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REVIEW ARTICLE

A BIBLIOMETRIC ANALYSIS OF AGARWOOD RESEARCH AND THE IMPACT OF CITES LISTING

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ABSTRACT

Agarwood is a renowned fragrant non-timber wood product primarily originating from the Indo-Malesia region. It also plays a pivotal role in the global industry due to its economic and cultural significance. As a response to illegal harvesting and trade activities leading to declining populations, all agarwood-producing species have progressively been incorporated into CITES Appendix II. We conducted an in-depth investigation into the temporal dynamics of the scientific literature pertaining to agarwood in this study. The evolving trends in agarwood research and the influence of CITES listing on publication numbers were elucidated by utilizing a bibliometric approach. The quantity of research activity was leveraged as an indicator of the engagement of a country, and the status of agarwood research before and after the CITES listing was analyzed. A rigorous selection process yielded 704 articles from the Web of Science (WoS) core database and 1,054 articles from Scopus, using four specific keywords: "agarwood," "*Aquilaria*," "*Gyrinops*," and "gaharu," spanning the years 1995–2022. A notable upswing in the number of scientific publications following the implementation of the CITES listing was identified, while China has been the leading country in most publications and research work since 2009 and 2008 based on WoS and Scopus, respectively. The journal "Molecules" has received the most related articles over the years, and the most popular keyword used is "agarwood." China is also, so far, the country with the most related patents filed. The trending research topics based on the keywords from 2021 to 2022 would be studies related to pharmacological effects, understanding the mechanism of agarwood formation, exploring alternative agarwood-producing species from *Gyrinops*, and promoting sustainability in agarwood production. Furthermore, the discussion also covered potential research initiatives that could address the existing knowledge gaps in agarwood research up to the present moment.

Keywords: *Aquilaria*; *Gyrinops*; Red List species; Scopus; Web of Science

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INTRODUCTION

Agarwood is a highly valued non-timber forest product due to its extensive utilization in pharmaceuticals, religious ceremonies, fragrances, and incense (Adhikari *et al.,* 2021). Throughout the course of history, Buddhist, Hindu, and Islamic ceremonies have integrated the revered and fragrant agarwood incense. In addition, its properties are utilized in Chinese traditional medicine to treat dysentery, coughing, rheumatism, and higher fevers (Chen *et al.,* 2022). Members of *Aquilaria* and *Gyrinops* from Thymelaeaceae are the major known agarwood producers in the world (Lee *et al.,* 2022). These trees grow naturally in the Indomalesia region. The collection of agarwood from these trees is destructive; the formation of agarwood is based on a defense mechanism of the tree towards mechanical wounding (Nobuchi and Siripatanadilok, 1991; Hishamuddin *et al.*, 2019). The formation of agarwood in the wild is rare; however, the increasing demand for agarwood has led to indiscriminate felling and illegal harvesting of the trees in the forest in search of agarwood, threatening its survival in the wild (Thompson *et al*., 2022; Hishamuddin *et al.,* 2023). In order to reduce and control the diminishing rate of agarwood-producing trees in the wild, *Aquilaria malaccensis* became the first species to be included in the Convention on International Trade in Endangered Species (CITES) Appendix II in 1995 (CITES, 1994), with all 30

species from both genera being added in 2005 (CITES, 2004).

The establishment of CITES is to combat illegal trade and manage global wild plant and animal commerce (www.cites.org). Appendix II of CITES includes species not necessarily threatened with extinction but in which trade must be controlled in order to avoid utilization incompatible with their survival (Dwianto *et al.*, 2019). About 84% of the recorded species are listed in Appendix II, enabling sustainable, legal, and supervised international trade (UNEP-WCMC, 2019). Based on recent studies, the IUCN Red List of Threatened Species, on the other hand, would influence researcher interest (Cazalis *et al.,* 2022). This is because, in competitive funding environments, researchers would be concerned with the probability of securing their research funding; thus, it would be more promising to address global biodiversity policies in their work to secure the fund. Also, government funding would favor studies related to economic and public-interest species to further exploit the potential of the targeted species (Jarić *et al.,* 2019).

In a time when biodiversity conservation and sustainable development are crucial in the life sciences, bibliometric analysis helps us understand agarwood research history and find new topics (Kokol *et al.,* 2021). Bibliometrics is a qualitative and quantitative analysis of research to evaluate researchers, research groups, institutions, countries, and publications (Todeschini and Baccini, 2016). It is also a good way to highlight important literature findings and knowledge gaps while, at the same time, identifying scientific literature norms. In recent years, scientists have adopted bibliometric approaches to track renewable energy, clinical medicine, and biodiversity development as online literature databases improve (Şenyapar, 2023); the method could inform knowledge perception and structure new and established scientific disciplines by analyzing thematic, methodological, and conceptual patterns throughout time. Bibliometric methods help to display a huge number of articles in an intuitive, quality-balanced format with ease; it is possible for researchers to reevaluate their research domain using bibliometrics (Donthu *et al.*, 2021).

To provide a deeper qualitative understanding of how the CITES listing influences agarwood research through quantitative metrics, in this study, we used bibliometric approaches to show the trend of agarwood-related scientific research from 1995 onward and its relevance to the CITES listing. Given the high commercial value of agarwood, having the two major agarwood-producing genera listed in the CITES listing could inflict a certain level of scientific preference (Wyn and Anak, 2010). This study covers various crucial aspects, including the number of related publications based on country, the popular scientific journals and keywords used, the interaction between counties in terms of research collaboration, trending topics, as well as the number of patents filed based on country. The study provides a thorough analysis that demonstrates the research pattern of the related publications and the impact of CITES on the scientific community by combining newly acquired data with previous knowledge.

MATERIALS AND METHODS

Data collection: By having the year when *Aquilaria malaccensis* was first added to the CITES listing, the scientific articles that were made available between January 1st, 1995, and December 31st, 2022, were included in the analysis. The researchers subjected two international journal indexing databases, the Clarivate Analytics Web of Science (WOS) and Scopus, to data filtering and collection. Four selected words, including "agarwood", "*Aquilaria*", "*Gyrinops*", and "gaharu", were designated as the theme in the search tools of both databases. To reduce bias caused by duplicated publications and minimize false-positive results, the search was limited to publications recorded in journals, specifically full research articles or review papers. Conference proceedings, book chapters, and books were not considered for both searches implemented in WOS and Scopus, as they might contribute to redundancy in content under different media sources. WOS and Scopus yielded a total of 704 and 1,054 papers, respectively, with fully recorded and cited references.

Data visualization: All computations and data analyses were performed using R software version 4.0.2 (R Core Team, 2022), utilizing packages such as ape v5.0 (Paradis and Schliep, 2019), nlme (Heisterkamp *et al.*, 2017), spatstat (Baddeley and Turner, 2005), and Vegan (Oksanen *et al.*, 2019. This includes statistical and bibliographic information processing, notably the publication year, authors' institutional affiliations, the residing country of the corresponding author, and trending keywords. We conducted these analyses using the Bibliometrix v3.2.1 pipeline (Aria and Cuccurullo, 2017).

We visualized the correlation between publications, institutions, and countries using Bibliometrix v3.2.1. To highlight the key research institutions and publication trends of related articles, the top five countries on agarwood research and their annual publications were identified using the citations function available in Bibliometrix. The collaboration network tool in the social structure series of Bibliometrix generated an international collaboration network diagram. The field "country" was set as the target for network construction, with the network layout set to "circle", and the Walktrap clustering algorithm was employed. We used the Three-Field Plot tool in the Overview series of Bibliometrix to create the Three-Field Plot, which illustrates the disparities in research themes across different nations.

The fields "countries", "keywords", and "sources" were chosen for constructing the three-field plot from left to right. The top 15 entities for each field were selected to build the three-field plot.

The keyword co-occurrence and research network maps were illustrated using VOSviewer v1.6.18 (Van Eck and Waltman, 2022). The publication data files derived from both Scopus and WoS were imported into VOSviewer. We selected author keywords occurring at least six times for the WoS data. The "association strength" method was applied for standardization. For Scopus data, extended keywords or keywords that appeared at least 50 times were chosen. We manually excluded low-relevance word combinations. We applied the default settings to visualize the keyword co-occurrence network for both datasets.

