Medicines. Similarly, a very low number of book chapters written on agarwood seems to be disproportionate with the long history of use and diverse scope of agarwood.

Table 1. Document types

Document Type	Total Publications (TP)	Percentage (%)
Article	411	80.12
Conference Paper	76	14.82
Review	14	2.73
Book Chapter	4	0.78
Note	4	0.78
Letter	3	0.58
Data Paper	1	0.19
Total	**513**	**100.00**

It is interesting to see that review papers on agarwood discussed several major issues including induction technology, chemical constituents and biological or pharmacological effects. Sesquiterpenes, the characteristic component of agarwood oil, appears to be the main interest of the Chinese researchers as shown in Table 2.

Table 2. Review papers on agarwood published between 2008 and 2019

Title	Year	Source title	Authors
The scent of stress: Evidence from the unique fragrance of agarwood	2019	Frontiers in Plant Science	Naziz P.S., Das R., Sen S.
History and perspectives of induction technology for agarwood production from cultivated *Aquilaria* in Asia: a review	2019	Journal of Forestry Research	Azren P.D., Lee S.Y., Emang D., Mohamed R.
Agarwood induction: Current developments and future perspectives	2019	Frontiers in Plant Science	Tan C.S., Isa N.M., Ismail I., Zainal Z.
Inducement of agarwood resin using various chemical formulation of stem tissue (*Aquilaria malaccensis*)	2019	Journal of Global Pharma Technology	Elias M.F., Ibrahim H., Mahamod W.R.W., Zain H.H.M., Azziz S.S.S.A., Bakri Y.M.
Overview of sesquiterpenes and chromones of agarwood originating from four main species of the genus *Aquilaria*	2019	RSC Advances	Gao M., Han X., Sun Y., Chen H., Yang Y., Liu Y., Meng H., Gao Z., Xu Y., Zhang Z., Han J.
History of use and trade of agarwood	2018	Economic Botany	López-Sampson A., Page T.
Review: Secondary metabolites of *Aquilaria*, a thymelaeaceae genus	2018	Mini-Reviews in Organic Chemistry	Kristanti A.N., Tanjung M., Aminah N.S.
Chemical constituents and pharmacological activity of agarwood and *aquilaria* plants	2018	Molecules	Wang S., Yu Z., Wang C., Wu C., Guo P., Wei J.
Pharmacological properties of agarwood tea derived from *Aquilaria* (Thymelaeaceae) leaves: An emerging contemporary herbal drink	2017	Journal of Herbal Medicine	Adam A.Z., Lee S.Y., Mohamed R.
New guaiane and acorane sesquiterpenes in high quality agarwood "Qi-Nan" from *Aquilaria sinensis*	2016	Phytochemistry Letters	Yang D., Wang J., Li W., Dong W., Mei W., Dai H.
Aquilaria spp. (agarwood) as source of health beneficial compounds: A review of traditional use, phytochemistry and pharmacology	2016	Journal of Ethnopharmacology	Hashim Y.Z.H.-Y., Kerr P.G., Abbas P., Mohd Salleh H.

Chemical constituents of agarwood originating from the endemic genus *Aquilaria* plants	2012	Chemistry and Biodiversity	Chen H.-Q., Wei J.-H., Yang J.-S., Zhang Z., Yang Y., Gao Z.-H., Sui C., Gong B.
The volatile and semi-volatile constituents of agarwood, the infected heartwood of *Aquilaria* species: A review	2011	Flavour and Fragrance Journal	Naef R.
Studies on perilla, agarwood, and cinnamon through a combination of fieldwork and laboratory work	2008	Journal of Natural Medicines	Ito M.

Document by source type

Scopus covered documents from two source types; serial publications such as journals, book series and some conference series; and non-serial publications such as one-off book publications or one-off conferences (Scopus Content Coverage Guide 2020). It is observed that the documents sourced from conference proceedings were from three main conference series or proceedings; namely AIP (American Institute of Physics) Conference Proceedings, IOP (Institute of Physics) Conference Series and IEEE (Institute of Electrical and Electronics Engineers) Conferences.

Table 3. Source type

Source Type	Total Publications (TP)	Percentage (%)
Journals	434	84.60
Conference Proceedings	67	13.06
Book Series	9	1.75
Books	3	0.59
Total	**513**	**100.00**

Year of publication

The first publication was recorded as early as 1959 in Tetrahedrons. The author, Jain and Bhattacharyya (1959) from the National Chemical Laboratory, Poona, India reported on the structure, stereochemistry and absolute configuration of agarol, a new sesquiterpene alcohol from agarwood oil. Following the publication, the same group of authors published several other articles in the scope of agarwood chemical compounds and structure in the same journal (Tetrahedron) between the years 1963 to 1965. Until 2000, the number of agarwood articles was relatively low, with paper focusing on chemical compounds or components of agarwood and its oil. However, the research scope began to diversify in the new millennium to include agroforestry, agarwood formation, biological or pharmacological effects, ecology and distribution and conservation. The number of publications increased exponentially from the year 2010 until present suggesting a growing interest in scholarly agarwood research.

