Chapter 2
Wood Resources, Identification, and Utilization of Agarwood in China

Yafang Yin, Lichao Jiao, Mengyu Dong, Xiaomei Jiang, and Shujuan Zhang

Abstract Agarwood, a compound substance of xylem tissue and its inclusions, is generally formed in some genera of Thymelaeaceae (e.g., *Aquilaria*) during the tree's natural growing process. Due to the medicinal and economic values of agarwood augmented by unsustainable harvesting techniques, calls have been made by international bodies such as CITES and IUCN to conserve agarwood-producing tree species. Consequently, identification of agarwood resources becomes an important issue to provide better protection for the species. In this chapter, we review the status, i.e., forest resources, wood features, identification, and market development of agarwood (*Aquilaria*) in China. Some suggestions for the sustainable development of *Aquilaria* resources in China are also provided.

2.1 Introduction

Agarwood has a distinctive fragrance and is a precious traditional medicine and a much-sought after perfume in Asian countries such as China, Japan, India, and countries in the Middle East. During the past 30 years, there has been a surge in demand for agarwood worldwide. However, due to its slow formation, limited output, and high volume of trading, the supply of agarwood has decreased gradually, and its price is constantly increasing. For better understanding on the status of agarwood development, the distribution of *Aquilaria* resources in China, both in the wild and planted, is provided here. Additionally, we discuss identification methods of *Aquilaria* resources based on wood anatomy, DNA barcode, and chemical analysis. However, the latter is preferably used to test for agarwood quality. To identify *Aquilaria* wood at species level, based on its wood anatomical features alone, is a difficult if not impossible task. Nevertheless, the newly developed DNA barcoding

Y. Yin (✉) • L. Jiao • M. Dong • X. Jiang
Department of Wood Anatomy and Utilization, Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing 100091, P.R. China
e-mail: yafang@caf.ac.cn

S. Zhang
Beijing Tian-yi-li-hua Institute of Agarwood, Beijing, P.R. China

© Springer Science+Business Media Singapore 2016
R. Mohamed (ed.), *Agarwood*, Tropical Forestry,
DOI 10.1007/978-981-10-0833-7_2

technology might transcend these limitations and result in effective information with a high resolution. Adopting such technique for specific and rapid identification of agarwood species will help conserve its natural resources in the forest while creating a sound and orderly environment for development of agarwood market.

2.2 Distribution of Agarwood Resources

2.2.1 Global Distribution

Discussions have taken place on the scope of the plant species that can produce agarwood. It is generally recognized that agarwood is mainly produced by the Thymelaeaceae trees, which include *Aquilaria*, *Aetoxylon*, *Enkleia*, *Gyrinops*, *Gonystylus*, *Phaleria*, and *Wikstroemia*; however, not all can form agarwood (Wyn and Anak 2010). Among them, the *Aquilaria* trees are widely recognized in China as the main source for producing agarwood. In this chapter, *Aquilaria* is the main genus in focus.

The wild resources of global *Aquilaria* plants are mostly concentrated in the southeast of Asia. There are about 20 *Aquilaria* species, the most common being *A. malaccensis*, *A. crassna*, *A. microcarpa*, *A. filaria*, *A. subintegra*, and *A. beccariana*. When it comes to Eastern Asia, there is a wide distribution of *A. sinensis* in Southern China. *Aquilaria yunnanensis* is also found in the same region but its distribution is sparser. Among the countries that produce agarwood, the Philippines has the most species of *Aquilaria* and the richest variety accounting for half of the world's total. Next is Indonesia, which has one third of the total. It also has the largest distribution area of resources for *Aquilaria* trees. Malaysia and Thailand are also rich in *Aquilaria* species. By comparison, there are fewer native *Aquilaria* species in Vietnam, Myanmar, Laos, India, and China. According to the records of the International Union for Conservation of Nature (IUCN), there is also a distribution of *A. malaccensis* in Iran in West Asia.

Due to the enormous market demand for agarwood and excessive felling and low natural growth rate for *Aquilaria*, the tree distribution has significantly decreased over the past 20 years in the Asian region. Meanwhile, for meeting the increasing demands of the international agarwood market, the development of plantations has now come into research focus. At present, *Aquilaria* trees are widely cultivated in many countries with the technology for artificial agarwood induction being increasingly perfected.

2.2.2 Distribution in China

There are currently two native *Aquilaria* species in China, i.e., *A. sinensis* and *A. yunnanensis* (Cheng et al. 1992; Editorial Board of Flora of China of Chinese Academy of Sciences 1999). Between the two, *A. sinensis* is the only plant resource