A patent search was conducted by searching related records deposited in the Google Patents database (https://patents.google.com/), using the same four keywords as in the previous analysis. The patent search is limited to the filing period from January 1st, 1995, to December 31st, 2022, which resulted in a total of 2,384 files being retrieved. We summarized and visualized the results using Excel (Microsoft, USA).

RESULTS

Number of publications and top publication-contributing countries: The variation in the number of publications over the years allowed us to examine the focus and development trends of agarwood research. From 1995 to 2022, the annual publication count exhibited an overall upward trajectory (Figure 1), and the findings based on the WoS and Scopus databases were consistent between the two databases. During the period between 1995 and 1999, publications on agarwood research were very limited. The Scopus database recorded the first appearance in a relevant article in 1995; however, there was a four-year gap before any subsequent publications. In 2000, the WoS database featured its first related article. Both the WoS and Scopus databases recorded less than 10 related publications until they reached 17 and 12 in 2008 and 2009, respectively. Since then, both databases underwent a rapid expansion in related articles, in which the number of related articles rose to its highest count before a reduction in numbers took place in 2011, 2014, and 2020 for WoS, as well as 2015 and 2020 for Scopus. The annual growth rates of publications for the WoS database and the Scopus database were averaged at 14.7% and 14.6% respectively, using the year when the first article was featured in both databases (WoS: 2000, Scopus: 1995). In 2019, both databases recorded the highest number of publications, with WoS featuring 84 articles and Scopus featuring 124 articles.

Based on the total number of related articles published between 1995 and 2022, both the WoS and Scopus databases recorded articles from 35 and 41 different countries, respectively. However, this study only analyzed the top five countries that contributed or participated in the articles. Both the WoS and Scopus databases had China, Malaysia, India, and Thailand in their top-five lists; however, WoS included Japan as one of their top five contributors, while Scopus recorded Indonesia.

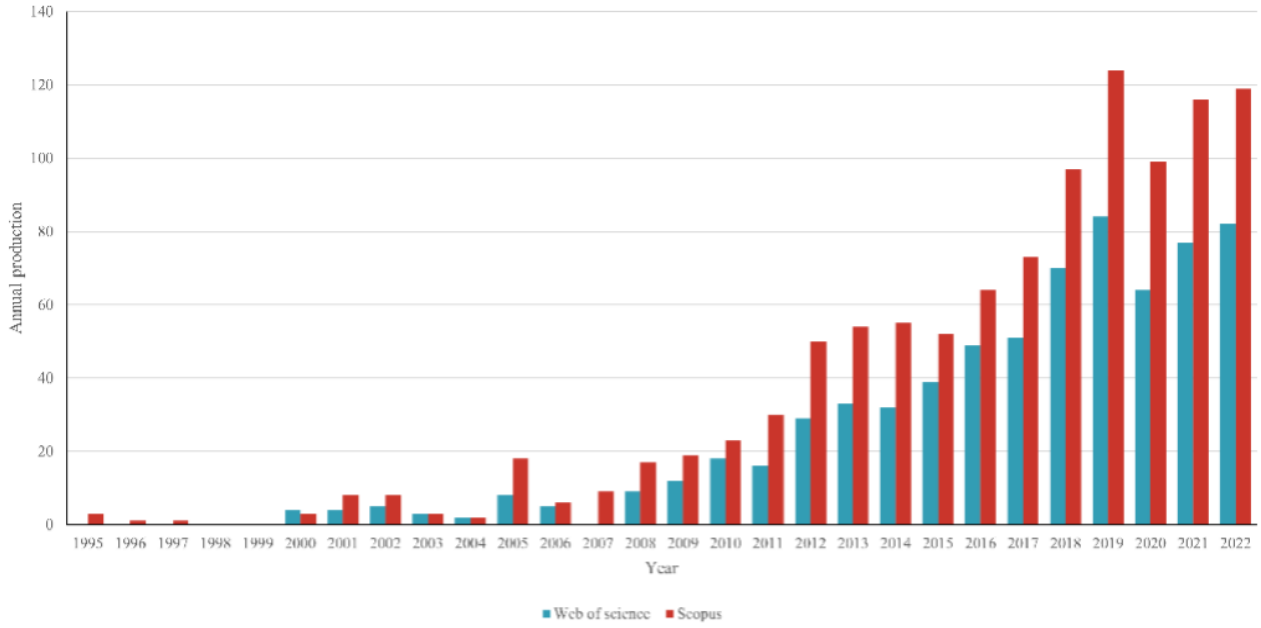

Figure 1. Annual publication of related articles based on the WoS and Scopus databases from 1995 to 2022.

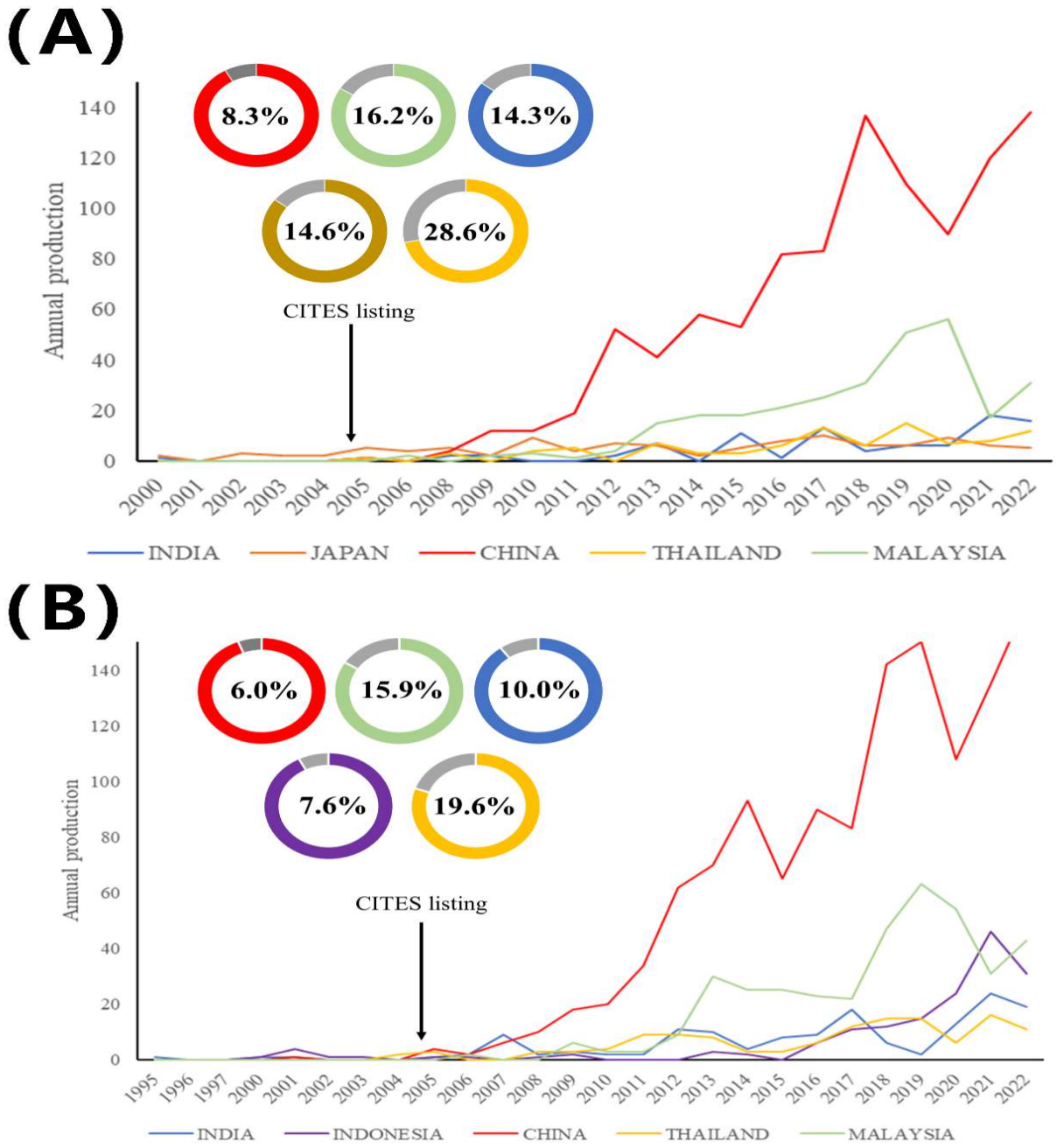

Figure 2. Annual production of the top 5 countries on agarwood research based on (A) WoS and (B) Scopus databases. The gray part of the donut chart and the percentage value at the center indicate the proportion of multiple-country participation for each country.