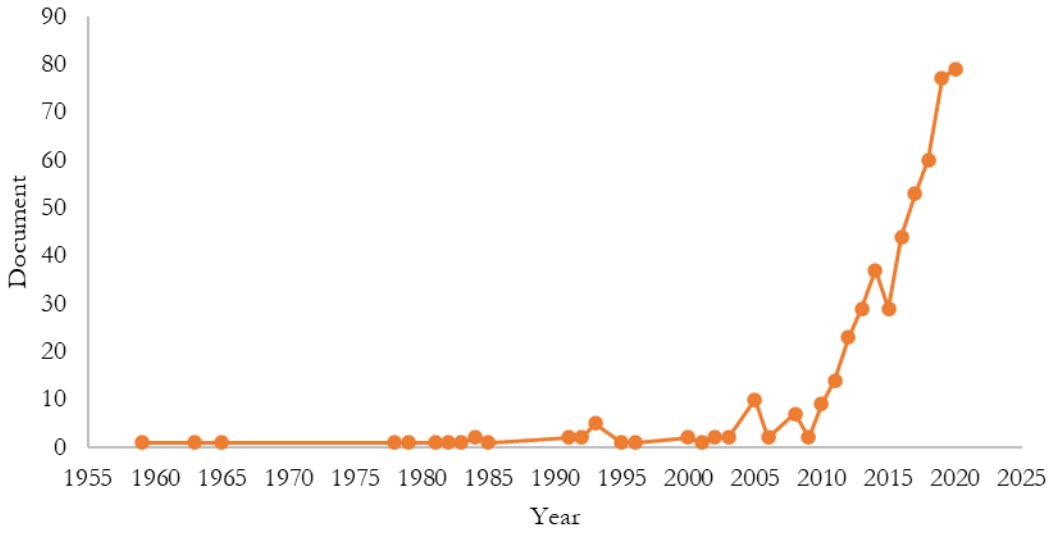


Fig. 2. Total publications by year

Looking into more details, the last ten years' evolution of published articles (Table 4) also suggests active research and publication by agarwood researchers, with the highest total publication of 79 in 2020 and the highest citation of 645 in 2014.

Table 4. Latest ten years evolution of published studies

Year	TP	TC	C/P	*H*	*G*
2012	23	426	18.52	11	20
2013	29	543	18.72	14	23
2014	37	645	17.43	17	24
2015	29	219	7.55	8	13
2016	44	530	12.05	13	21
2017	53	373	7.04	13	16
2018	60	278	4.63	9	12
2019	77	183	2.38	7	10
2020	79	55	0.70	4	4
2021	9	1	0.11	1	1

Notes: TP=total number of publications; TC=total citations; C/P=average citations per publication; H=h-index; and G=g-index.

Languages of documents

Table 5 presents the frequency of languages of all documents initially retrieved at screening stage considering the ethnopharmacological use of agarwood such as in Chinese Traditional Medicine, Ayurveda and several other Asian traditional based medicines, at this stage the aim was to see the relationship of ethnopharmacologic use and languages (hence culture and countries/nations) of publication. Most of the publications (87.75%) are in English and 10.23 % are in Chinese. The Chinese publications were published between 2010 until present in several journals, namely Chinese Traditional and Herbal Drugs, Chinese Pharmaceutical Journal, Journal of International Pharmaceutical Research, Yaoxue Xuebao and Zhongguo Zhongyao Zazhi. These publications seem to involve modern techniques, including gene expression, molecular biology and plant tissue cultures. It is argued that if the work was published in English, or dual language they can reach and benefit the global agarwood research community. Publication in Japanese constitutes 0.84% of the total document.

Interestingly, all the Japanese articles were related to the pharmacological effects of agarwood and its materials such as leaf. Taking advantage of the authors' native language, the two full Malay texts were included in the analysis. Both articles were published in the Malaysian Journal of Analytical Sciences by Ismail et al. (2013a, b), in the area of agarwood oil quality. Meanwhile, the article with dual and tri-languages of English, Spanish and French which described the study on chemotaxonomic marker to identify genus *Aquilaria* (Andary et al., 2019) was from the same group that studied the development of controlled production of agarwood from *Aquilaria crassna* Pierre ex Lecomte in French Guiana (Zaremski, 2020). The German article was published in Tetrahedron in 1963 by the same researchers from the National Chemical Laboratory, Poona, India (see section Year of Publication). It is also interesting to note that the Russian article was in oriental study (research in humanities) and published in the Novosibirsk State Pedagogical University Bulletin. Finally, the Thai article was published in Kasetsart Journal - Social Sciences in 2007, discussing socioeconomic and entrepreneurship surrounding agarwood.

Table 5. Languages

Language	Total Publications (TP)	Percentage (%)
English	523	87.75
Chinese	61	10.23
Japanese	5	0.84
English; Malay	2	0.33
English; Spanish; French	1	0.17
Spanish; English	1	0.17
German	1	0.17
Russian	1	0.17
Thai	1	0.17
Total	**596**	**100.00**

Subject area

Titles in Scopus are classified under four broad subject clusters (life sciences, physical sciences, health sciences, social sciences, and humanities), further divided into 27 major subject areas and 300+ minor subject areas (Scopus Content Coverage Guide, 2020). Table 6 shows that most agarwood publications in Scopus fall under the science subject area of agricultural and biological science, followed by biochemistry, genetics and molecular biology; chemistry; and pharmacology, toxicology and pharmaceutics. The agarwood publication also falls under the subject area of engineering, materials science and computer science; upon closer look, these are found to be contributed by the conference papers. Although the number is lower than science-related papers, agarwood publications were also found in social science subjects, including business, management and accounting; art and humanities; and economics, econometrics and finance. Taken together, this shows that the agarwood research area is diverse and as such, may impact various agarwood-related sectors.

Table 6. Subject area

Subject Area	Total Publications (TP)
Agricultural and biological sciences	200
Biochemistry, genetics and molecular biology	168
Chemistry	126
Pharmacology, toxicology and pharmaceutics	120
Engineering	58
Medicine	57
Environmental science	50

Computer science	30
Physics and astronomy	27
Materials science	21
Chemical engineering	20
Immunology and microbiology	19
Multidisciplinary	17
Mathematics	14
Earth and planetary sciences	13
Social sciences	5
Business, management and accounting	4
Art and humanities	3
Economics, econometrics and finance	3
Energy	2
Health professions	1
Neuroscience	1
Nursing	1
Psychology	1
Veterinary	1

Document by affiliation- most influential institutions with a minimum of ten publications

Scopus data indicated that China has the most agarwood-related publications, followed by Malaysia, Japan and Indonesia. Universiti Teknologi MARA topped the list, followed by the Chinese Academy of Tropical Agricultural Sciences and Universiti Putra Malaysia (Table 7).

