Chapter 1
The Origin and Domestication of *Aquilaria*, an Important Agarwood-Producing Genus

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Abstract The *Aquilaria* (Thymelaeaceae) tree is a well-known important agarwood-producing genus, which is endemic to the Indomalesia region. The genus is currently protected under CITES regulation and the IUCN Red List due to its heavy declination in the natural population in various sourcing countries. Derived from its precious non-wood fragrant products, the genus was given different names throughout the history until it was finalized in 1783. To date, there are 21 recognized *Aquilaria* species recorded, of which 13 are reportedly fragrant resin producers, and the status of the remaining eight *Aquilaria* species is yet to be investigated. *Aquilaria* is heavily exploited in the wild due to the destructive agarwood harvesting technique that requires hacking of the wood parts to induce agarwood production. Various conservation efforts have been carried out to avoid further destruction toward its gene pool. This includes introducing the species for cultivation and planting the trees in large plantations or home gardens, which further provide a sustainable agarwood production in the industry and indirectly contribute to the local economy. At present, an accurate classification of *Aquilaria* species is yet to be achieved; misidentification happens frequently, either genuinely because of lack of information and training or intentionally for business gains. In conclusion, a proper taxonomy and classification system are essential for conserving *Aquilaria* species genetic diversity and for identifying species origin of agarwood products aimed at international trade control.

1.1 Introduction

The *Aquilaria* genus is well known for its fragrant non-wood product, the agarwood. Highly demanded in several countries, agarwood is further processed into perfumes, incenses, and ornamental displays and used as a raw material in traditional and modern medicines. Historically, human's encounter with agarwood was first

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recorded in ancient literatures and religious scriptures. The Sanskrit language poet, Kâlidâsa (c. 353–c. 420), once wrote: *Beautiful ladies*, *preparing themselves for the feast of pleasures*, *cleanse themselves with the yellow powder of sandal*, *clear and pure*, *freshen their breast with pleasant aromas*, *and suspend their dark hair in the smoke of burning aloes*. The word "aloes" has the same meaning as agarwood. It was also found occurring in the biblical text (Duke 2007). In ancient days, the Egyptians used agarwood to embalm honored dead bodies, and in several Asian countries, agarwood products were introduced along with Buddhism from India. During those days, the most familiar *Aquilaria* species producing agarwood were *Aquilaria agallocha* (synonym to *Aquilaria malaccensis*) from India and nearby countries and *Ophispermum sinense* (synonym to *Aquilaria sinensis*) from China (Don 1832). The former was widely applied in fragrance production and religious practices while the latter in Chinese medicines.

From a total of 21 accepted species names for *Aquilaria* at present (The Plant List 2013), about thirteen are reported as fragrant resin producer: *A. baillonii*, *A. beccariana*, *A. crassna*, *A. filaria*, *A. hirta*, *A. khasiana*, *A. malaccensis*, *A. microcarpa*, *A. rostrata*, *A. rugosa*, *A. sinensis*, *A. subintegra* and *A. yunnanensis* (Hou 1960; Ng et al. 1997; Compton and Zich 2002; Kiet et al. 2005; Yang Y 2015, personal communication). As for the remaining eight *Aquilaria* species, their competencies at producing agarwood need to be further investigated.

1.2 A Brief History of the Genus

The genus name, *Aquilaria*, was originally derived from its non-wood fragrant product, presently known as agarwood. Agarwood has many names that have been passed down over many generations. When the product is introduced into various societies, each mimicked the pronunciation of the original name using her own language; thus, more names were created. From recorded history, the earliest name given was *ahalim* in Hebrew and *ahila* from the Scripture of the East (Ridley 1901), followed by *agalukhi* in Arabic. It was also described as *agallochee*, a Greek synonym to a Hindi word for incense wood *aod-i-kimaree* from India and Arabia. In the Malayan region, it has been known as *agila*, which possibly descended from the Sanskrit *agara* (in Hindi *aggur*). In more recent days, the Portuguese gave several names: *pao-d'agila*, *pao-d'aguila*, *pao-d'aquila*, *bois d'aigle*, *eagle-wood*, and *agel-hout*. The genus established its final name, *Aquilaria*, in 1783, given by the botanist Jean-Baptiste Lamarck after replacing its synonym, *Agallochum* of Dioscorides.