When compared across the five countries, China is clearly in the lead, contributing the most articles to both the WoS and Scopus databases. In WoS, China has started to overtake the other countries in terms of the number of articles since 2009. Despite China's growing trend in the number of articles overall, there are at least three distinct reduction points, i.e., 2013, 2015, and 2020. The reduction rate was between 8.6% and 21.2%. Subsequently, Malaysia became the first runner-up as the second contributor to the WoS database from 2013 onwards. Malaysia showed substantial growth for the next seven years, until it encountered a reduction in the number of articles in 2021, which collided with the achievement by India. Eventually, India, Japan, and Thailand were contributing not more than 20 articles every year; India, Japan, and Thailand contributed the most in 2021 (n = 18), 2017 (n = 10), and 2019 (n = 15), respectively.

In Scopus, China, as the leading country in terms of the number of articles, was in second place in 2007, behind India, yet the country started to contribute to numbers gradually from 2008 onwards. However, a reduction in the number of articles was recorded in 2014, 2017, and 2020, with a reduction rate between 7.8% and 30.1%. Malaysia, as the second-most contributing country, began to distance itself from the other three countries in 2013. Despite there being a gradual reduction in the number of articles in that country over the past four years, the country still turned out to be in second place. Malaysia continued to expand in the number of articles until 2019, when the number of articles started to decline and was overtaken by Indonesia in 2021. Eventually, Indonesia drops back to third place in the subsequent year. In fourth and fifth place, India and Thailand were not producing more than 20 articles per year until 2021, when India marked her highest record in the number of articles per year (n = 24).

To elucidate the participation of authorship at the international level, a total of 126 and 108 related articles derived from WoS and Scopus had corresponding authors from more than one country (co-corresponding authors from another country different from the main corresponding author). We label these articles as multi-country participation (MCP) articles. Among the top five contributing countries, Thailand exhibits the highest MCP proportion (WoS: 28.6%; Scopus: 19.6%), while China marks the lowest (WoS: 8.3%; Scopus: 6.0%). The other three countries would account for a percentage of MCP between 7.6% and 15.9% for WoS, as well as 14.3% and 16.2% for Scopus.

The international collaboration network map revealed the pattern of collaboration between researchers at an international level (Figure 3). Among the top 15 contributing countries included in the analysis, 13 of them were present in both network maps, including Australia, Canada, China, Egypt, Germany, India, Indonesia, Japan, Korea, Malaysia, Sri Lanka, Thailand, and the USA. Saudi Arabia and Vietnam were specific to the network map derived from the WoS database, while Bangladesh and Iran were specific to the network map generated from the records in the Scopus database.

The Walktrap algorithm identified four clusters in the network map using the WoS database, while the network map derived from the Scopus database obtained five clusters. In the network map using the WoS database, the largest cluster consisted of six countries, including China, Germany, Indonesia, Japan, Thailand, and the USA. The second largest cluster had five countries, including Australia, Egypt, Malaysia, Saudi Arabia, and Sri Lanka, while the third and fourth clusters each had two countries, including Korea and Vietnam, as well as Canada and India, respectively.

The largest cluster in the network map derived from the Scopus database included seven countries: China, Germany, Indonesia, Iran, Japan, Thailand, and the USA. The second-largest cluster was recorded with three countries, including Canada, India, and Korea. Australia and Sri Lanka, along with Egypt and Malaysia, formed two separate clusters, while Bangladesh remained unclustered with any other countries.

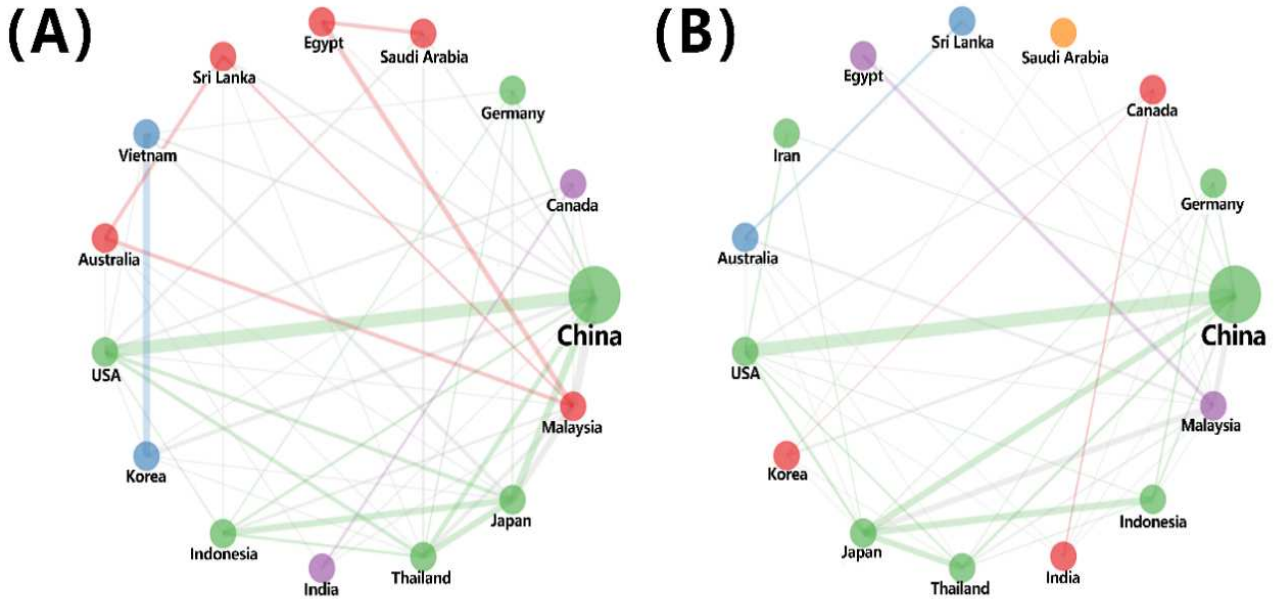

Figure 3. International collaboration network map of the top 15 contributing countries on related articles based on the (A) WoS and (B) Scopus databases. We used the Walktrap clustering algorithm for this analysis.

Popular keywords and preferred journals in agarwood related research: As the keyword with the most occurrence, the word "agarwood" has become a distinct research preference among 14 countries of the WoS database and 15 countries of the Scopus database (Figure 4). This was followed by five keywords that are related to the family name (i.e., Thymelaeaceae), genus name (i.e., *Aquilaria*), and species name (i.e., *Aquilaria crassna*, *A. malaccensis,* and *A. sinensis*) of the research subject. Other occurring keywords recorded were related to the three major chemical compounds in the agarwood, including "sesquiterpene", "sesquiterpenoid", and "2-(2-phenylethyl) chromone", as well as other popular keywords such as "conservation", "cytotoxicity", "gaharu", and "GC-MS". Keywords that occur in the related articles indexed under the Scopus database but not in the WoS database are "agarwood oil", "*Aquilaria agallocha*", "essential oil", and "expression analysis".

Concerning the choice of journals among the 14 and 15 contributing countries of the WoS and Scopus databases, respectively, "Molecules" received and published the highest number of related articles in both databases. Other well-received journals that are indexed under the WoS database in descending order would be "Fitoterapia", "Chemistry of Natural Products", "Natural Product Communications", "Journal of Asian Natural Products Research", "Journal of Natural Medicine", "Phytochemistry Letters", "Journal of Tropical Forest Science", "Mitochondrial DNA Part B: Resources", "Bioscience Research", "Forests", "Phytochemistry", "Scientific Reports", and "Journal of Forestry Research".

Aside from "Molecules", there are at least nine journals, including "Fitoterapia", "Chemistry of Natural Products", "Natural Product Communications", "Journal of Asian Natural Products Research", "Journal of Natural Medicine", "Phytochemistry Letters", "Journal of Tropical Forest Science", "Forests", and "Phytochemistry", that are indexed under both databases, while eight are recorded in the analysis based on the Scopus database but not WoS. The eight Scopus-indexed journals are "Biodiversitas", "Chinese Pharmaceutical Journal", "Chinese Traditional and Herbal Drugs", "Industry Crops and Products", "Journal Ethnopharmacology", "Yaoxue Xuebao", and "Zhongguo Zhongyao Zazhi".