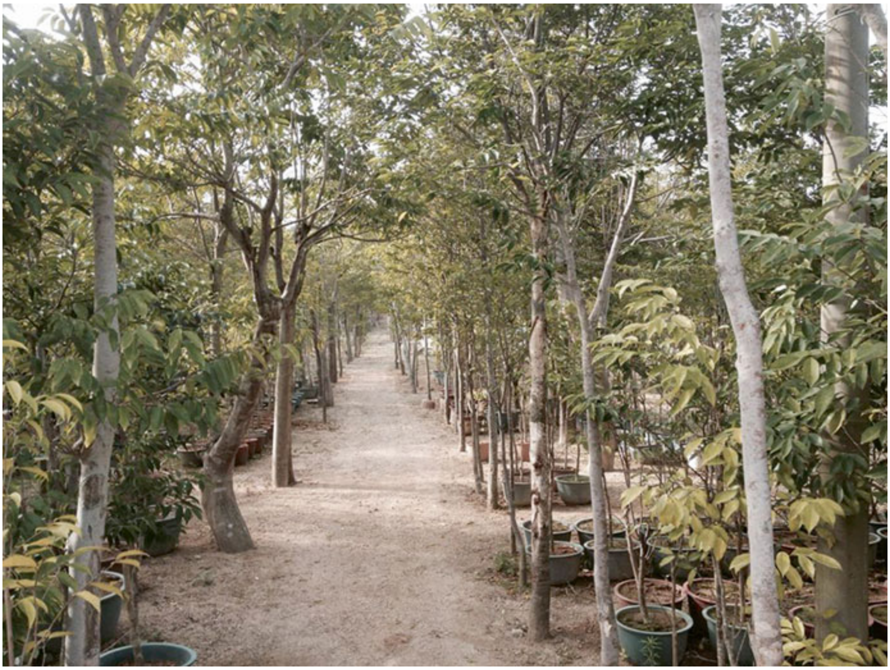

Fig. 2.1 Planted *Aquilaria sinensis* in Guangdong Province

that can be used for producing agarwood for traditional medicine in China (Fig. 2.1). It has been used as genuine medicine for more than a thousand years. *Aquilaria sinensis* originates in Hainan, Guangdong, and parts of Guangxi and Yunnan provinces. At present, it is mainly produced in the Hainan Province. As early as the Tang and Song Dynasties, *A. sinensis* has been widely cultivated in the Dongguan area, where it became a local specialty. Consequently, agarwood has also been called "Guan Xiang," which means the agarwood of Dongguan. According to textual research on medicinal history, the evolution of the variety, and the origin of agarwood in "Nanyao" (the traditional medicine in South China), the sources of medicinal agarwood have been grouped into native agarwood (*A. sinensis*) and imported agarwood since the time of Ancient China (Mei et al. 2011).

2.2.2.1 Wild Resources

At present, the distribution of wild resources of *A. sinensis* occurs mainly in Guangdong, Hainan, and Guangxi provinces. Due to excessive felling in recent years, its wild resources have been greatly destroyed. *Aquilaria yunnanensis* S. C. Huang (http://db.kib.ac.cn), a new *Aquilaria* species found in China, mainly originated in Mengla Town (Youle Mountain) and Shuangjiang Town in Yunnan Province, but its distribution is mostly scattered or patchy.

Current distribution of wild resources of *Aquilaria* tree is becoming sparse in China. Guangdong and Hainan provinces, the two most renowned regions for agarwood in China, have *A. sinensis* scattered in coastal, offshore, hilly and low mountain areas, and within limits of certain natural protection zones. To guarantee the sustainable development of *Aquilaria* resources, the Dongguan Botanical Garden of Guangdong Province has started to preserve a considerable number of *A. sinensis* resources. It has collected *A. sinensis* from several provenances including six from Hainan Province, three from Guangxi Province, two from Yunnan, and 20 from Guangdong Province, where special works on seedling cultivation have been carried out. Historically, Guangxi Province was once one of the important distribution areas of wild resources of the *Aquilaria* tree. However, according to official 2011 statistics, there were only 354 wild *A. sinensis* occurring in a relatively concentrated area, e.g., Pubei County, whereas in Yunnan Province, there were only a few wild resources of *A. sinensis* and *A. yunnanensis* that were scattered in the natural protection zones.

The protection of *A. sinensis* is an important issue in China. The few remaining wild *A. sinensis* resources have even become the target of offenders who are increasingly destroying trees and illegally felling them. In 1992, the China Plant Red Data Book emphasized that the quantity of *A. sinensis* was seriously decreasing. In 1998, the IUCN listed *A. sinensis* on the list of Endangered Species of Wild Fauna and Flora. A year later, *A. sinensis* was listed in the second-class category of the National List of Local Protected Flora, issued by the Chinese government (The State Council of the People's Republic of China 1999). Consequently, all species from the genus *Aquilaria* have been listed in Appendix II of CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) since 2005 (http://www.cites.org/eng/app/appendices).

2.2.2.2 Plantation Resources

Since 2007, the Chinese agarwood market has experienced rapid growth. Due to their geographic advantage of being in the tropics and subtropics and because of their mild climate conditions, Guangdong, Guangxi, Hainan, Yunnan, and Fujian provinces have all started planting *Aquilaria*. At present, millions of *Aquilaria* trees are being cultivated, with a great deal of success and progress (Fig. 2.2). According to statistical data published in 2011, the total new planted area of national *Aquilaria* plantation resources from 2006 to 2010 had reached 5285 hectares. Of these, *A. sinensis* occupied 5245 hectares, accounting for 99 % of the total area (Table 2.1). The planting density of *A. sinensis* was generally 2 m × 1.5 m or 2 m × 3 m, with 1500–3000 trees per hectare.

A. crassna, which occupied 40 hectares and accounted for less than 1 % of the total, is a relatively successful exotic species. The species grew under good conditions, after being tested, which resulted in the successful accomplishment of artificial agarwood induction. Since the leaves of *A. crassna* are bitter tasting, they have the capacity of being insect resistant; they seldom suffer from plant diseases introduced by insects. In addition, some *A. subintegra* have also been introduced.

Fig. 2.2 Logs of *Aquilaria sinensis* plantation in Guangdong Province

Table 2.1 Resources of new planted *Aquilaria* plantation in China (2006–2010)

Province	Species	Area (ha)					Total area (2006–2010)	Percentage (%)
		2006	2007	2008	2009	2010		
Guangdong	*Aquilaria sinensis*	1528.4	39.7	132.2	260.4	918.5	2879.2	54. 45
Guangxi	*Aquilaria sinensis*	1.5	1.1	0	6.5	42.0	51.1	0.97
Hainan	*Aquilaria sinensis*	39.1	28.5	26.1	44.8	121.4	259.9	4.92
Fujian	*Aquilaria sinensis*	0.1	0	2.0	1.4	1.8	5.3	0.10
Yunnan	*Aquilaria sinensis*	466.7	300.0	453.3	433.3	396.7	2050	38.76
Subtotal		2035.8	369.3	613.6	746.4	1480.4	5245.5	99.24
Guangdong	*Aquilaria crassna*	40.0					40.0	0.76
Guangdong	*Aquilaria subintegra*	A few						
Total		**2075.8**	**369.3**	**613.6**	**749.4**	**1480.4**	**5285.5**	**100 %**

Note: The total distribution area of *Aquilaria* resources could be higher because only data of new planted *Aquilaria* resources collected since 2006 are presented here. Data from the Endangered Species Import and Export Management Office of the People's Republic of China (2011)

Guangdong Province has the longest history in *Aquilaria* planting in China. In 1978, Shantou City initiated plantations of *Aquilaria* while introducing *A. crassna* from the Kachin State of Myanmar. They were soon afterward introduced into Yunnan, Hainan, and Guangxi provinces. After 2006, *A. sinensis*, recognized as the native tree of the best quality has been widely cultivated throughout Guangdong Province. The transformation of an ecological noncommercial forest in the Pearl River Delta region has also become an effective ex-situ conservation measure for *A. sinensis*. Currently, the planting of *A. sinensis* in Guangdong Province is concentrated in Dongguan, Dianbai, Gaoyao, and Huazhou cities. This work gradually spreads throughout the province, where the scale of planting in Dianbai City is relatively considerable. Until the end of 2010, the total area of planted *A. sinensis* was 3867 hectares; 2000 hectares belong to plantations and the remaining to individual farmers.