The first scientific record of agarwood usage was likely that of Avicenna, an Arab physician (980–1037), who described several types of *agallochum* (Society for the Diffusion of Useful Knowledge 1838). Among the different types of *agallochum*, he recorded two names, *xylaloes* and *agalugen*. *Xylaloes* is a Greek form of an Arabic word *alud*, literary described as "the wood." Further, it was modified into aloe wood/aloes-wood and also Lignum aloes. As for *agalugen*, it was also called *aghaloojee*, which was then defined as *agallochee* or *agallochum*. The word

agallochum was simplified to *agalloch*, referring to the fragrant wood produced from *A. agallocha* in India.

The first formal account to the tree itself was by Garcia de Orta (1501–1568), a Portuguese Renaissance physician and naturalist, who practiced in Goa, India, and was a pioneer of tropical medicine (Ridley 1901). He visited Malacca in Peninsular Malaysia roughly in 1534 and named the fragrant wood *garo*. He recorded that the wood was brought by the Chinese from Malacca and Sumatra; thus, he referred it as *Garo de Malacca*. Garcia successfully collected the twigs and leaves from trees growing in Malacca but failed to get the fruits or flowers as there was difficulty to access the forest. Georg Eberhard Rumphius (1627–1702), a German-born botanist who was studying on the specimen brought back from Malacca, distinguished two types of *agallochum*: the *calambac* (*Agallochum primarium*) and the *garo* (*Agallochum secundarium*) (Society for the Diffusion of Useful Knowledge 1838). The *calambac* or *calembouc* (French) had other names such as *kỳ nam* (Vietnam) and *kyara* (Japanese) (Li 1998). The first collection of *calambac* was native to Eastern Cochin China and Siam, collected by Loureiro from the tree called *Aloexylum agallochum* Lour., while the second collection was native to Cochin China and Laos, also collected by Loureiro from the tree called *Ophispermum sinense* Lour. (known as *A. sinensis* at present) (Ridley 1901). William Roxburgh (1751–1815), a Scottish surgeon and botanist, who is known as the Father of Indian Botany, described that the real *calambac* comes from *A. agallocha Roxb.*, which was exported to China from the eastern frontier instead of Cochin China. *Calambac* from both origins had equal demands and were growing at similar latitudes, yet no one could conclude that they derived from the same species because botanical description was incomplete at that time (Society for the Diffusion of Useful Knowledge 1838).

Garo was later known as *garos*, which was recorded as an article of export from Malacca and the kingdom of Siam (Thailand at present). It was given the name *garu* (in Malay, later updated to *gaharu*), derived from the Sanskrit *aquaru* but only referring to the fragrant wood. The *garu* tree is given a different name and is known as *karas*, *tuikaras*, *tengkaras*, *engkaras*, and *kakaras* by the Malays (Ridley 1901). Pierre Sonnerat (1748–1814), a French naturalist and explorer, successfully obtained the specimens of the tree during his second voyage to India, based on the figures and description done by Jean-Baptiste Lamarck (1744–1829) for the *bois d'aloes*, *Agallochum officinarum*. Lamarck concluded that the collected specimen greatly resembles the *A. secundarium* from Rumphius; thus, it was renamed as *A. malaccensis* (Royle 1839). Upon confirmation, Francis Hamilton (1762–1829, also known as Francis Buchanan) concluded that *A. malaccensis* and *A. agallocha* are both of the same tree in nature but prefers the name *A. officinarum* as the official name for the plant (Hamilton 1836). Today, the name *A. malaccensis* retains as a type specimen for the genus *Aquilaria* in taxonomy identification. Since the official genus *Aquilaria* was agreed upon in 1783, it replaced several synonym genera including *Agallochum* Lam. (1783), *Aloexylum* Lour. (1790), *Aquilariella* Tiegh. (1893), *Decaisnella* Kuntze (1891), *Gyrinopsis* Decne. (1843), and *Ophispermum* Lour. (1790) (Tropicos 2016).