For the linkage network generated using the popular keywords based on the related articles indexed under WoS, a total of 10 clusters were identified, of which the largest cluster (red) contains 10 keywords. The keywords "*Aquilaria sinensis*" and "agarwood" have the most occurrences among all keywords. Scopus identified a total of 11 clusters. Two clusters, i.e., red and green colors, contain the most keywords, i.e., nine; "*Aquilaria sinensis*" and "agarwood" also occur to be the most popular keywords indexed.

Trending topics based on keywords: Between 2002 and 2006, agarwood-related articles were only limited to the keyword "non-timber forest product" (ntfp) in both databases. However, the trend diverged since 2004 when the keyword "CITES" was consistently emphasized in related articles until 2018 when referring to WoS, making it the longest-spanning keyword, while the keyword "*Aquilaria agallocha*" became popular from 2005 to 2015 under Scopus (Figure 6). The keyword "*Aquilaria agallocha*" was indexed as a top-three keyword under Scopus in 2008 but ranked top-three under WoS in 2009. Under WoS, keywords that were popular in 2010 were "eaglewood" and "trade", while between 2011 and 2015, keywords such as "antimicrobial activity", "Chinese eaglewood", "constipation", "endophytic fungus", "farnesyl diphosphate synthase", "laxative effect", "methyl jasmonate", "nitric oxide", "phylogeny", and "sesquiterpene" gradually surfaced. Among the 15 popular keywords recorded between 2016 and 2020, the keyword "agarwood" received the most attention in 2018, followed by the keywords "2-(2-phenylethyl) chromones", "*Aquilaria sinensis*", and "Thymelaeaceae", as well as "*Aquilaria*", "*Aquilaria malaccensis*", and "cytotoxicity activity", which occurred at higher frequencies in 2017 and 2019, respectively. In 2021 and 2022, keywords such as "*Gyrinops walla*", "sustainability", "synthesis", "transcriptome", and "quality evaluation" became prominent.

For Scopus, besides the keywords "ntfp" and "*Aquilaria agallocha*", there was only one more keyword being focused on before 2010, which was "*Aquilaria* spp.". There were no popular keywords recorded in 2011, but prior to 2015, leading keywords such as "agilawood", "*Aquilaria microcarpa*", "callus", "chemical constituent", "chromone", "cytotoxic activity", "eaglewood", "endophytic fungus", "fungus", "gaharu", and "methyl jasmonate" became present. Between 2016 and 2020, among the 15 popular keywords, two were recorded with the highest frequencies, including "agarwood" and "*Aquilaria sinensis*". While three popular keywords were identified in 2021, including "depression", "stress", and "sustainably", "agarotetrol" was the only popular keyword known in 2022.

Global patent trends and geographic distribution analysis: Based on the analysis of the Google Patent Database, the global number of related patents amounted to 2,384 between 1995 and 2022 (Figure 7). The annual distribution of related patents revealed a substantial increase over the years, in which related patents accounted for 18 records in 1995 and exceeded 100 per annum in 2011. In 2021, a total of 229 related patents were recorded, which is the maximum record achieved per annum in the past 26 years. Noticeable declines in the number of related patents were observed in 2004, 2006, 2008, 2017, and 2022. The most substantial decrease

occurred in 2006, with a decline of 46.3%, followed by 35.2% in 2004.

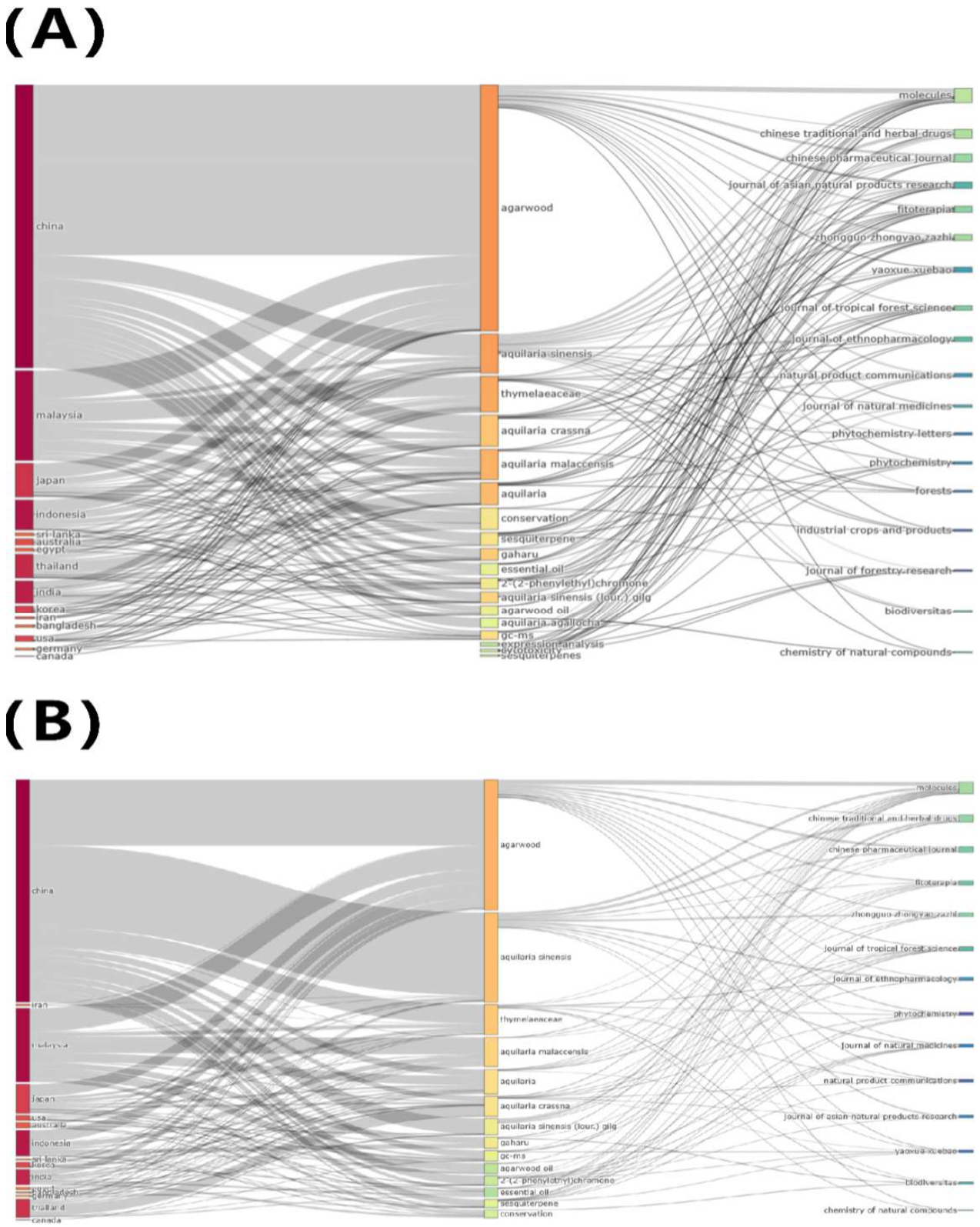

Figure 4. Three-field plots depict the top contributing countries, popular keywords, and preferred journals of related articles between 1995 and 2022.