The mass development of *Aquilaria* plantations in Hainan Province started with the introduction of a local development project. According to incomplete statistics in 2012, the plantation area is over 2000 hectares, with about three million trees distributed mainly in the Dingan, Danzhou, Chengmai, and Dunchang counties. At present, local areas of *Aquilaria* plantations are continually expanding in most cities and counties in the Hainan Province. With more people realizing the economic value inherent in planting *Aquilaria*, a developing pattern of corporatization and scaling is gradually taking place.

In Guangxi Province, the development of *Aquilaria* plantations started relatively late, focusing mainly on *A. sinensis*. Until 2011, the relatively concentrated new planted areas of 51 hectares were mainly found in Shangsi and the Fangcheng counties, among others. According to statistics in Yunnan Province, the plantation area of *Aquilaria* included about 733 hectares in Xishuangbanna and 67 hectares in Puer City. The main species was *A. sinensis* along with some *A. yunnanensis*.

Fujian Province is not a natural distribution zone for *Aquilaria*. However, it is currently carrying planting activities. By the end of 2011, the number of new planted *A. sinensis* trees mainly in young seedlings had reached about 50,000 in an area of 5.3 hectares, and they are mainly found in Quanzhou and Zhangzhou cities.

2.3 Wood Anatomical Characters of Agarwood

An examination of the anatomical characters of *Aquilaria* wood can be undertaken at both the macroscopic and microscopic levels. A macroscopic examination can be made with the naked eye or with the aid of a small magnifying glass. A microscopic examination requires the sectioning of a sample with an optional staining of the sections, followed by observation under a light microscope and making a comparison with reference samples (wood xylarium). The wood anatomical characteristics are described in the standard terminology of the International Association of Wood Anatomists (IAWA) (IAWA Committee 1989).

2.3.1 Macroscopic Features

When observing the macroscopic feature of *Aquilaria* wood with the naked eye or magnifier with a magnification of 10×, the following should be noted: the wood color, odor, growth rings, vessel arrangements and size, rays, and included phloem.

The wood color is yellowish white (Fig. 2.3). Once the wood is exposed to the air for a long term, its surface will turn dark (Fig. 2.4a). The wood is glossy and has a mild fragrant and sweet odor. If the xylem starts to produce agarwood, black lines or conglomerations will appear in that place. After producing more agarwood, the entire piece of wood will become black or dark brown.

Growth rings are indistinct. The wood is diffuse porous. The vessels are slightly small to medium, distinct under magnification. The size of vessels is consistent and evenly distributed in a dispersive arrangement. The axial parenchyma is absent. The rays are small to medium, very fine to slightly fine, and visible under magnification. Ripple marks and intercellular canal are absent. The included phloem is visible with the naked eye. There is an island-type pattern with uniform distribution, which is the key character when it comes to *Aquilaria* wood identification (Fig. 2.4b). However, the included phloem with pores should be distinguishable.

2.3.2 Microscopic Features

For microscopic observation, wood samples were excised into small blocks [10 mm (L) × 10 mm (R) × 10 mm (T)] with a razor blade and then softened in water at 80 °C for 5 h. Thereafter, transverse, radial, and tangential sections were cut into

Fig. 2.3 Wood stem of *Aquilaria* spp.

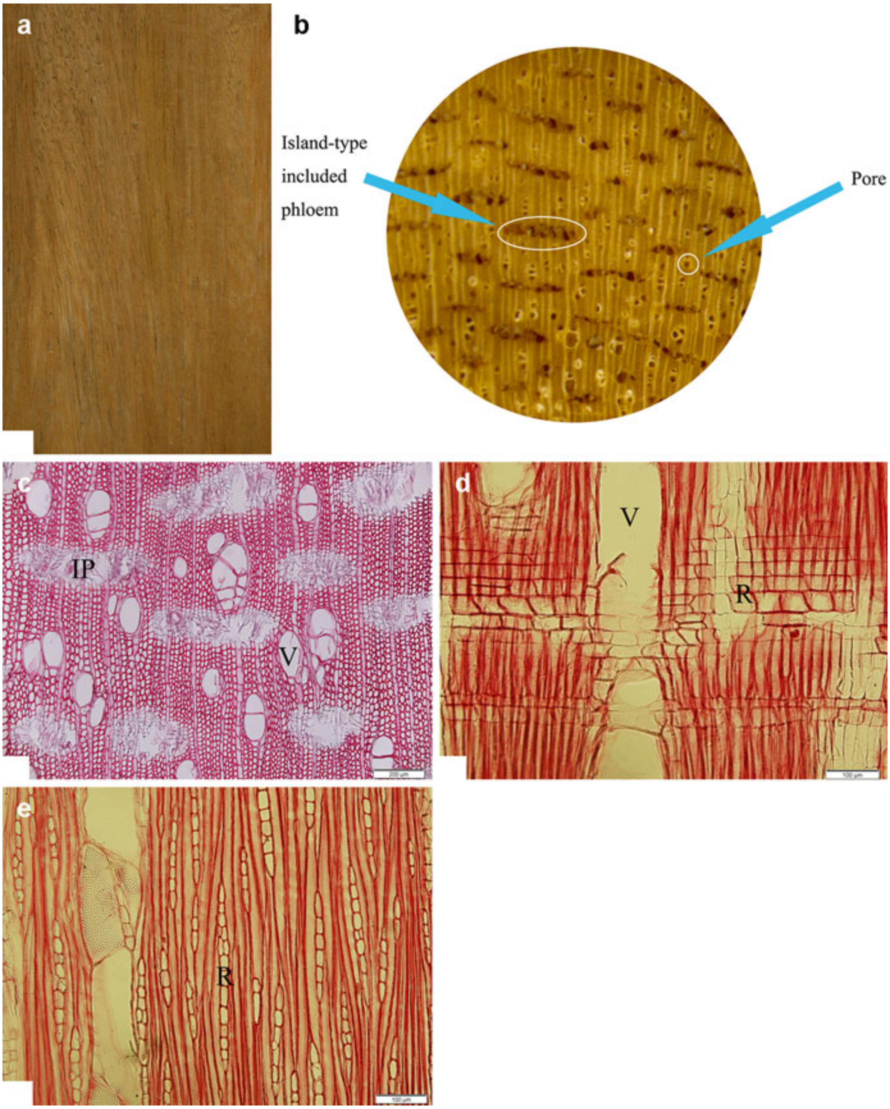

Fig. 2.4 Wood specimen (**a**), wood cross section (16×) (**b**), and anatomical features (**c**–**e**) of *Aquilaria sinensis*. (**c**–**e**) Transverse, radial, and tangential sections, respectively. Scale bars, 200 μm (**c**) and 100 μm (**d**, **e**). *IP* included phloem, *R* ray, *V* vessel