1.3 Generic Status and Relationships

Aquilaria is a member of the Thymelaeaceae (Malvales) family and belongs to the subfamily Thymelaeoideae (previously Aquilariodeae). There was a minor controversy in the classification of the subfamilies in Thymelaeaceae. Until today, a stable circumscription in the taxon of Thymelaeaceae is yet to be achieved. Conventional classification of the Thymelaeaceae is always related to the identification through morphological and reproductive characteristics of the plant itself. Earlier in 1836, before an international taxonomy system was established, *Aquilaria* was once under the order Aquilariaceae, Alliance Daphnales. However in 1880, the Bentham and Hooker system removed the genus on reasons that there was no recollection exercise since previous identification (Watt 2014). Years later, it was re-added, together with *Gyrinopsis* and *Gyrinops* into the family Thymelaeaceae, under subfamily Aquilarioideae (including Phalerioideae, Thymelaeoideae, and Drapetoideae) and tribe Aquilarieae (Gilg 1894). Thymelaeaceae was under the order of Thymelaeales. Later in 1967, Hutchinson proposed to include Aquilariaceae under Thymelaeales. However in 1968, Cronquist proposed to embed Thymelaeaceae under the order Myrtales, then further suggested by Thorne to place under Euphorbiales, instead of Myrtales. The debate between Myrtales and Euphorbiales was ongoing from 1968 to 1993, with a small different opinion whereby Cronquist's proposal was accepted from 1988 to 1992, in which Thymelaeaceae was placed as the sole family under the order Thymelaeales (Cronquist 1988). In 1993, Heywood placed Thymelaeaceae under the order Myrtales after removing it from the previous order Euphorbiales, which was proposed by Thorne in 1992. In 1998, the Angiosperm Phylogeny Group included the family Thymelaeaceae in the Malvales order, disregarding indication toward families adjacent to it (Angiosperm Phylogeny Group 1998). Chronology of the events is shown in Table 1.1.

Subfamilies within the Thymelaeaceae were not established as well throughout the centuries. As such in 1894, Gilg proposed four subfamilies under Thymelaeaceae: Aquilarioideae, Phalerioideae, Thymelaeoideae, and Drapetoideae. However in 1921, he reviewed the list and added three new subfamilies: Microsemmatoideae, Octolepidoideae, and Synandrodaphnoideae. Domke (1934) scaled down the list by retaining two names and adding two new ones: Aquilarioideae, Gilgiodaphnoideae, Gonystyloideae, and Thymelaeoideae. The latest update in the subfamilies within the Thymelaeaceae was by Herber in 2002 and 2003, concluding only two big subfamilies: Octolepidoideae and Thymelaeoideae, with Aquilarieae placed under Thymelaeoideae. At present, *Aquilaria* and its closely related genus *Gyrinops* are under the order Malvales, family Thymelaeaceae, subfamily Thymelaeoideae, and tribe Aquilarieae.

The four-subfamily classification, proposed by Gilg (1894), was mostly supported by molecular phylogeny as revealed from the sequences of the chloroplast DNA, the *rbc*L gene and the *trn*L-*trn*F intergenic spacer region, of forty-one samples under the Thymelaeaceae (Van der Bank et al. 2002). Unfortunately, the phylogenetic relationship was not supported at level of tribe. The study was further investigated by

Table 1.1 Chronology of events following changes in taxonomy affinities of the genus *Aquilaria* (Thymelaeaceae)