Table 7. Most influential institutions with a minimum of ten publications

Affiliation	Country	TP
Universiti Teknologi MARA	Malaysia	54
Chinese Academy of Tropical Agricultural Sciences	China	49
Universiti Putra Malaysia	Malaysia	45
Universiti Malaysia Pahang	Malaysia	44
Forest Research Institute Malaysia	Malaysia	41
Chinese Academy of Medical Sciences & Peking Union Medical College	China	39
Institute of Medicinal Plant Development, Chinese Academy of Medical Sciences & Peking Union Medical College	China	38
Ministry of Agriculture of the People's Republic of China	China	35
Kyoto University	Japan	22
Hainan University	China	18
Ministry of Education China	China	13
Hainan Engineering Research Center of Agarwood	Cina	12
Beijing University of Chinese Medicine	China	12
International Islamic University Malaysia	Malaysia	12
Universitas Gadjah Mada	Indonesia	12
IPB University	Indonesia	11
Guandong College	China	10

Notes: Minimum of ten publications

Most active source titles

'Molecules' is the most active source title, with the earliest article on agarwood published in 2011. Most articles described agarwood's chemical constituents while a small fraction reported on the biological effects. Fitoterapia is the second most active source title with all articles reported on characterization and identification of chemical constituents in agarwood. Interestingly, two conference proceedings appear to be in the list of the most active source titles. Articles in the IOP Conference Series: Earth and Environmental Science mainly discussed agroforestry with specific scope of reports on agarwood in some parts of Indonesia and a focus on *Gyrinops* which is endemic in the country. Meanwhile, the articles in the AIP Conference Proceedings have more varied themes but with some focus on *Gyrinops*.

Table 8. Most active source title

Source Title	TP	Publisher
Molecules	20	Multidisciplinary Digital Publishing Institute (MDPI)
Fitoterapia	18	Elsevier B. V.
IOP Conference Series: Earth and Environmental Science	13	N/A
Journal of Tropical Forest Science	13	Forest Research Institute Malaysia
Journal of Natural Medicine	11	Springer Nature
AIP Conference Proceedings	11	N/A
Biodiversitas	11	Society for Indonesian Biodiversity
Phytochemistry	11	Elsevier B. V.
Phytochemistry Letters	7	Elsevier B. V.
Journal of Forestry Research	6	Northeast Forestry University
Journal of Asian Natural Products Research	6	Taylor and Francis Ltd.
Natural Product Communications	5	Natural Product Incorporation
Mitochondrial DNA Part B: Resources	5	Taylor and Francis Ltd.
Journal of Essential Oil Research	5	N/A
Frontiers in Plant Science	4	Frontiers Media S.A.

Keyword analysis

Table 9 shows unfiltered top keywords used in the articles. The important compounds of agarwood; chromone and sesquiterpene, are among the top keywords used, suggesting that a good proportion of research is related to these compounds. In addition, two species appeared to be highly researched namely *Aquilaria sinensis* and *Aquilaria malaccensis*.

Table 9. Top keywords

All Keywords	Number of keyword
Agarwood	261
Thymelaeaceae	179
Article	144
Aquilaria	130
Unclassified drug	112
Chemistry	102
Nonhuman	100
Wood	98
Aquilaria sinensis	90
Controlled study	75
Aquilaria malaccensis	66
Priority journal	59
Chromone derivative	58
Plant extract	57
Chemical structure	54
Sesquiterpenes	49
Isolation and purification	48
Molecular structure	48
Mass spectrometry	47
Metabolism	46
Sesquiterpene	46
Chromones	42

Meanwhile, Fig. 3 shows the visualization of index keywords. In Scopus, the index terms are added to records are derived from thesauri that is owned or licensed by Elsevier whereby index terms are assigned based on a set of controlled vocabularies such as Emtree for medical terms, MsSH for life science and health science and GEO-BASE Subject Index for geology, geography, earth and environmental sciences (Scopus Content Coverage Guide 2020).

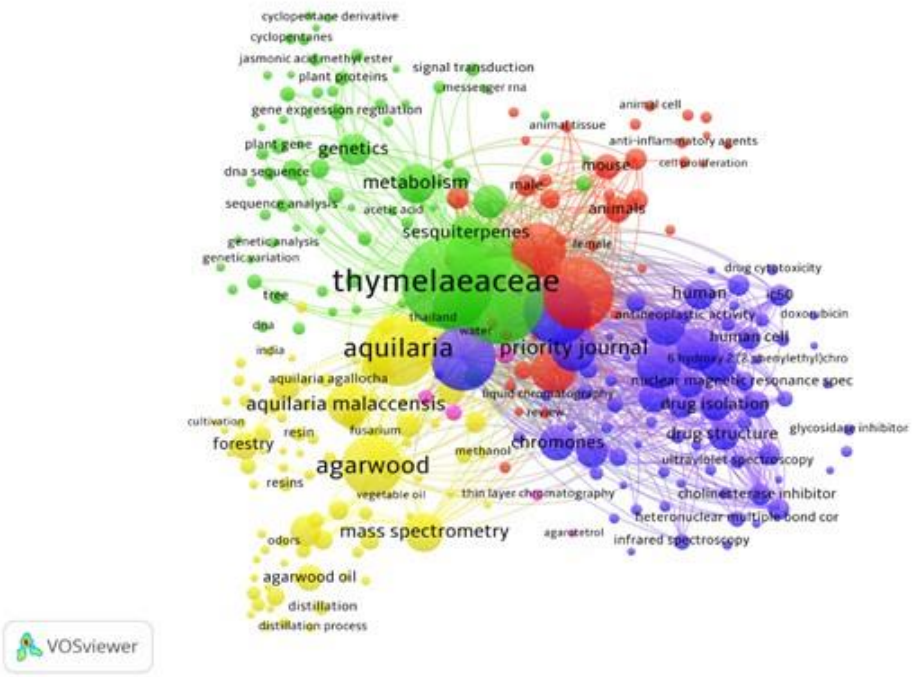


Fig. 3 Index keyword as visualized by VOSviewer

Based on the author keyword (Fig. 4), several pieces of information can be gathered. First, there is a theme on biological activities including anti-inflammatory, anti-bacterial and acetylcholinesterase inhibitory activities. Next, there is also a theme of chemical compounds, including chromone and sesquiterpene. Author seems to focus on specific species and *Aquilaria sinensis* appears to be the most studied compared to other species. Relationships between species, chemical compounds, type of raw material and field of study can also be seen. For instance, *A. sinensis* is closely related to 2-(2-phenylethyl) chromone, sesquiterpene and acetylcholinesterase inhibitory activities. Further, *A.malaccensis* is related to bioactive compounds, *A.crassna* to agarwood leaves and *Gyrinops* to genetic diversity and conservation. In terms of technique, gas chromatography-mass spectrometry (GCMS) appears to be a widely used method considering a fairly visible bubble.