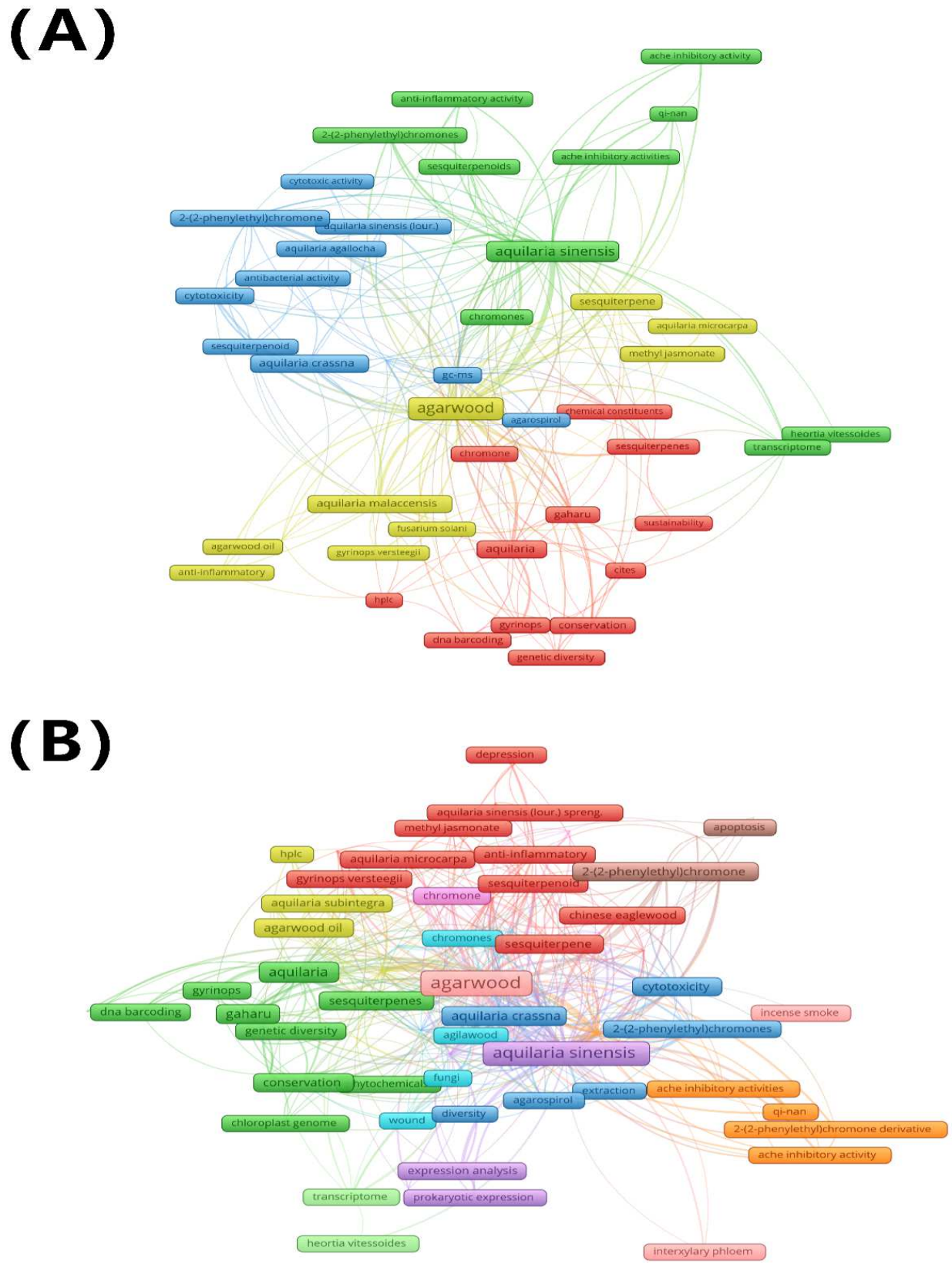

Figure 5 illustrates the linkage network of popular keywords indexed under (A) WoS and (B) Scopus databases. The font size indicates the occurrence level of the keywords, while the color-coding represents their relatedness.

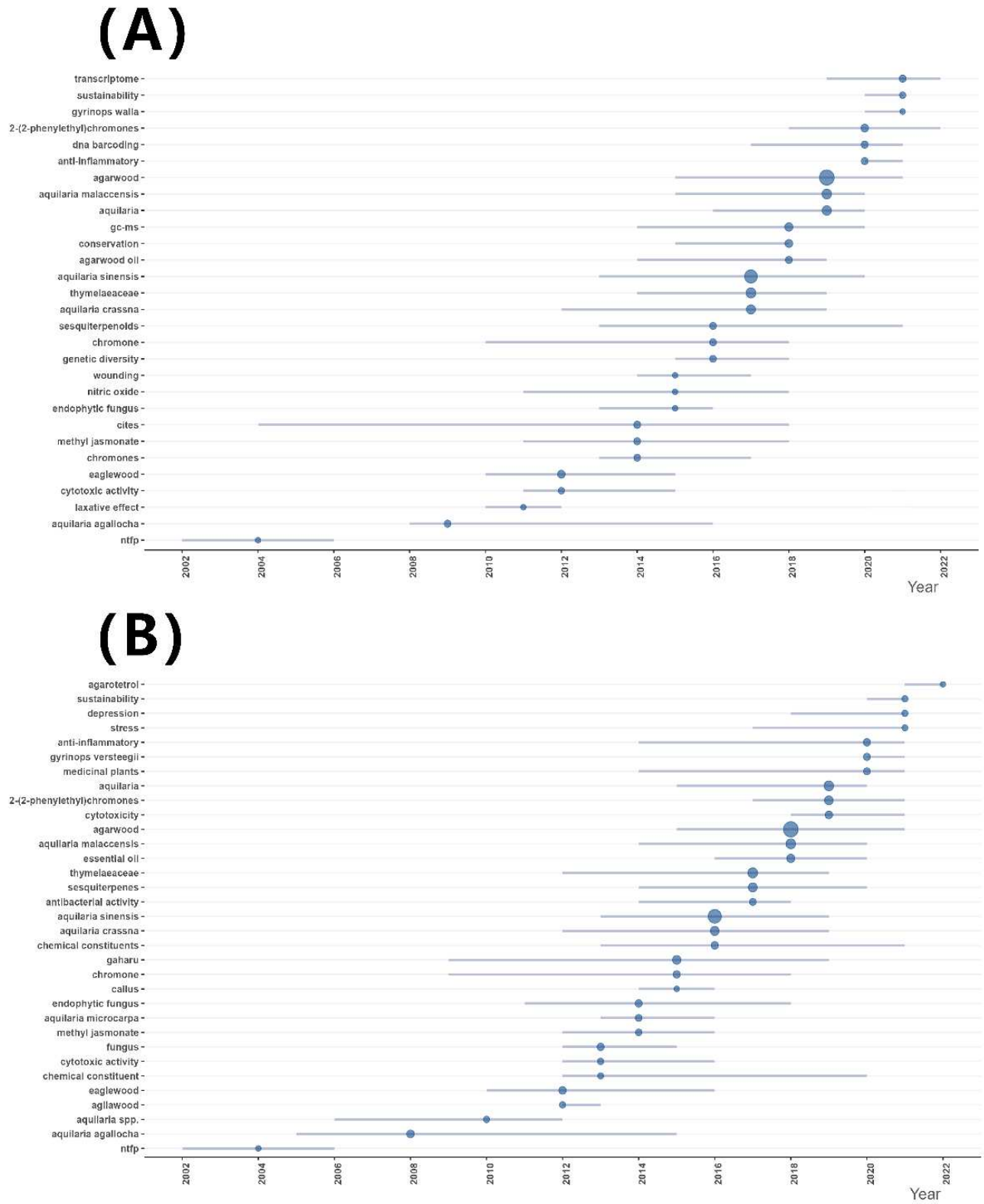

Figure 6. Topics of related articles derived from keywords indexed under (A) WoS and (B) Scopus from 2002–2022. The horizontal blue line shows the period where the keyword appeared at least three times. The size of the circle depicts the occurrence level, and the placement of the circle indicates the year where the keyword appeared the most.