Taxonomist	Year proposed		Changes made
Lidney	1836	Alliance Order Genera	**Daphnales** **Aquilariaceae**; Elaeagnaceae; Hernandiaceae; Thymelaeaceae; ***Aquilaria***; *Gyrinops*; *Ophiospermum*
Bentham and Hooker	1880	Genera	***Aquilaria*** was removed
Gilg	1894	Subfamily Tribe Genera	**Aquilarioideae**; Phalerioideae; Thymelaeoideae; Drapetoideae **Aquilarieae** ***Aquilaria***; *Gyrinopsis*; *Gyrinops*
Gilg	1921	Subfamily	**Aquilarioideae**; Phalerioideae; Thymelaeoideae; Drapetoideae; Microsemmatoideae; Octolepidoideae; Synandrodaphnoideae
Domke	1934	Subfamily General Tribe Genera	**Aquilarioideae**; Gilgiodaphnoideae; Gonystyloideae; Thymelaeoideae **Aquilariidae** ***Aquilaria***; *Gyrinops*
Hutchinson	1959	Order	**Thymelaeales**
Hutchinson	1967	Order Family Genera	**Thymelaeales** **Aquilariaceae**; Thymelaeaceae ***Aquilaria***; *Deltaria*; *Gyrinops*; *Lethedon*; *Octolepis*; *Solmsia*
Cronquist	1968	Order	**Myrtales**
Thorne	1968	Order	**Euphorbiales**
Cronquist	1988	Order	**Thymelaeales**
Thorne	1992	Order	**Euphorbiales**
Heywood	1993	Order	**Myrtales**
The Angiosperm Phylogeny Group	1998	Order	**Malvales**
Herber	2002	Subfamily Tribe Genera	Octolepidoideae; **Thymelaeoideae** **Aquilarieae**; Daphneae; Synandrodaphneae ***Aquilaria***; *Gyrinops*

Rautenbach (2008) who performed molecular phylogenetic analysis using 143 specimens from the Thymelaeaceae members, which was three times greater in sample size compared to the previous study. The two regions from the chloroplast DNA were analyzed in addition to the nuclear ribosomal DNA internal transcribed spacer (ITS). The results were in support of the classification proposed by Herber in 2002. Considering that molecular phylogeny approach can provide remarkable results that complement conventional taxonomic classification in Thymelaeaceae, it has been applied for identifying agarwood-producing species from the genus *Aquilaria*. Ito and Honda (2005) sequenced the ITS1 and *psb*C-*trn*S regions in their study, while Eurlings and Gravendeel (2005) sequenced the *trn*L-*trn*F intergenic spacer region.

Both studies used authentic samples from herbarium specimens and concluded that molecular-based approach is possible for identifying *Aquilaria* species. Eurlings and Gravendeel (2005) provided a wider scope when they included *Gyrinops* specimens and concluded that *Aquilaria* and *Gyrinops* are paraphyletic, indicating that the two genera had shared the last common ancestor. Although molecular-based study seems promising in assisting identification at genus and species levels, further studies are needed for conservation and trade control purposes.

1.4 Distribution of the Species

Aquilaria is widely distributed in the Indomalesia region. The most dominant species, which has its population over several countries, is *A. malaccensis*. The accepted species according to The Plant List, their distributions based on previous records, and their conservation status as classified by IUCN, are compiled in Table 1.2.

To help illustrate the distribution, an imaginary horizontal line parallel to the equator is drawn going from across the Sumatra Island to Borneo Island, and a vertical line is drawn from the east of Taiwan going through the west of the Philippines, separating Borneo from Sulawesi and west of Sumba Island (Fig. 1.1). For the benefit of this discussion, these crossing lines divide the Indomalesia region into four sections and reflect the distribution of the related species in a congruent manner. Starting with the northwest end, this first region is widely populated by *A. crassna*, *A. malaccensis*, and *A. sinensis*. The distribution of *A. crassna* has been reported in Cambodia, south of Laos, north of Thailand, and Cochin China of Vietnam; *A. malaccensis* in Bangladesh, Bhutan, Assam of northeast India, Sumatra and Kalimantan of Indonesia, Iran, Malaysia, Myanmar, south of the Philippines, Singapore, and south of Thailand; and *A. sinensis* meanwhile endemic to China, confined mainly to the south, Hainan Island, Hong Kong, and Taiwan. Besides that, records have shown that *A. baillonii* is endemic to Cambodia; *A. banaensis* to Bana of Vietnam; *A. beccariana* to East Malaysia, Brunei, and Kalimantan of Indonesia; *A. hirta* to south of Thailand and northeast and south of Peninsular Malaysia including Singapore; *A. khasiana* to Khasi, Meghalaya, of northeast of India; *A. rostrata* to Peninsular Malaysia; *A. rugosa* to Kontum of Vietnam and north of Thailand; *A. subintegra* to south of Thailand; and *A. yunnanensis* to Yunnan in China.