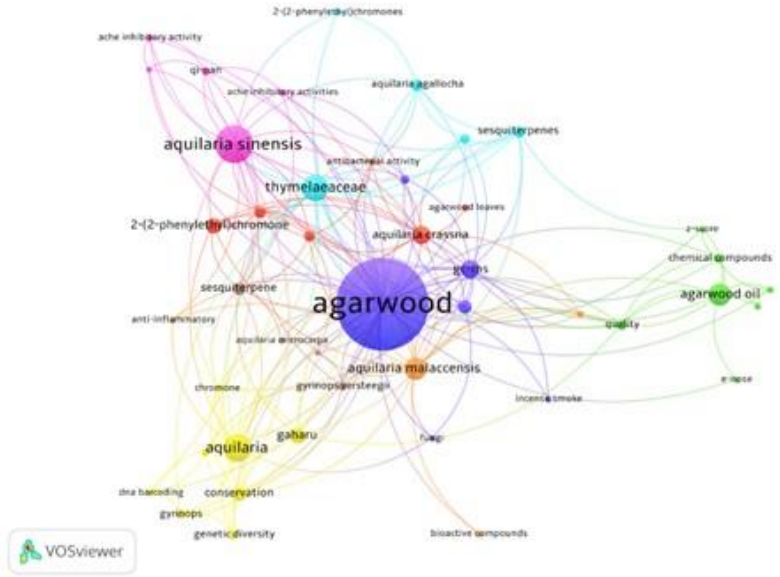


Fig. 4. Author keyword as visualized by VOSviewer

Citation analysis

This section described findings related to the citation which include citation metrics, most influential articles, geographical distribution, citation by source and citation by author. In general, citation indicates influence (Tsay, 2009). Citation analysis is a tool to measure the relative importance or impact of an article or author by counting the number of times that article or author has been cited by other works (Scholarly Impact and Citation Analysis, 2018). However, it is important to understand that there exists in bias in citation analysis where citation frequency is influenced by factors such as author, organization, impact factor and time (studies published earlier versus recent studies) hence the academic impact should be carefully evaluated (Lu et al., 2019).

Citations metric

Number of citations across the 513 papers analysed is 6216 with citations per year of 100.26 and H-index of 42.

Table 10. Citations metrics

Metrics	Data
Papers	513
Number of citations	6216
Years	62 (1959-2021)
Citations per year	100.26
Citations per paper	12.12
Authors per paper	5.41
H-index	42
G-index	59

Most cited article

The top 20 cited articles in Agarwood were all published between 1963 and 2016 (Table 11), with citations ranging from 60 to 204. Twelve of the top twenty highly cited articles were about chemical compounds that work on identification, characterization, and structural analysis on the compounds, followed by six papers reported on biological activities and two on agroforestry. Despite being the only author and the only article from records in Scopus in the area of agarwood research, Naef (2011)'s article "The volatile and semi volatile constituents of agarwood, the infected heartwood of *Aquilaria* species: A review receives the highest citations (204) with a comprehensive review on the volatile and semi-volatile constituents of agarwood with structural and analytical aspects. With 117 citation counts, the second most cited article by Chen et al., (2012) was a review article on the chemical compounds of endemic genera of *Aquilaria* plants and their biological activity. The third most cited article was by the same research team, Chen et al. (2011) reported on the biological activities of agarwood oil from three different sources (chemically simulated, wild and healthy agarwood) received 109 citations.

Table 11. Top 20 highly cited articles

No.	Authors	Title	Year	Cites	Cites per year
1	Naef, R.	The volatile and semi volatile constituents of agarwood, the infected heartwood of *Aquilaria* species: A review	2011	204	20.40
2	Chen, H.Q., WE, J.H., Yang, J.S., (…), Sui, C., Gong., B.	Chemical constituents from endemic genus *Aquilaria* plants	2012	117	13
3	Chen, H., Yang, Y., Xue, J., (…), Zhang, Z., Chen, H.	Comparison of compositions and antimicrobial activities of essential oils from chemically stimulated agarwood, wild agarwood and healthy *Aquilaria sinensis* (Lour.) Gilg trees	2011	109	10.90
4	Yagura, T., Ito, M., Kichi, F., Honda, G., Shimada, Y.	Four new 2-(2-phenylethyl)chromone derivatives from withered wood of *Aquilaria sinensis*	2003	105	5.83
5	Liu, Y., Chen, H., Yang, Y., (…), Chen, B., Chen, H.	Whole-tree agarwood-inducing technique: An efficient novel technique for producing high-quality agarwood in cultivated *Aquilaria sinensis* trees	2013	97	12.13
6	Ishihara, M.., Tsuneya, T.,Uneyama, K.	Fragrant sesquiterpenes from agarwood	1993	94	3.36
7	Kumeta, Y., Ito, M.	Characterization of δ-guaiene synthases from cultured cells of *Aquilaria*, responsible for the formation of the sesquiterpenes in agarwood	2010	93	8.45
8	Okudera, Y., Ito, M.	Production of agarwood fragrant constituents in *Aquilaria* calli and cell suspension cultures	2009	92	7.67
9	Takemoto, H., Ito, M.,Shiraki, T., Yagura, T., Honda, G,	Sedative effects of vapour inhalation of agarwood oil and spikenard extract and identification of their active components	2008	88	6.77
10	Büchi, G., Wüest, H.	New Synthesis of β-Agarofuran and of dihydroagarofuran	1979	87	2.07
11	Yagura, T., Shibayama, N., Ito, M., Kiuchi, F., Honda, G.	Three novel diepoxy tetrahydrochromones from agarwood artificially produced by intentionally wounding	2005	79	4.65
12	Hashim, Y.Z.H-Y., Kerr, P.G., Abbas, P., Mohd Salleh, .	*Aquilaria* spp. (Agarwood) as source of health beneficial compounds: A review of traditional use, phytochemistry and pharmacology	2016	73	14.60
13	Xu, Y., Zhang, Z., Wang, M., (…), Meng, H., Li, w.	Identification of genes related to agarwood formation: Transcriptome analysis of healthy and wounded tissues of *Aquilaria sinensis*	2013	72	9.0
14	Maheshwari, M.L., Jain, T,C., Bates, R,B., Bhattacharyya, S.C,	Terpenoids-xli. Structure and absolute configuration of of α-agarofuran, {amalgamation}-agarofuran and dihydroagarofuran	1963	71	1.22
15	Kakino, M., Tazawa, S., Maruyama, H., (…),Shimazawa, M., Hara, H,	Laxative effects of agarwood on low-fiber diet-induced constipation in rats	2010	65	5.91
16	Gasson, P.	How precise can wood identification be? Wood anatomy's role in support of the legal timber trade especially cites	2011	63	6.30
17	Ishihara, M.,Tsuneya, T.,Shiga, M., Uneyama, K.	Three sesquiterpenes from agarwood	1991	62	2.07