thicknesses of 15–20 μm on a sliding microtome and then observed under a light microscope (Olympus BX61, Japan) after being stained with 1 % aqueous safranine. The wood can be identified according to the features of the three wood sections. The main characteristics to be observed are the included phloem, the vessel arrangements and size, the intervessel pits, the axial parenchyma, the fibers, and the rays (Figs. 2.4c–e).

Included Phloems They are better observed in the transverse section. They are unevenly oval or elliptically long and evenly distributed.

Vessels The vessels are round or oval, sometimes partly with an angular outline. They are in radial multiples of 2–5 (mainly 2–4), occasionally with vessel clusters. They are diffuse, thin walled. Their tangential diameters are mainly 70–130 μm, with a maximum of up to 150 plus μm. They are partly storied. Tyloses are absent, with few inclusions. Helical thickenings are absent. The simple perforations are round or oval. The perforation plates mostly are slightly sloped, few slope, and parallel. The intervessel pits are alternate. The vessel-ray pits are similar to intervessel pits in size and shape.

Axial Parenchyma The axial parenchyma cells are scarce and paratracheal. They have end wall thickenings that are distinct. Gums and crystals are absent. There are few inclusions.

Fibers The fibers have thin to very thin walls, with more bordered pits; they are distinct with round or oval pit apertures included or extended, lenticular, and crack shaped, usually circular or X shaped.

Rays The rays are nonstoried, 5–14/mm, mostly uniseriate with occasional biseriate rays. They are 3–12 cells in height. They are mostly uniseriate rays with procumbent, square, and upright cells mixed throughout the ray. They have body ray cells procumbent with one row of occasional square marginal cells. The height of the upright or square ray cells is greater than that of the procumbent ray cells, with the latter being rectangular. The inclusions are usually visible. Crystals are absent. The thickening in the end walls is slightly distinct. Pits are indistinct in the horizontal walls (Figs. 2.4c–e).

2.4 Identification Methods for Agarwood

2.4.1 Wood Anatomy

Wood identification is essential in the context of timber trade, to combat illegal logging, for wood certification, and for forensic know-how. In order to achieve a definitive identification of *Aquilaria* wood, macroscopic and microscopic examinations are required in most instances. The observation of wood anatomy generally facilitates an identification at genus level (*Aquilaria* spp.), since the wood characteristics tend to be very well conserved within the genera.

However, there are other woods, belonging to mainly the genera *Memecylon* (Melastomataceae) (Fig. 2.5a, b) and *Strychnos* (Loganiaceae) (Fig. 2.6a, b), that are similar to *Aquilaria* wood. Both have included phloem, so they have been sold under the guise of *Aquilaria* wood on the wood market in the Guangdong, Guangxi, and Yunnan provinces. Fortunately, there are still some differences in their wood anatomical

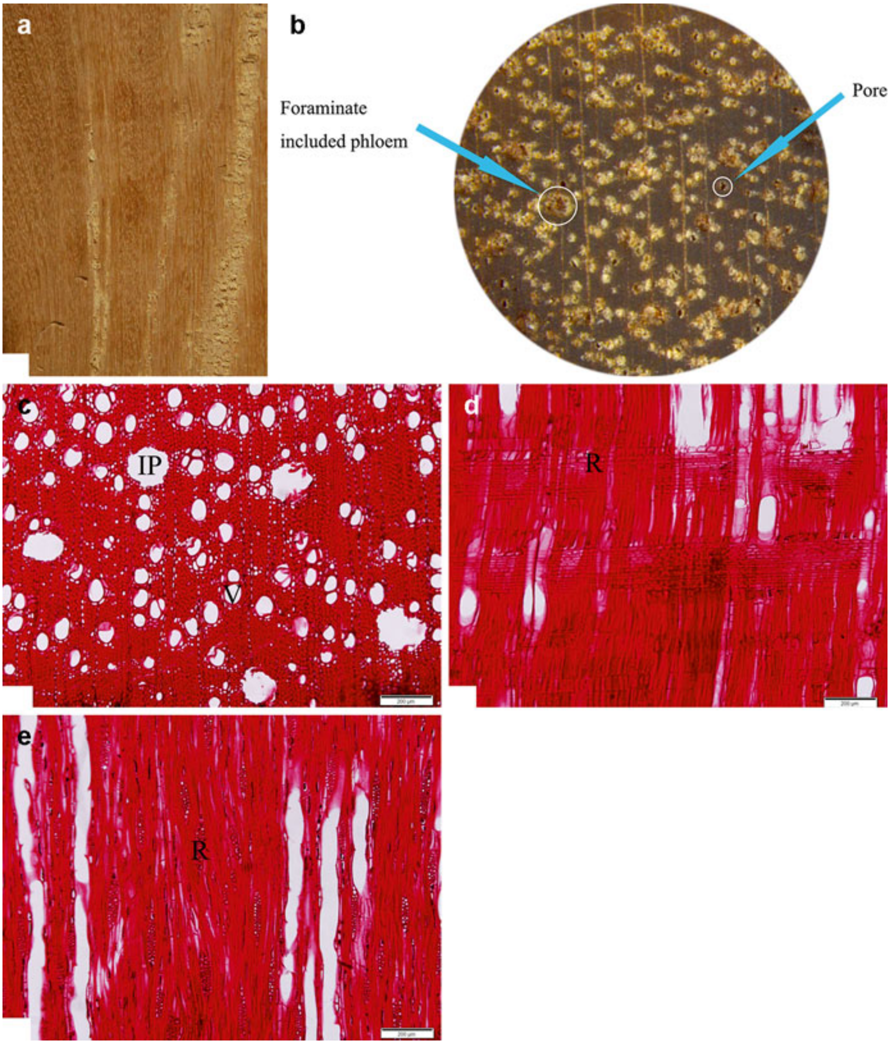

Fig. 2.5 Wood sample (**a**), wood cross section (16×) (**b**), and anatomical features (**c**–**e**) of *Memecylon* spp. (**c**–**e**) Transverse, radial, and tangential sections, respectively. Scale bars, 200 μm (**c**) and 100 μm (**d**, **e**). *IP* included phloem, *R* ray, *V* vessel

features, when comparing them to *Aquilaria* wood (Miles 1978; Cheng et al. 1992; Liu et al. 2008). The main characteristics of *Memecylon* and *Strychnos* are as follows.