Interestingly, the Philippines, situated in the northeast, is the only country within that region having six endemic species: *A. brachyantha* in Cagayan, *A. decemcostata* in Laguna, and *A. parvifolia* in Camarines, all three species being concentrated in the Luzon Island, while *A. apiculata* in Bukidnon and *A. citrinicarpa* and *A. urdanetensis* in Mount Urdaneta, all in Mindanao, the south island. In addition, *A. cumingiana* was also recorded in Mindanao, besides the Maluku Island of neighboring Indonesia. Following the horizontal line, *A. microcarpa* was recorded in Johor, the most southern state in Peninsular Malaysia and in Singapore. It was also found on the Borneo Island, consisting of East Malaysia, Brunei, and Kalimantan of Indonesia.

Table 1.2 Accepted names, distribution, and conservation status of *Aquilaria* species

No	Species names[a]	Basionyms and synonyms	Year first reported	Distribution	Conservation status (IUCN)
1	*Aquilaria apiculata* Merr.	–	1922	Philippines	–
2	*Aquilaria baillonii* Pierre ex Lecomte	–	1915	Cambodia	–
3	*Aquilaria banaensis* P.H.Hô	*Aquilaria banaensae*	1986	Vietnam	1998: Vulnerable D2
4	*Aquilaria beccariana* Tiegh.	*Aquilaria cumingiana var. parvifolia* *Aquilaria grandifolia* *Gyrinops brachyantha* *Gyrinopsis grandifolia*	1893	Brunei Indonesia Malaysia	1998: Vulnerable A1d
5	*Aquilaria brachyantha* (Merr.) Hallier f.	*Gyrinopsis brachyantha*	1922	Philippines	–
6	*Aquilaria citrinicarpa* (Elmer) Hallier f.	*Gyrinopsis citrinicarpa*	1922	Philippines	–
7	*Aquilaria crassna* Pierre ex Lecomte	–	1914	Cambodia Laos Thailand Vietnam	1998: Critically Endangered A1cd
8	*Aquilaria cumingiana* (Decne.) Ridl.	*Aquilaria pubescens* *Decaisnella cumingiana* *Gyrinopsis cumingiana* *Gyrinopsis cumingiana var. pubescens* *Gyrinopsis decemcostata* *Gyrinopsis pubifolia*	1922	Indonesia Philippines	1998: Vulnerable A1d
9	*Aquilaria decemcostata* Hallier f.	–	1922	Philippines	–
10	*Aquilaria filaria* (Oken) Merr.	*Aquilaria cuminate* *Aquilaria tomentosa* *Gyrinopsis acuminate* *Pittosporum filarium*	1950	Indonesia Philippines	–
11	*Aquilaria hirta* Ridl.	*Aquilaria moszkowski*	1901	Indonesia Malaysia Singapore	1998: Vulnerable A1d

(continued)

Table 1.2 (continued)

No	Species names[a]	Basionyms and synonyms	Year first reported	Distribution	Conservation status (IUCN)
12	*Aquilaria khasiana* Hallier f.	–	1922	India	–
13	*Aquilaria malaccensis* Lam.	*Agallochum malaccense* *Aloexylum agallochum* *Aquilaria agallocha* *Aquilaria agallochum* *Aquilaria ovate* *Aquilaria moluccensis* *Aquilaria secundaria* *Aquilariella malaccense* *Aquilariella malaccensis*	1783	Bangladesh Bhutan India Indonesia Iran Malaysia Myanmar Philippines Singapore Thailand	1998: Vulnerable A1cd
14	*Aquilaria microcarpa* Baill.	*Aquilaria borneensis* *Aquilariella borneensis* *Aquilariella microcarpa*	1875	Indonesia Malaysia Singapore	1998: Vulnerable A1d
15	*Aquilaria parvifolia* (Quisumb.) Ding Hou	*Gyrinopsis parvifolia*	1960	Philippines	–
16	*Aquilaria rostrata* Ridl.	–	1924	Malaysia	1997: Vulnerable 1998: Data Deficient 2012: Critically Endangered B1ab(v)
17	*Aquilaria rugosa* K.Le-Cong & Kessler	–	2005	Thailand Vietnam	–
18	*Aquilaria sinensis* (Lour.) Spreng.	*Agallochum grandiflorum* *Agallochum sinense* *Aquilaria chinensis* *Aquilaria grandiflora* *Aquilaria ophispermum* *Ophispermum sinense*	1825	China	1997: Vulnerable 1998: Vulnerable B1 + 2cde