18	Isihara, M.,Tsuenya, T.,Uneyama, K.,	Guaiane sesquiterpenes from agarwood	1991	62	2.07
19	Li, W., Cai, C.-H., Dong, W,-H., (….), Mei, W,-L., Dai, H,- F.	2-(2- Phenylethyl) chromone derivatives from Chinese agarwood induced by artificial holing	2014	61	8.71
20	Hashimoto, K., Sumida, Y., Takashi, M., (…), Inoue, T., Nakahara, S.	A New Chromone from Agarwood and Pyrolysis Products of Chromone Derivatives	1985	60	1.67

The document citation pattern is depicted in Fig. 5. The visualisation map clearly shows seven research areas/scopes. The research area of identifying and classifying chemical components in agarwood is represented in yellow, where Naef (2011)'s work was the most cited (Table 12). The second study focus (marked in blue) is also on chemical compounds but on chromone chemical derivatives. Due to extensive study in this subject, they were able to form their own cluster. On the other hand, the grey coloured cluster is a collection of research related to sesquiterpene chemical compounds, including agarofuran. Research on biological activities such as pharmacological, inhibitory, anti-inflammatory, anti-microbial, and anti-hypoglycaemic is represented by the green colour. The magenta indicates agro-forestry field, which is concerned with the identification, classification, and grading of agarwood plants based on the genome sequence, DNA barcoding, and genetic diversity. The agronomy research scope (indicated in red) focuses on population and regeneration, product value, commercialization, management, and conservation. Turquoise was used to colour the study section dedicated to plant induction. This comprises studies on induction technology and the quality of plants induced by chemical, biological and technical means. Some small but visible clusters are also identified. Agarwood oil (shown in light pink) has a study scope that focuses on agarwood oil extraction process, chemical ingredients, and quality performance. The brown, beige and orange clusters formed from a mixture of research areas and cannot be discerned upon checking.

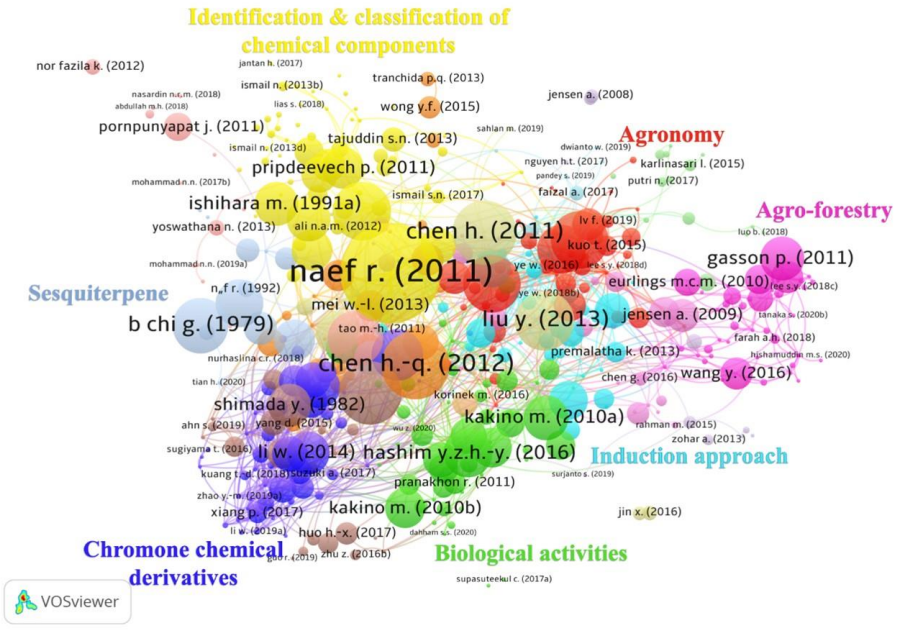


Fig. 5. Network visualization map of the citation by documents

Citation by author

Fig. 6 shows the network citation based on authors. Interestingly, there are four distinctive groups of authors seen in the visualization map with red and green bubbles being the two big groups. The purple bubbles are distant from the olive-shaped network on the left. Upon further investigation, the group of researchers in purple

work on agarwood oil classification and quality. The green bubbles and network appear to be dominated by Chinese authors working in characterization and identification of compounds. Meanwhile, the red bubbles are subtly segregated into two networks, one focus on biological activities and the other on forestry or agronomics.