2.4.1.1 *Memecylon*

Vessels are mainly solitary and partly in radial multiples. Axial parenchyma is a winged aliform, confluent-like, vasicentric, and diffuse in aggregates. Most rays are uniseriate; the multiseriate rays consist of 2–4 cells in width. The height of the upright or square

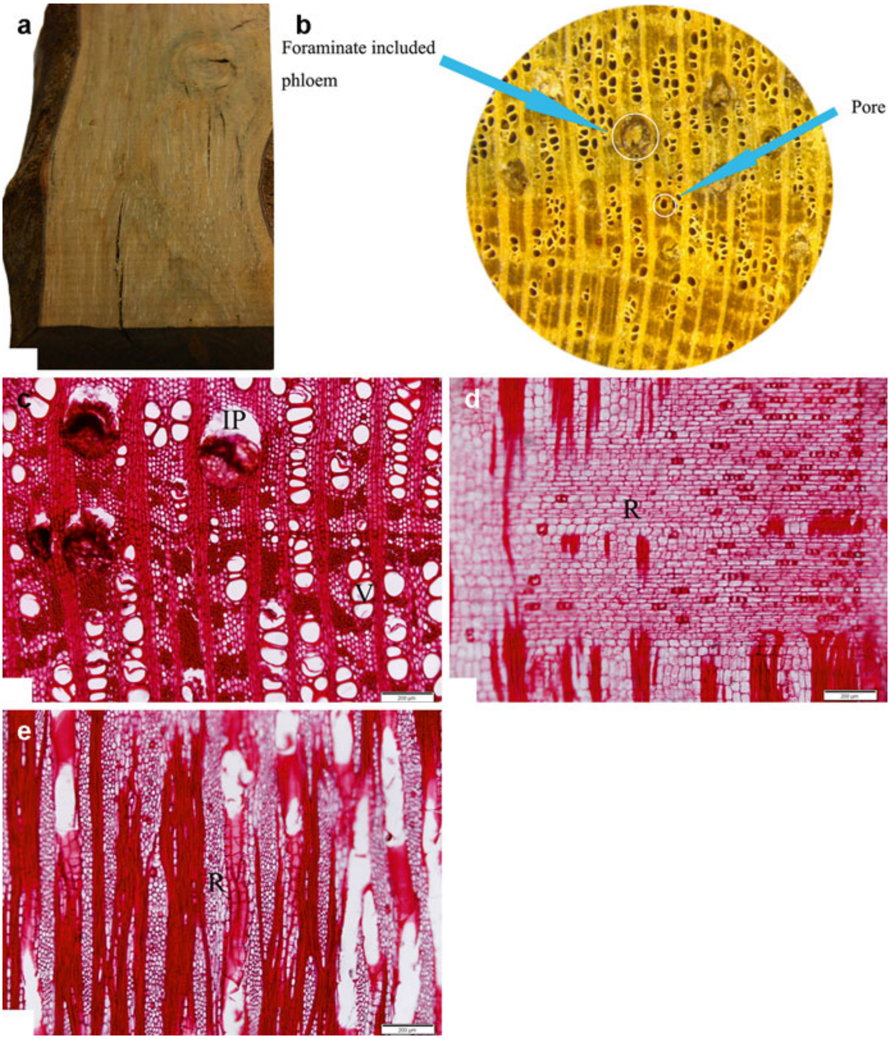

Fig. 2.6 Wood sample (**a**), wood cross section (16×) (**b**), and anatomical features (**c–e**) of *Strychnos* spp. (**c–e**) Transverse, radial, and tangential sections, respectively. Scale bars, 200 μm (**c**) and 100 μm (**d**, **e**). *IP* included phloem; *R* ray, *V* vessel

ray cells is greater than that of the procumbent ray cells. The body ray cells are procumbent with two to several rows of upright and/or square marginal cells (Fig. 2.5c–e).

2.4.1.2 *Strychnos*

The vessels are mainly solitary, with partially multiple radials up to 10 plus cells. The parenchyma is in marginal or seemingly marginal bands. The banded parenchymas are 2–8 cells in width. The larger rays are normally two to eight seriate.

Uniseriate rays are absent or extremely rare. The body ray cells are procumbent with two to several rows of upright and/or square marginal cells (Fig. 2.6c–e).

There are currently some other kinds of woods that are being sold under the guise of *Aquilaria* wood on the local market in China including *Dalbergia* spp., *Terminalia* spp., *Thuja* spp., and even *Cocos nucifera*, among others. The differences between their anatomical features and those of *Aquilaria* wood are huge. However, after treatment with resin and essential oils, these woods become dark and submerged, and the odor is similar to agarwood. Therefore, based on appearance only, it is difficult to distinguish between genuine and counterfeit agarwood. When necessary, samples should be sent to professional institutions for identification purposes.

2.4.2 DNA Barcode

DNA barcoding is a genetic approach based on a short DNA sequence from a standard part of a genome. Differences in the nucleotide sequence, specifically in targeted DNA regions, are utilized for species identification. Currently, the chloroplast genome regions, such as *rbc*L, *mat*K, *trn*L-*trn*F, and *psb*A-*trn*H, and the nuclear ribosomal DNA internal transcribed spacer (ITS), have emerged as good candidates for plant DNA barcoding (Kress et al. 2005; Gonzalez et al. 2009).