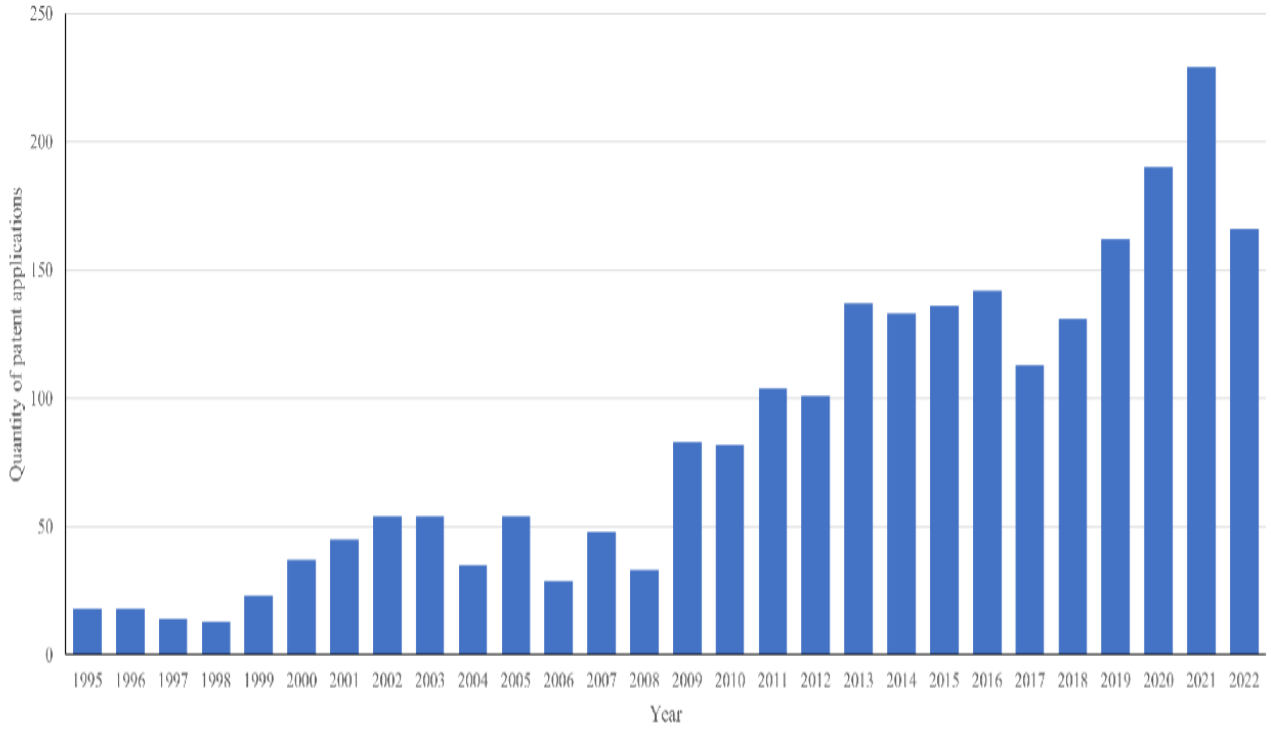

Figure 7. Quantity of related patent applications from 1995—2022 based on the Google Patent Database.

Table 1. Top 15 countries or international organizations of related patent application quantity, excluding the World Intellectual Property Organization (WIPO).

Rank	Country or International Organization	Quantity of patent applications
1	China	1072
2	Japan	422
3	USA	209
4	Korea	152
5	European Patent Office	112
6	Thailand	53
7	France	49
8	Canada	26
9	Australia	20
10	Spain	17
11	Malaysia	13
12	Germany	11
13	Brazil	6
14	Ireland	4
15	Bulgaria	3

Between 1995 and 2022, a total of 32 national agencies or international organizations handled applications on the related patents. In terms of country, excluding the World Intellectual Property Organization (WIPO), China (including Taiwan) had the highest number of accepted applications, totaling 1,072, representing 45.5% of the total applications thus far (Table 1). Japan had 422 applications, followed by the United States with 209, South Korea with 152, and the European Patent Office with 112. By looking into other Asian countries that strived in publication numbers, including India, Indonesia, Malaysia, and Thailand, only two countries had made it into the top 15, in which Thailand had 53 applications (ranked 6th) and Malaysia recorded 13 applications (ranked 11th).

DISCUSSION

Keywords and emerging research areas in agarwood studies: The earliest literature on agarwood was dated in 1959, which reported on the extraction of sesquiterpene alcohol from the agarwood oil (Jain and Bhattacharyya, 1959), but our sampling scope is insufficient to encompass the entire research history. However, there were only a few systematic studies published over the decades, indicating a low level of academic interest in agarwood during that period. Eventually, our finding shows a clear increase in research output during the first decade of the 21st century, while the inclusion of the agarwood-producing genera, *Aquilaria* and *Gyrinops*, in CITES Appendix II in 2005 could be considered a stimulant to agarwood research activities. Evidently, a noticeable increase in the number of related articles was recorded during post-CITES implementation.

China, Malaysia, India, and Thailand are among the world's agarwood producers (López and Page, 2018; Du *et al.,* 2022), which they have been playing an exceptional role in producing great number of publications throughout the years. Several factors have contributed to China and Malaysia's renewed attention. The cultural and economic importance of agarwood in these regions creates a favorable setting for comprehensive research. Agarwood, which is essential to traditional practices and has a high market value, has emerged as a priority in scientific research in these countries (Hashim *et al.,* 2016; Liu *et al.,* 2017). Furthermore, the large population and excellent research infrastructure, particularly in China, allow for a wide range of research, including sustainable harvesting methods, quality improvement, and innovative applications. Government policies and financing in these countries frequently align with the purpose of encouraging research in areas that support national economic and cultural interests, such as agarwood. Furthermore, the presence of strong local and international academic and research cooperation broadens the scope and depth of such research. These reasons, taken together, thrust China and Malaysia to the forefront of agarwood research, demonstrating their dedication to understanding and capitalizing on this important natural resource. In addition to China, other countries, including Malaysia, India, and Thailand, have demonstrated proactive engagement in the pursuit of research grants and funding for the investigation of agarwood (Jha, 2014; Lau *et al.*, 2022; Dutta and Bhuyan, 2023). These grants function as catalysts for innovative research endeavors, technological progressions, and conservation initiatives that are associated with agarwood. The investigation of the medicinal properties of agarwood and sustainable cultivation methods has been sparked by the pursuit of such funding in these countries (Chen *et al.,* 2017; Tan *et al.,* 2019; Li *et al.,* 2021). As one of the agarwood-producing countries, the substantial funding initiatives for research in Malaysia, India, and Thailand have substantially contributed to the advancement of agarwood science and related fields in the country. Their attempts in this regard are highlighted by their commitment to cultivating dynamic research ecosystems and promoting worldwide cooperation and the exchange of knowledge, while at the same time developing the local agarwood industry. Comparable to China, the way these nations proactively pursue research grants demonstrates their dedication to agarwood resource conservation and sustainable development (Liu *et al.,* 2013; Yin *et al.,* 2016).

Established research networks with well-defined clusters offer significant opportunities to strengthen and foster relationships (Leskovec *et al.*, 2009). They foster knowledge sharing, resource sharing, and coordinated initiatives to address worldwide agarwood research challenges. However, it is critical to specify that the advantages of gathering go beyond the agarwood industry. Industry clusters, which are composed of companies that gain a competitive edge through interdependence and local proximity, provide a compelling framework for state and local leaders to analyze and support their economies (Baily and Montalbano, 2018). Furthermore, the expansion of regions is contingent on their capacity to offer favorable conditions for companies to unite (Luo, 2000). Although the precise mechanisms underlying agglomeration remain elusive, it seems that various aspects do influence its occurrence. These include the capacity to foster perpetual innovation, establish dynamic entrepreneurial systems that infuse economies with high-quality employment opportunities, and involve robust local academic, civic, and public institutions that can facilitate these processes (Donahue *et al.,* 2018).

Among all keywords recorded, the keyword “agarwood” is recognized to be the most frequently occurring keyword in most related articles. However, the disparities in keyword occurrence between both databases could be due to database-specific peculiarities in research trends (Chae *et al.*, 2020). In conjunction with the increasing market demand for agarwood, the decline in wild agarwood tree populations has caused a substantial increase in the number of scientific publications addressed to this topic. Notably, the year 2019 witnessed the highest publication count in this domain (Figure 1). Additionally, this study revealed that agarwood induction technology, agarwood chemical composition, and agarwood pharmacological activity are the most frequently investigated subjects in agarwood research. Predicting the precise subject matter that will dominate agarwood research over the next three years is a challenging endeavor. However, based on current trends in the field, it is likely that academic studies will continue to try to improve the quality of agarwood products, come up with effective ways to induce agarwood, and look into the possible pharmacological properties of agarwood (Ma *et al*., 2021; Zhang *et al.*, 2021). Over the past two years, there has been a notable surge in scholarly investigations pertaining to agarwood induction technology, which pertains to the manipulation of tree growth to produce agarwood (Tan *et al.,* 2019; Peng *et al.,* 2021). To make sure that the agarwood yield from domesticated *Aquilaria* trees stays stable, it is important to create good induction technology. This is because natural agarwood formation takes a very long time—up to ten years (Tan *et al.,* 2019). Additional areas of research that have garnered interest over the past two years encompass the pharmacological properties of agarwood, its chemical composition, as well as the sustainable management and conservation of agarwood resources (Kanazawa, 2017; Wang *et al.,* 2018; Chen *et al.,* 2022). Therefore, in the future, it is anticipated that research into the sustainable management

and conservation of agarwood resources is going to be a significant area of emphasis (Desa *et al.*, 2021; Hazarika *et al.*, 2023).