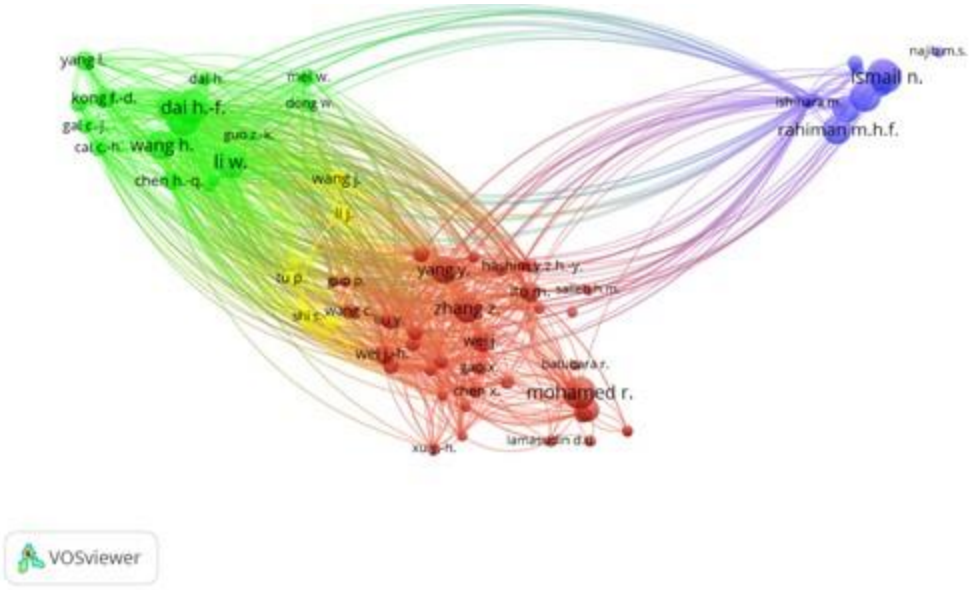


Fig. 6. Network visualization map of the citation by authors

It is important to note that although citation is widely used, citation counts did not accurately reflect an article's quality. The results of citation numbers may be influenced by factors such as publication dates, research disciplines or specialties. In addition, the investigation was limited to a single database. Other data sources, such as Web of Science and Google Scholar, may also provide citation information. According to reports, these databases may exhibit differing citation results, resulting in different analysis outcomes (Yang et al., 2020). Furthermore, the articles chosen were all written in the English language. As a result, the search results will exclude high-impact publications written in languages other than English, which could lead to a bias against this result. For example, China has many excellent researchers and their low numbers may be due in part to their desire to publish in their own tongue.

Geographical distribution of publications and citation - most influential

Fig. 7 shows a citation visualization map of countries for agarwood research. The bubble size reflects the citation number of the countries, which also informs the relative importance or impact of the country's agarwood research output. China and Japan are the two most cited countries, followed by Malaysia. It is interesting to point out that although Malaysia (n =143) published more documents than Japan (n=62), the high document number is not fully translated into the high number of citations, hence scholarship influence and impact (Table 12).

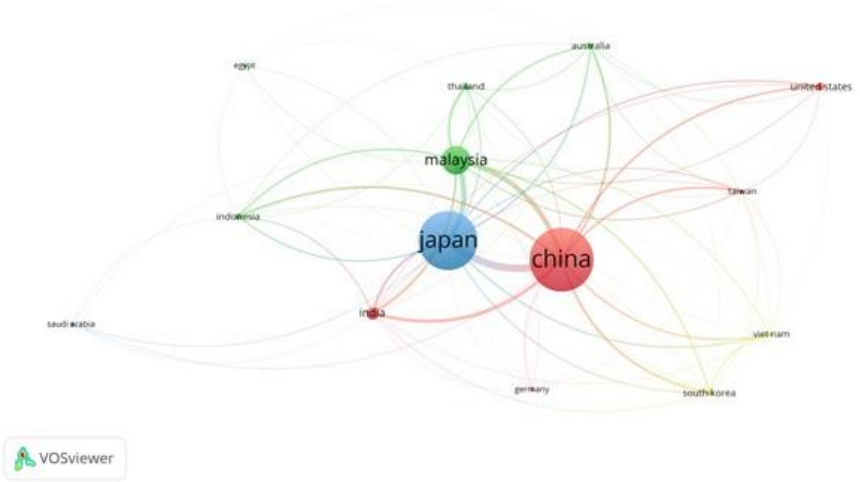


Fig. 7. Network visualisation map of most influential country based on citations

Table 12. Documents and citations based on country

Country	Document	Citations	Total link strength
China	153	1978	998
Japan	62	1846	843
Malaysia	143	899	691
India	32	401	298
Indonesia	63	215	177
Australia	9	184	166
South Korea	11	168	163
Thailand	15	195	127
Vietnam	13	123	127
Taiwan	15	93	118
United stated	13	241	115
Saudi Arabia	5	34	22
Germany	5	33	20
Egypt	6	8	17

Funding sponsors

It is interesting that China makes up two-third of the top funding sponsors of agarwood research (Table 13). The National Natural Science Foundation of China topped the list with 57 publications. The Natural Science Foundation of Hainan Province and the Agriculture Research System of China are in second and third place respectively. However, for each entity, the number of publications sponsored was less than half of that sponsored by the National Natural Science Foundation of China. Universiti Putra Malaysia is at fifth place of the overall list, and the top funder in Malaysia, followed by the Ministry of Higher Education Malaysia and Universiti Teknologi MARA.