There are only a few studies on identification of *A. sinensis* based on DNA barcoding of fresh plant tissues (Eurlings and Gravendeel 2005). The main obstacle is because the available and identified material is usually dried and has been stored for a long time. To increase our chance in getting relatively intact DNA, we modified a commercial DNA extraction kit protocol for the use with *Aquilaria* samples derived from dried wood and a xylarium specimen stored for 39 years. The yielded DNA samples were successfully used in PCR amplifications. However, PCR was not successful when using DNA samples extracted from the intra-wood that were dried at 120 °C for 10 days or from the intra-wood of the xylarium specimen. Extracting DNA from dry wood treated at high temperatures or when wood has been stored for a long time is challenging (Schlumbaum et al. 2008; Rachmayanti et al. 2009; Jiao et al. 2012) because the wood DNA had extremely degraded. Nonetheless, we were able to differentiate *A. sinensis* from other species in the *Aquilaria* genus with the aid of genetic loci differences and phylogenetic analysis (Jiao et al. 2014) (Fig. 2.7).

For the *trn*L-*trn*F region, a strict consensus tree is shown, with bootstrap supports indicated at the nodes (Fig. 2.7a). The maximum parsimony (MP) analysis showed that sequences obtained from fresh wood, dried wood, wood xylarium, and leaves clustered together with *A. sinensis* sequences from the GenBank, supported by a bootstrap value of 74 % (Fig. 2.7a). Meanwhile for the ITS region, the total aligned length was 266 characters, of which 29 (10.9 %) were variable characters and 12 (4.5 %) were parsimony informative. The topology of the bootstrap 50 % majority-rule consensus tree of the MP analysis showed that sequences from fresh wood, dried wood, wood xylarium, and leaves clustered together in polytomy

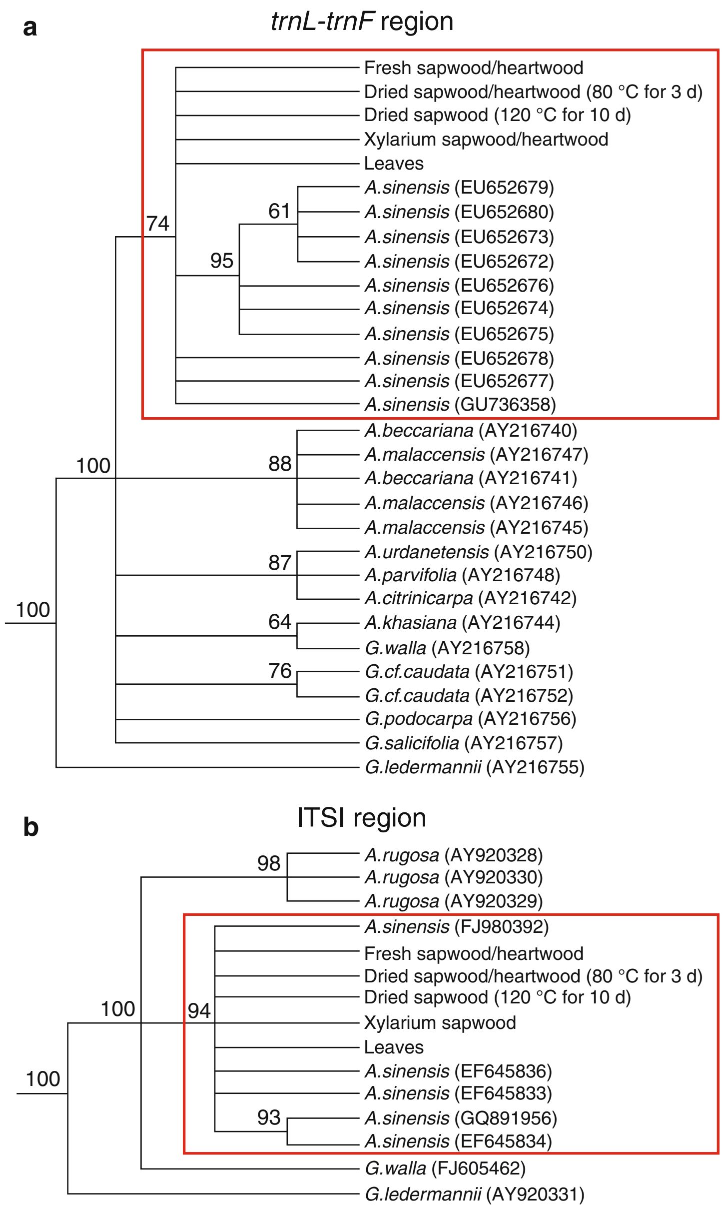

Fig. 2.7 A 50 % majority-rule consensus tree obtained with the MP method, based on (**a**) the *trn*L-*trn*F region and (**b**) the ITS1 region. The branches indicate the percentage of bootstrap values calculated from 1000 bootstrap replicates. *A Aquilaria*, *G Gyrinops* (Source: Jiao et al. (2014))

with *A. sinensis* sequences deposited in the GenBank, with 94 % bootstrap support (Fig. 2.7b). These results indicate the potential use of DNA barcoding in *Aquilaria* wood identification at species level. However, there is a need to improve the process of DNA extraction from severely degraded wood such as heartwood that has been dried and stored for a long period of time. DNA barcoding technology is an effective, feasible, and promising wood identification tool for timber trade control and forensic work, supporting conventional wood anatomy approach.

2.4.3 Chemical Analysis

As explained above, the main identification method for the determination of *Aquilaria* wood is to analyze and recognize the key features, based on macrostructure, microstructure, and DNA sequences. However, because agarwood is a compound substance, identifying the timber species accurately is only the first significant step.

At present, the medicine administration agencies in China are using China Pharmacopoeia (2010 edition) as a reference when implementing a technical standard for identifying agarwood. Apart from testing the anatomical features of agarwood, its ethanol-soluble extract content must also be tested using the hot-dipping method. A value of not less than 10.0 % is deemed acceptable. Thin-layer chromatography (TLC) is also an important method for testing agarwood in the market. With this method, a solution is prepared with 0.5 g sample, and its chromatography is compared to that of the control by checking the corresponding location of the compound's fluorescence under an ultraviolet lamp.

In the Chinese domestic market, imported agarwood is often mixed with native, causing huge differences in the price of different agarwood types or classes, and may result in the frequent occurrences of fake agarwood. In some cases, premature agarwood without inclusions can be made into handcrafts, e.g., beads and carvings, as well as medicinal raw materials, after it is given suitable treatment such as dyeing, smearing, or dipping into agarwood oil, rosin, or other chemical perfumes. This is causing a major concern, as an accurate judgment on timber identification based on scientific analysis will not be achieved by depending on a particular method only such as the ethanol-soluble extract content. In other words, the existing testing technology cannot fully meet practical demands in quality supervision and identification of agarwood.