The journal "Molecules" was found to be the key publication platform for related articles, indicating that the editor of the journal could be well-informed on the importance of agarwood-related research and promote the publication of related articles to improve the scientific knowledge of this valuable natural product. We do not exclude the possibility that the journal was preferred by related researchers due to its speed in the article reviewing process, which is also done rigorously (Björk, 2021). Aside from the quality of a journal, the fast decision as well as the peer review and publication process of a journal would somewhat influence the preferences of researchers to submit their work to a particular journal (Kapoor *et al.,* 2013). While the related topics are competitive among related researchers, having the work to be first in publication would be advantageous for researchers to be a pioneer in the work of an understudied topic (Fanelli, 2010).

Trends, prolific entities, and growth prospects in global agarwood patents: Global agarwood patents have increased over time, indicating a growing interest in intellectual property rights in this specialized subject (Figure 7). However, increases and reductions in patent counts throughout specific years imply innovation, market, or regulatory changes affecting patent applications (Hegde *et al.*, 2023). Registered patents in related subjects would include agarwood inducers, commercial fungal inoculum, agarwood-related manufacturing facilities, as well as commercial products such as herbal drinks and health supplements. The increase in patents in a country indicates the growing trend of the local agarwood industry to diversify supplies to meet market demand (Santangelo, 2002). It is worth noting that, according to this study, first-world countries including Japan, Korea, and the USA, which do not cultivate agarwood-producing trees and lack natural populations, would obtain a greater number of patents than agarwood-producing nations like Thailand and Malaysia. This observation suggests that the commerce of agarwood products has potentially reached these developed nations, thereby constituting a substantial catalyst for the growth of the agarwood sector. Nevertheless, the number of patents granted may not accurately reflect the actual amount of agarwood and derivatives produced and consumed, due to the influence of numerous variables on patenting activity, including innovation level, legal system, market demand, and cultural preferences. As a result, it is essential to conduct additional research on the environmental and social impacts of agarwood harvesting and cultivation, as well as the global agarwood market and its dynamics.

Conclusion: This bibliometric analysis provides valuable insights into the patterns and influence of agarwood research, particularly due to the inclusion of agarwood-producing genera in the CITES listing. The notable surge in publications following the listing, China's prominent position in research and patent applications, and the prevalence of selected reputable journals and trending topics highlight the dynamic nature of the field. The importance of international collaboration in agarwood research is evident, given the worldwide character of the field. China's extensive knowledge and experience in agarwood make it well-suited to take a leading role in guiding and assisting other countries in this field. In the future, it is anticipated that the emphasis will be on the importance of conducting further research on new trends, biological processes, and creative conservation methods to effectively manage agarwood resources in a sustainable manner. Nevertheless, this study enhances the comprehension of agarwood research dynamics and its implications for biodiversity conservation and sustainable development by connecting fresh data with current information.

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REFERENCES

Adhikari, S.R., K. Pokhrel and S.D. Baral (2021). Economic value of agarwood and its prospects of cultivation. Int. J. Appl. Sci. Biotechnol. 9(1): 23-31. doi: 10.3126/ijasbt.v9i1.35984.

Aria, M. and C. Cuccurullo (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. J. Informetr. 11(4): 959-975. doi: 10.1016/j.joi.2017.08.007.

Baddeley, A. and R. Turner (2005). Spatstat: an R package for analyzing spatial point patterns. *J. Stat. Softw. 12:* 1-42. doi: 10.18637/jss.v012.i06.

Baily, M. N. and N. Montalbano (2018). Clusters and innovation districts: Lessons from the United States experience. *Economic Studies at Brookings, The Brookings Institutions; Washington (US)*. 35 p.

Björk, B.C. (2021). Publishing speed and acceptance rates of open access Mega journals. *Online Inf.*

Rev. 45(2), 270-277. doi: 10.1108/OIR-04-2018-0151.

Cazalis, V., M. Di Marco, S.H. Butchart, H.R. Akçakaya, M. González-Suárez, C. Meyer, V. Clausnitzer, M. Böhm, A. Zizka, P. Cardoso and L. Santini (2022). Bridging the research-implementation gap in IUCN Red List assessments. Trends Ecol. Evol. 37(4): 359-370. doi: 10.1016/j.tree.2021.12.002.

Chae, C., J.H. Yim, J. Lee, S.J. Jo and J.R. Oh (2020). The bibliometric keywords network analysis of human resource management research trends: The case of human resource management journals in South Korea. *Sustain.* 12(14): 5700. doi: 10.3390/su12145700

Chen, S.T. and Y.K. Rao (2022). An overview of agarwood, phytochemical constituents, pharmacological activities and analyses. Tradit. Med. 3(1): 1-71. doi: 10.35702/Trad.10008

Chen, Y., T.T. Yan, L.L. Shang, Y.J. Fu and G.Y. Li (2017). Distinguish the wild from cultivated agarwood by using HPLC combined with PCA. Asian J. Plant Sci. Res. 7(2): 23-31.

CITES. (1994). Text of the Convention; Resolution Conference No. 9.24 Regarding the amendment of appendices and Inclusion of species in Appendix II. Fort Lauderdale (US).

CITES. (2004) Consideration of proposals for amendment of Appendices I and II- *Aquilaria* spp. and *Gyrinops* spp. Thirteenth meeting of the Conference of the Parties, Bangkok.

Desa, A.P., S.Y. Lee, M.Z. Mustapa, R. Mohamed and D. Emang (2021). Trends in the agarwood industry of Peninsular Malaysia. Malays. For. 84(1): 152-168.

Donahue, R., J. Parilla and B. McDearman (2018). Rethinking cluster initiatives. Metropolitan Policy Program at Brookings; Washington (US). 52 p.

Donthu, N., S. Kumar, D. Mukherjee, N. Pandey and W.M. Lim (2021). How to conduct a bibliometric analysis: An overview and guidelines. J. Bus. Res. 133: 285-296. doi: 10.1016/j.jbusres.2021.04.070.

Du, T.Y., C.J. Dao, A. Mapook, S.L. Stephenson, A.M. Elgorban, S. Al-Rejaie, N. Suwannarach, S.C. Karunarathna and S. Tibpromma (2022). Diversity and biosynthetic activities of agarwood associated fungi. Diversity. 14(3): 211. doi: 10.3390/d14030211.

Dutta, J. and M. Bhuyan (2023). Traditional cultivation and management practices of agarwood (*Aquilaria malaccensis*) in Golaghat district of Assam. Indian J. Tradit. Knowl. 22(4): 783-790. doi: 10.56042/ijtk.v22i4.7202.

Dwianto, W., S.S. Kusumah, T. Darmawan, Y. Amin, A. Bahanawan, D.A. Pramasari, E. Lestari, S.K. Himmi, E. Hermiati, W. Fatriasari, R.P.B. Laksana and R. Damayanti (2019). Anatomical observation and characterization on basic properties of agarwood (gaharu) as an Appendix II CITES. IOP Conf. Ser. Earth Environ. Sci. 374(1): 012062. doi: 10.1088/1755-1315/374/1/012062.

Fanelli, D. (2010). Do pressures to publish increase scientists' bias? An empirical support from US States Data. PloS One. 5(4): e10271. doi: 10.1371/journal.pone.0010271.

Hashim, Y.Z.H.Y., P.G. Kerr, P. Abbas and H.M. Salleh (2016). *Aquilaria* spp.(agarwood) as source of health beneficial compounds: A review of traditional use, phytochemistry and pharmacology. J. Ethnopharmacol.189: 331-360. doi: 10.1016/j.jep.2016.06.055.

Hazarika, A., J.R. Deka, P.C. Nath, G.W. Sileshi, A.J. Nath, K. Giri and A.K. Das (2023). Modelling habitat suitability of the critically endangered Agarwood (*Aquilaria malaccensis*) in the Indian East Himalayan region. *Biodivers. Conserv. 32*(14): 4787-4803. doi: 10.1007/s10531-023-02727-3.

Hegde, D., K. Herkenhoff and C. Zhu (2023). Patent publication and innovation. *J. Pol. Econ. 131*(7): 1845-1903. doi: 10.1086/723636.

Heisterkamp, S.H., E. van Willigen, P.M. Diderichsen and J. Maringwa (2017). Update of the nlme package to allow a fixed standard deviation of the residual error. *R J. 9*(1): 239.