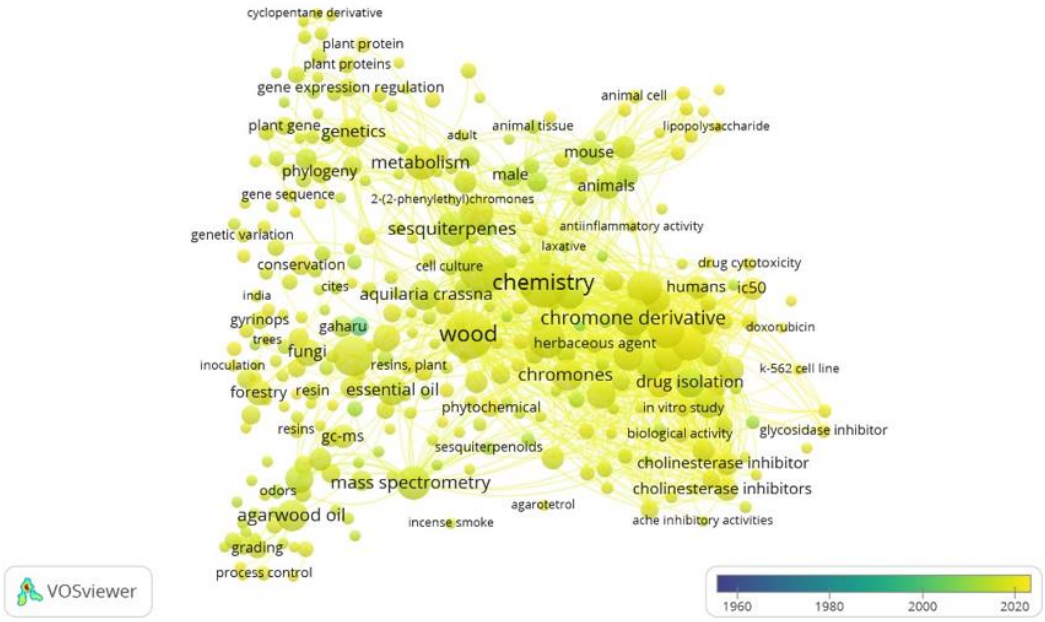
Table 13. Top 15 funding sponsors

Funding Sponsor	Total Publication (TP)	Country
National Natural Science Foundation of China	57	China
Natural Science Foundation of Hainan Province	21	China
Agriculture Research System of China	20	China
Central Public-interest Scientific Institution Basal Research Fund for Chinese Academy of Tropical Agricultural Sciences	14	China
Universiti Putra Malaysia	14	Malaysia
Ministry of Higher Education, Malaysia	14	Malaysia
Program for New Century Excellent Talents in University	9	China
Universiti Teknologi MARA	9	Malaysia
Ministry of Education, Culture, Sports, Science and Technology	8	Japan
Ministry of Science and Technology of the People's Republic of China	7	China
National Research Foundation of Korea	7	Korea
Natural Science Foundation of Guangdong Province	7	China
Science and Technology Planning Project Guandong Province	7	China
Special Fund for Agro-scientific Research in the Public Interest	7	China
Major Science and Technology Project of Hainan Province	6	China

The evolution of agarwood research: where from and where to go?

To see the evolution of agarwood research, the keyword analysis was mapped to the year of publication. At this stage, several common keywords such as agarwood, *Aquilaria*, articles, controlled study and Thymelaeaceae were omitted to better represent themes or scope of research. When mapped against around 60 years of agarwood research, the keyword analysis showed most of the work was reported in the last 10 years (Fig. 8a, uniform yellowish green bubbles and network). To investigate further, the time period was zoomed in as shown in Fig. 8b. Chemistry appears to be the biggest bubble suggesting a major focus in the area around 2016. The term 'wood' also appears to be similar in size and colour to 'chemistry' indicating that researchers around that time studied 'fragrant resinous wood'. However, it could also be that the term 'wood' also refers to the work done on agarwood trees (regardless which type of material) hence not unique to the resinous wood.

a)



b)

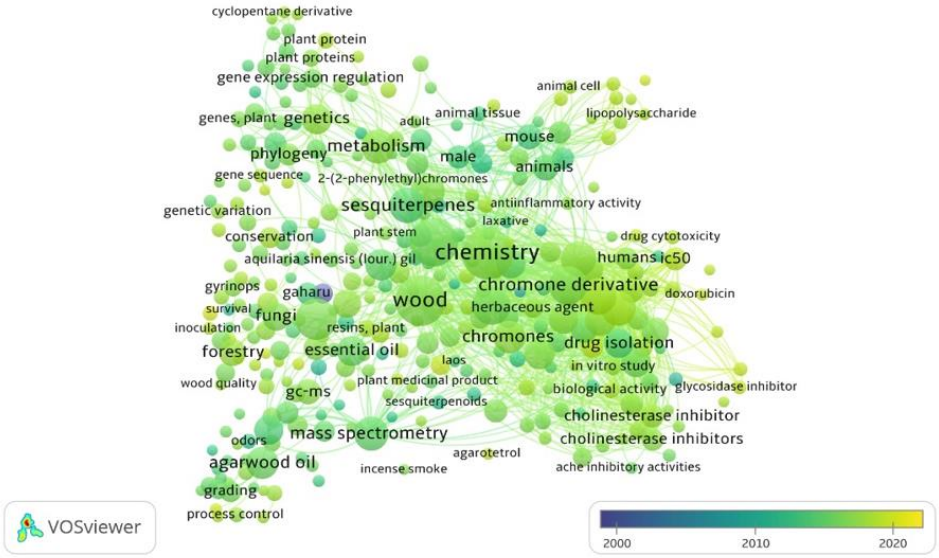


Fig. 8. Network visualization map based on all keywords a) across the time period studied and b) focused time period

Several notable scopes of research can be deduced from Fig. 8b. These include, biological effects or activities (appearing in the last five years based on the yellowish and yellowish green bubbles), agarwood oil and grading, techniques or methods used for identification of compounds in agarwood oil, genetic studies as well as forestry and conservation. Research on inoculation is also evident but it does not appear to be a major research area despite the increased acreage of agarwood cultivation or plantation. Inoculants are indispensable in modern agronomic practice to systematically induce the trees to produce the fragrant resinous wood for commercial harvesting. Researchers in the field may have opted to protect the intellectual property of their formulation or composition of inoculant considering the economic potential of it. Some examples of such patents include WO/2018/006104 (Nguyen, 2018) and CN102649939 (Shunxing et al. 2012).

While *Aquilaria* is the main genus producing agarwood, research on another genus, *Gyrinops*, gained momentum in the last five years, particularly contributed by Indonesian agarwood researchers. It is also observed that the more recent work leveraged on new technologies and methods. This is consistent across the field of research. Although the network visualization map provides some insights into the evolution and scope of research it cannot discern the type of material used (for example, the wood or leaf) and whether the materials are from infected trees or otherwise. In recent years, researchers are interested in studying materials from uninfected agarwood trees due to its abundant supply in agarwood plantations. This is also in trend with sustainability agenda where resources are used responsibly as such the waste or by-products of a process is used as raw material.

To gain more insights, authors also manually dissected the 513 articles. It could be observed that early years focused on identifying and characterizing chemical compounds followed by studies on biological effects before the themes became more varied in the last ten years. Research on economics, management, social science and humanities is not evident from the network visualization although agarwood plantation has become models of agro-based industry particularly for communities in the rural area. However, upon further investigation, this important scope of work has been undertaken as regional based research. For instance, the issues have been discussed by Desa et al. (2021) (Malaysia), Turjaman and Hidayat (2017); and Bariyah (2020) (Indonesia), Rahman et al. (2015) (Bangladesh), Saikia and Khan (2014); and Nath et al. (2020) (Northeast India) and Nakashima et al. (2005) (Vietnam). Interestingly, there is no academic paper from China in this work despite being an important industry supported by the local government such as in South China's Guangdong province (Wenfang, 2019).