Up to now, there has not been a testing standard or a grade standard that is internationally acknowledged, although there are some research findings that could be applicable depending on the situation. For example, agarwood has been classified into five grades according to its odor, e.g., sweet, acidic, peppery, salty, and bitter (Morita 1992), or if agarwood oils into grades known as Ultra A, B, C, and D (Heuveling van Beek and Phillips 1999). Others focus on the chemical composition analysis (Ishihara et al. 1992; Konishi et al. 2002). Over the years, Chinese researchers in the fields of wood science, medicobotany, molecular biology, and other related fields in plant sciences, have done a great deal of studies on the subject of agarwood, using many technical methods, such as the infrared spectroscopy (IRS), thermogravimetry (TG), mass spectrometry (MS), and gas chromatography-mass spectrometry (GC-MS). For example, a detailed analysis on chemical contents such as sesquiterpenes and others in agarwood has been conducted by GC-MS (Yang 1998; Lin and Qi 2000).

Recently, the Research Institute of Wood Industry at the Chinese Academy of Forestry has initiated a research work to establish a technology for identifying agarwood, with the aim of setting up an agarwood standard for the industry in China. The identification process follows a series of steps: (1) to observe and analyze the macrostructural and microstructural features, (2) to detect the alcohol-soluble extract content and conduct TLC analysis following requirements of the China Pharmacopoeia, and (3) to employ GC-MS for detection of major chemical contents, e.g., aromatic compounds, sesquiterpenoids, and 2-(2-phenylethyl) chromones, among other compounds that are contained in agarwood. The different chemical contents in agarwood could be an important index for measuring the various grades of agarwood. Additionally, the performance of thermal decomposition at different temperatures can be tested using the TG method, while any heavy metals, such as Pb and Hg, in the sample can be detected with inductively coupled plasma mass spectrometry (ICP-MS). Using Fourier transform infrared (FT-IR) analysis, the location and scope of the characteristic absorption peak of its primary chemical contents can be determined. All these sophisticated detection systems are conducive toward realization of a rapid-testing technology for agarwood identification and quality assurance.

2.5 Utilization and Trade of Agarwood in China

Agarwood is traded in various ways, including as a whole plant piece, wood blocks, wood chips, oil, and even waste powder. In Asia, these are widely used in perfumes, medicines, works of art, and others. The annual trading volume of agarwood is approximately several hundred tonnes, with its trading scale reaching millions of dollars. There are two major terminal markets in the international trade of agarwood. They are northeast Asia (Taiwan, Japan and South Korea) and West Asia (the Middle East). As a very important trading hub, Singapore has been the largest trading market for the import and export trade of agarwood. The import volume alone of agarwood wood chips in the Middle East rapidly increased from 56 tonnes in 2004 to 162 tonnes in 2007, an increase of 300 % within 4 years. Taiwan and Hong Kong in China have also been major importing regions. Part of these imports were transhipped and sold to Mainland China. As the biggest terminal market, the import volume into Taiwan increased to 402 tonnes from 1995 to 1997.

The very first book in the world concerning agarwood trading came from official Chinese Customs in AD 1200. According to the records, agarwood trading activities were mainly conducted in Borneo, Sumatra in Indonesia, the Malay Peninsula, and Cambodia. In addition, agarwood history goes back more than a thousand years ago as an application in traditional herbal medicine in China. Up to now, many Chinese herbal medicines have agarwood as an ingredient, such as the “Bawei Chenxiang San,” which contains eight kinds of medicinal herbs, with agarwood as its major ingredient. Furthermore, the perfume from agarwood was the exclusive favorite of emperors, high officials, and noble lords in ancient China while also being one of the psychological dependencies of the literati class, such as scholars and bureaucrats. In the Song Dynasty, agarwood was recognized as the King of Perfumes. This was when the culture of perfume reached its peak. The custom of using perfume was intensely promoted afterwards. In the Ming Dynasty, the price of agarwood became particularly high. An old saying goes – "An inch of agarwood is worth an inch of gold." However, the fall of the late Qing Dynasty discouraged people from using agarwood perfume so it was gradually put to the sidelines and forgotten. It was not until modern times, together with the economic and cultural development of the Chinese society, that people's attention was once again drawn to agarwood, and this has contributed to the rapid development in the agarwood market in recent decades.

As the technologies for the cultivation of *Aquilaria* plantations and artificial agarwood induction are perfected progressively, a fundamental condition is provided for the agarwood market in China. At present, some enterprises in Guangdong, Guangxi, Hainan, and Yunnan provinces are conducting beneficiary exploration for industrialization development of agarwood by developing various agarwood products, including tea, oil, alcohol, bracelets, herbal products, powders, ointments, and incense, among others. Diversification of agarwood products and market-driven factors had increased the price of agarwood to more than 10-fold in 2011 from its 2007 price. In general, the market benefits of *Aquilaria* plantations are still considerable. On the other hand, China has held agarwood expos several times. For instance, the China (Dongguan) Agarwood Culture & Art Expo, which was held in 2011, had attracted 150 enterprises to the exhibition from the domestic provinces, and Southeast Asian countries, involving approximately 400,000 visitors. This expo brought in approximately RMB 300 million along with contracted projects worth approximately RMB 250 million.

The city of Putian in the Fujian Province has become the major center in China for making, collecting, and distributing domestic wood-carved handicrafts. It has also become the largest trading center for sandalwood and agarwood in the world. Up to now, native Fujian agarwood has been mainly used for producing wood-carved handicrafts, such as Buddha figures, hanging decorations, and Buddha beads, while the waste is used in the making of spices. Just in the first half of 2011, the city of Putian made use of about 2.75 tonnes of agarwood, reaching revenues of approximately RMB 26.75 million, with agarwood handcrafts accounting for 75 % of this.