Hishamuddin, M.S., S.Y. Lee, N.M. Isa, D.U. Lamasudin, S.A.Z. Abidin and R. Mohamed (2019). Time-based LC-MS/MS analysis provides insights into early responses to mechanical wounding, a major trigger to agarwood formation in *Aquilaria malaccensis* Lam. RSC Adv. 9(32): 18383-18393. doi: 10.1039/C8RA10616A.

Hishamuddin, M.S., S.Y. Lee, S.A. Syazwan, S.I. Ramlee, D.U. Lamasudin and R. Mohamed (2023). Highly divergent regions in the complete plastome sequences of *Aquilaria* are suitable for DNA barcoding applications including identifying species origin of agarwood products. 3 Biotech. 13(3): 78. doi: 10.1007/s13205-023-03479-1.

Jain, T.C. and S.C. Bhattacharyya (1959). Structure, stereochemistry and absolute configuration of agarol, a new sesquiterpene alcohol from agarwood oil. *Tetrahedron Lett.*, *1*(9): 13-17. doi: 10.1016/S0040-4039(01)82745-3.

Jarić, I., R.A. Correia, D.L. Roberts, J. Gessner, Y. Meinard and F. Courchamp (2019). On the overlap between scientific and societal

taxonomic attentions—Insights for conservation. Sci. Total Environ. 648: 772-778. doi: 10.1016/j.scitotenv.2018.08.198.

Jha, K.K. (2014). Agarwood plantation and products as livelihood strategy: a case study from Ban Khlong Sai village, northeast Thailand. *Int. J. Rural Dev. Manag. Stud. 8:* 45-59.

Kanazawa, K. (2017). Sustainable harvesting and conservation of agarwood: A case study from the Upper Baram River in Sarawak, Malaysia. Tropics. 25(4): 139-146. doi: 10.3759/tropics.MS15-16.

Kapoor, S., P. Sikka and K.K. Saxena (2013). Publication of research article: An art or science? Ann. Med. Health Sci. Res. 3(1): 96-98. doi: 10.4103/2141-9248.109459.

Kokol, P., H. Blažun Vošner and J. Završnik (2021). Application of bibliometrics in medicine: A historical bibliometrics analysis. Health Info. Libr. J. 38(2): 125-138. doi: 10.1111/hir.12295.

Lau, K. H., L. S. L. Chua, M. A. Azyraf Azmi (2022). Outreach action plan of the *Aquilaria malaccensis* arboretum 2022-2031: An early concept. Forest Research Institute Malaysia; Selangor (Malaysia). 26 p.

Lee, S.Y., M. Turjaman, A. Chaveerach, S. Subasinghe, Q. Fan and W. Liao (2022). Phylogenetic relationships of *Aquilaria* and *Gyrinops* (Thymelaeaceae) revisited: Evidence from complete plastid genomes. Bot. J. Linn. 200(3): 344-359. doi: 10.1093/botlinnean/boac014.

Leskovec, J., K.J. Lang, A. Dasgupta and M.W. Mahoney (2009). Community structure in large networks: Natural cluster sizes and the absence of large well-defined clusters. *Internet Math. 6*(1): 29-123. doi: 10.1080/15427951.2009.10129177.

Li, W., H.Q. Chen, H. Wang, W.L. Mei and H.F. Dai (2021). Natural products in agarwood and *Aquilaria* plants: Chemistry, biological activities and biosynthesis. Nat. Prod. Rep. 38(3): 528-565. doi: 10.1039/D0NP00042F.

Liu, Y., H. Chen, Y. Yang, Z. Zhang, J. Wei, H. Meng, W. Chen, J. Feng, B. Gan, X. Chen and H. Chen (2013). Whole-tree agarwood-inducing technique: An efficient novel technique for producing high-quality agarwood in cultivated *Aquilaria sinensis* trees. Molecules. 18(3): 3086-3106. doi: 10.3390/molecules18033086.

Liu, Y.Y., J.H. Wei, Z.H. Gao, Z. Zhang and J.C. Lyu (2017). A review of quality assessment and grading for agarwood. Chin. Herb. Med. 9(1): 22-30. doi: 10.1016/S1674-6384(17)60072-8.

López-Sampson, A. and T. Page (2018). History of use and trade of agarwood. Econ. Bot. 72(1): 107-129. doi: 10.1007/s12231-018-9408-4.

Luo, Y. (2000). Dynamic capabilities in international expansion. *J. World Bus. 35*(4): 355-378. doi: 10.1016/S1090-9516(00)00043-2.

Ma, S., Y. Fu, Y. Li, P. Wei and Z. Liu (2021). The formation and quality evaluation of agarwood induced by the fungi in *Aquilaria sinensis*. *Ind. Crops Prod. 173:* 114129. doi: 10.1016/j.indcrop.2021.114129.

Nobuchi, T. and S. Siripatanadilok (1991). Preliminary observation of *Aquilaria crassna* wood associated with the formation of aloeswood. Bull. Kyoto Univ. For. 63: 226-235.

Oksanen, J., F.G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P. Solymos, M.H.H. Stevens, E. Szoecs and H. Wagner (2019). Vegan. *Community Ecology Package.* R package version 2.5-4. https://CRAN.R-project.org/package=vegan

Paradis, E. and K. Schliep (2019). ape 5.0: An environment for modern phylogenetics and evolutionary analyses in R. *Bioinform. 35*(3): 526-528. doi: 10.1093/bioinformatics/bty633.

Peng, C.S., M.F. Osman, N. Bahari, R. Zakaria and K.A. Rahim (2021). Production of agarwood resin in *Aquilaria beccariana* using inducement technology. J. Agric. Biotechnol. 12(1): 57-67. doi: 10.37231/jab.2021.12.1.227.

R Core Team. (2022). R: A language and environment for statistical computing R Foundation for Statistical Computing; Vienna (Austria).

Santangelo, G.D. (2002). The regional geography of corporate patenting in information and communications technology (ICT): Domestic and foreign dimensions. *Reg. Stud. 36*(5): 495-514. doi: 10.1080/00343400220137119.

Şenyapar, H.N.D. (2023). A bibliometric analysis on renewable energy's public health benefits. J. Energy Syst. 7(1): 132-157. doi: 10.30521/jes.1252122.

Tan, C.S., N.M. Isa, I. Ismail and Z. Zainal (2019). Agarwood induction: Current developments and future perspectives. Front. Plant Sci. 10: 122. doi: 10.3389/fpls.2019.00122.

Thompson, I. D., T. Lim and M. Turjaman (2022). Expensive, exploited and endangered. A review of the agarwood-producing genera *Aquilaria* and *Gyrinops*: CITES considerations, trade patterns, conservation, and management, ITTO Technical Series No. 51. International Tropical Timber Organization (ITTO), Yokohama.

Todeschini, R. and A. Baccini (2016). Handbook of bibliometric indicators: Quantitative tools for studying and evaluating research. John Wiley & Sons; Hoboken (US).

UNEP-WCMC. (2019). The checklist of CITES species website. CITES Secretariat; Geneva (Switzerland). http://checklist.cites.org. Accessed 7th December 2023.

Van Eck, N.J. and L. Waltman (2022). Crossref as a source of open bibliographic metadata. Centre for Science and Technology Studies, LEI, Leiden. 16 p. doi: 0.31222/osf.io/smxe5.

Wang, M.R., W. Li, S. Luo, X. Zhao, C.H. Ma and S.X. Liu (2018). GC-MS study of the chemical components of different *Aquilaria sinensis* (Lour.) Gilg. organs and agarwood from different Asian countries. Molecules. 23(9): 2168. doi: 10.3390/molecules23092168.

Wyn, L.T. and N.A. Anak (2010). Wood for the trees: a review of the agarwood (gaharu) trade in Malaysia. TRAFFIC Southeast Asia; Kuala Lumpur (Malaysia).

Yin, Y., L. Jiao, M. Dong, X. Jiang and S. Zhang (2016). Wood resources, identification, and utilization of agarwood in China. Mohamed, R. (Ed.) Agarwood: Science behind the fragrance. Springer Nature Singapore; Singapore. 21-38. doi: 10.1007/978-981-10-0833-7_2.

Zhang, N., S. Xue, J. Song, X. Zhou, D. Zhou, X. Liu, H. Zhou and D. Xu (2021). Effects of various artificial agarwood-induction techniques on the metabolome of *Aquilaria sinensis*. *BMC Plant Biol. 21:591*. doi: 10.1186/s12870-021-03378-8.