Work on biological effects are motivated by ethnopharmacological evidence of agarwood and other materials from the tree. However, there has not been a clear relationship shown between the traditional medicinal use of a certain formulation containing material from agarwood to its clinical use. There are quite a number of studies using in vitro techniques to investigate the effects of these materials on certain pharmacologic interests but animal study constitute only five percent of the total number of articles studied in this bibliometric work. This could explain the disrupted path or the missing link between the proof of concept type of research and the clinical use, thus raising questions on whether the research has not benefited the people. To this end, more translational work with real impact should be considered.

The missing link between ethnopharmacology to drug discovery in agarwood research can be illustrated by the famous but mysterious traditional use of agarwood in terms of its sedative effects. For example, agarwood has been used as sedative in Traditional Chinese Medicine (Chinese Pharmacopoiea Commission, 2010) and in Japanese traditional herbal medicine formulation for sedative or tranquilizing effects (Compton and Ishihara, 2005). Despite the ethnopharmacologic records, only a small number of articles reported on the sedative effects of agarwood (Takemoto et al., 2008; Miyoshi et al, 2013; Wang et al., 2017). Wang et al. (2017) reported that the agarwood oil sedative-hypnotic effects are related to its ability to regulate GABAergic system. In a bibliometric study by Yeung et al. (2018), the authors reasoned that there will be a stronger link of ethnopharmacology to neuroscience, neuropharmacology and food science in the near future considering the general increase of neuroscience and neuronutritional science literature. This calls for a further systematic scientific approach to look into neuroscience and neuropharmacology aspects of agarwood that could benefit modern society.

The agarwood research work thus far also concurs with food science as an upcoming area in natural products as stated by Yeung et al. (2018). There are several works on tea from agarwood leaves such as Adam et al. (2017), Surjanto, Batubara, Hanum, Julianti (2019), Surjanto, Batubara, Hanum, Pulungan (2019), Surjanto, Batubara, Rangkuti (2019), Wangiyana et al. (2019) and Kuo et al. (2020). Agarwood-food science related works have also been patented. For instance, KR102061607 (Cho and Lee, 2020) patented the method for manufacturing agarwood salt while CN101991715A (Li et al., 2011) patented the preparation method of *A.sinensis* fruit skin extract for the potential purpose as food preservative.

Other observations include the exploration of the less researched agarwood-producing species *Wikstroemia tenuiramis* which is endemic in North Sumatera (Batubara et al., 2018; Surjanto, Batubara, Hanum, Julianti (2019); Batubara et al., 2020). Despite the importance of agarwood safety data, particularly for future consumption as medicine and food, there is very limited work on the safety and toxicity of agarwood tree plant materials, including the oil, the fragrant resin itself and the smoke produced when burnt.

The bibliometric study thus far has shown that agarwood research cuts across many disciplines with layers of complexity due to its rich history, use, varied species, different agarwood plant materials including whether they are from infected or non-infected trees, country of origin, process of extraction and many other parameters. Considering future research is built on the incumbent research, good scientific work shall be replicable by other researchers in the most effective way to achieve the ultimate aim of creating new knowledge. Therefore, to benefit the agarwood research vicinity, it is highly recommended that a standard reporting guideline or standard is adhered to. Examples of standard reporting guideline include the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis), MIAME (Minimum Information About a Microarray Experiment) and MINSEQE (Minimum Information About a Next-generation Sequencing Experiment). The challenge, perhaps, is the lack of an entity or institution that could formally put forward this requirement for standard reporting guidelines for agarwood research.

It is foreseen that the guideline with its systematic and complete reporting structure shall increase transparency and reduce dispersion of data leading towards lean and responsible research conduct. This fits into the ecopharmacognosy approach put forward by Cordell (2017, 2018) as a future direction of natural product research. Akin to the food security concept, the ecopharmacognosy approach aims to achieve medicine security through sustainable practices (Cordell, 2017). This could be done through in sharing datasets, leveraging technologies and establishing smart and genuine partnerships.

While there are still many challenges, with smart and genuine partnership, sharing of datasets and leveraging of new techniques, agarwood as an economic plant species can be realized as a commodity that drives a progressive yet sustainable socioeconomic development and benefit to humanity.

Limitations

Although this study is broad in nature, it is limited by using a single database (of Scopus) as a source of publication data. Scopus is chosen due to its credibility and wide coverage of science and social science. However, a substantial number of articles within the agarwood research area are available on other platforms. Some of these publications contain interesting and important findings. However, they may not have reached publication standards that could render them into indexed journals.

Another limitation or discrepancy is the discontinuation of certain journal titles from Scopus index as part of the database's routine quality control exercise. Therefore, it is important to note that while the records included in this study were extracted from the Scopus database at a specific time, some articles may have been delisted afterward

CONCLUSION

The findings based on bibliometric analysis on agarwood revealed that China, Malaysia, Japan and Indonesia were major contributors. Most of the publications were in agricultural and biological sciences; biochemistry, genetics and molecular biology; chemistry; and pharmacology/pharmaceutics. The earliest article was published in 1959. The literature seems to be in a planar state until 2010 where there is exponential growth potentially fueled by the advancement of technology, interest from the funding sponsors and demand for new knowledge as well as affirmation of certain information particularly those related to ethnopharmacology. The evolution of agarwood research themes was also observed with the early years focused on chemical compounds followed by studies on biological effects before the themes become varied in the last ten years. Critical knowledge gaps identified include the safety of agarwood and its related materials, the translational link between the proof of concept with clinical applications, and the role of agarwood in socioeconomic development of a nation. Improved standard reporting of agarwood research is seen to be a way forward to increase transparency, reduce dispersion of data leading towards lean and responsible research conduct. Future research could be directed towards neuroscience, nutritional neuroscience and food science that leverage both the ethnopharmacologic characteristics of agarwood and the modern demands. All in all, this work could be used as a landscape to chart future research that leverages agarwood-producing trees as economic plant species towards progressive yet sustainable socioeconomic development and benefit mankind.

DISCLOSURE STATEMENT

The authors have no competing interests and ethical approval to declare relevant to this article's content.

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