The expanding demands of the domestic market in China have caused the volume of imported agarwood to increase from year to year. In 2013, the import volume reached 81.42 tonnes (Table 2.2), mainly in the form of wood blocks, wood chips, medicinal herbs, and pure essential oils. These were shipped mostly from Singapore to China; the tree sources were *A. malaccensis*, *A. crassna*, and *A. filaria*. Almost all of the imported agarwood was sold to the city of Putian, while the exported agarwood products, mainly in the form of Chinese herbal medicines and wood, were exported to Japan, Malaysia, Thailand, and the USA; the tree sources were *A. sinensis* and *A. malaccensis*. Due to the expansion of domestic demands and the limitation of agarwood resources in China, the export volume of agarwood in 2013 was a mere 40.2 kg (Table 2.2).

Table 2.2 Import and export status of *Aquilaria* products of China (2010–2013)

	Export (kg)				Import (kg)			
Species	2010	2011	2012	2013	2010	2011	2012	2013
Aquilaria sinensis	107.0	175.2	58.6					
Aquilaria malaccensis	58.8	77.6	167.2	40.2	7157.4	504.5	14,130.3	17,996.7
Aquilaria crassna					5287.2	9900.0	2.5	29.5
Aquilaria filaria					60.0	13,243.0	6756.6	62,406.0
Aquilaria spp.					27.6	2.2	5.0	998.0
Total	**165.8**	**252.8**	**225.8**	**40.2**	**12,532.2**	**23,649.7**	**20,894.4**	**81,420.2**

Note: Data from the Endangered Species Import and Export Management Office of the People's Republic of China

An enormous market profit is the fundamental reason for the cause of illegal felling of *Aquilaria* trees and trading in agarwood. According to the statistics of Chinese Customs, the amount of imports in each province far exceeds that of exports, with Guangdong and Fujian provinces being the main offenders. From 2006 to the first half of 2011, there were 211 cases of smuggling discovered by Guangdong Customs, most of which were carried out by people traveling, transportation, shipping, and express delivery. Because of united efforts by the State Forestry Administration and General Customs Administration of China, the illegal logging and trading has been effectively under control in the past 3 years.

2.6 Concluding Remarks

In China, plantation resources of *Aquilaria* experienced rapid growth recently, to protect and supplement the global wild resources and to supply raw materials to the mounting agarwood industry. To ensure quality supervision of agarwood market, several identification methods, i.e., wood anatomy, DNA barcoding, and chemical analysis, have been demonstrated. However, a reliable international standard containing scientific and rapid-testing technologies to tackle issues in agarwood identification, grading, and quality assurance is still not in place. Efforts should be made at the international level where a practical solution can be suggested and adopted by all concerned parties in the agarwood trade. Only by international coordination, a systematic quality assurance scheme could be inaugurated for agarwood.

References

Cheng J, Yang J, Liu P. Atlas of Chinese woods. Beijing: Chinese Forestry Publishing House; 1992.

Editorial Board of Flora of China of Chinese Academy of Sciences. Flora of China, vol. 52. Beijing: Science Press; 1999.

Endangered Species Import and Export Management Office of the People's Republic of China. Survey report of protection and trade of Chinese agarwood, Beijing, China; 2011.

Eurlings MCM, Gravendeel B. *Trn*L-*trn*F sequence data imply paraphyly of *Aquilaria* and *Gyrinops* (Thymelaeaceae) and provide new perspectives for agarwood identification. Pl Syst Evol. 2005;254:1–12.

Gonzalez MA, Baraloto C, Engel J, Mori SA, Pétronelli P, Riéra B, Roger A, Thébaud C, Chave J. Identification of Amazonian trees with DNA barcodes. PLoS One. 2009;4, e7483.

Heuveling van Beek H, Phillips D. Agarwood: trade and CITES implementation in Southeast Asia. Unpublished report prepared for TRAFFIC Southeast Asia, Malaysia; 1999.

IAWA Committee. IAWA list of microscopic features for hardwood identification. IAWA Bull. 1989;10:219–332.

Ishihara M, Masatsugu Y, Uneyama K. Preparation of (−)-guaia-1(10),11-dien-15,2-olide and (−)-2-hydroxyguaia-1(10),11-dien-15-oic acid, fragrant sesquiterpenes in agarwood (*Aquilaria agallocha* Roxb.). Tetrahedron. 1992;48:10265–76.

Jiao L, Yin Y, Xiao F, Sun Q, Song K, Jiang X. Comparative analysis of two DNA extraction protocols from fresh and dried wood of *Cunninghamia lanceolata* (Taxodiaceae). IAWA J. 2012;33:441–56.

Jiao L, Yin Y, Cheng Y, Jiang X. DNA barcoding for identification of the endangered species *Aquilaria sinensis*: comparison of data from heated or aged wood samples. Holzforschung. 2014;68:487–94.

Konishi T, Konoshima T, Shimada Y, Kiyosawa S. Six new 2-(2-phenylethyl) chromones from agarwood. Chem Pharm Bull (Tokyo). 2002;50:419–22.

Kress WJ, Wurdack KJ, Zimmer EA, Weigt LA, Janzen DH. Use of DNA barcodes to identify flowering plants. Proc Natl Acad Sci U S A. 2005;102:8369–74.

Lin L, Qi S. Triterpenoid from Chinese eaglewood (*Aquilaria sinensis*). Chinese Herbal Med. 2000;31:658–9.

Liu P, Yang J, Lu H. Tropical woods imported from Southeast Asia (version 2). Beijing: Chinese Forestry Publishing House; 2008.

Mei Q, Li H, Wang K, Wu H, Li H. History and origin of "Nanyao" agarwood. Pharmacy Today. 2011;21:3–5.

Miles A. Photomicrographs of the world wood. Building Research Establishment report, Department of the Environment, London. Her Majesty's Stationery Office; 1978.

Morita K. The book of incense. Tokyo: Kodansha International; 1992.

Rachmayanti Y, Leinemann L, Gailing O, Finkeldey R. DNA from processed and unprocessed wood: factors influencing the isolation success. Forensic Sci Int Genet. 2009;3:185–92.

Schlumbaum A, Tensen M, Jaenicke-Despres V. Ancient plant DNA in archaeobotany. Veget Hist Archaeobot. 2008;17:23–244.

The State Council of the People's Republic of China. The first part directory of national protected flora on emphasis. Beijing, China; 1999.

Wyn LT, Anak NA. Wood for trees: a review of the agarwood (gaharu) trade in Malaysia. Petaling Jaya/Selangor/Malaysia: TRAFFIC Southeast Asia; 2010.

Yang Q. The research of chemical composition of agarwood. Nat Product Res Development. 1998;10:99–103.