Table 1.2 (continued)

No	Species names[a]	Basionyms and synonyms	Year first reported	Distribution	Conservation status (IUCN)
19	*Aquilaria subintegra* Ding Hou	–	1964	Thailand	–
20	*Aquilaria urdanetensis* (Elmer) Hallier f.	*Gyrinopsis urdanetense* *Gyrinopsis urdanetensis*	1922	Philippines	–
21	*Aquilaria yunnanensis* S.C. Huang	–	1985	China	–

[a]According to Version 1.1 of The Plant List (2013), http://www.theplantlist.org, assessed on 26 January 2016
– not available

Fig. 1.1 A map of the Indomalesia region. The imaginary lines are drawn to illustrate the distribution of *Aquilaria* species into four parts of the region

In the southwest end, endemic species has not been reported. The common *Aquilaria* species are again *A. malaccensis* in Sumatra and Kalimantan of Indonesia, *A. beccariana* in Kalimantan, and *A. microcarpa* in Singapore and Kalimantan. Meanwhile, the southeast region consists of mainly West Papua of Indonesia and Papua New Guinea, where *A. filaria* dominates.

1.5 Conservation Status

In modern days, beginning from the twentieth century, *Aquilaria* receives great attention from societies around the world because of agarwood's economic value. Demand for agarwood increased when the market flows extensively into the Arab society for perfumery, Indian society for religious application, and Chinese society for incense and medicinal purposes, triggering the needs to search for more of these agarwood-producing trees. The production of agarwood was not consistent, and extensive harvesting of the trees threatened the reproduction cycle in its natural environment. The undesirable phenomenon draws the attention of the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES) to control the trade of agarwood by restricting the quota of goods exported from each country. When *Aquilaria* tree was first exploited, much of the demand in the agarwood market was sourced by *A. malaccensis*, threatening its sustainability in the wild. Consequently, the species became the first *Aquilaria* listed in the Appendix II of CITES, bringing its status to "potentially threatened with extinction" (CITES 1994). While agarwood trades were under strict controls by official authorities, traders tend to locate alternative agarwood sources to meet the ever-increasing demand from the consumers. It was then discovered that several other *Aquilaria* species and members of at least another genera, *Gyrinops*, also produce agarwood. As a result, in the 13th CITES Conference meeting for Consideration of Proposals for Amendment of Appendices I and II, Indonesia as the proponent raised the issue for the inclusion of *Aquilaria* species and *Gyrinops* species in Appendix II. The new inclusion was accepted in 2005 (CITES 2004). Other international organization also heightened public awareness toward this genus. The global environmental organization, the International Union for Conservation of Nature and Natural Resources (IUCN), for example, listed nine *Aquilaria* species under the IUCN Red List of Threatened Species since 1998. At present, seven species are reportedly vulnerable while two others are critically endangered.

Since the very first species was identified in 1783, the understanding of the genus *Aquilaria* is still subject to reviewing and information collection from natural stands in the wild. On herbarium basis, misidentification often occurs for this genus. As *Aquilaria* trees in the wild are rarely seen with fruits and flowers, identification efforts can be really difficult. This problem was highlighted by The Wildlife Trade Monitoring Network (TRAFFIC) (Wyn and Anak 2010), giving example on Browne's (1955) findings of *Aquilaria* species occurrence in the state of Sarawak in Malaysia, speculating most of them as *A. malaccensis*. However, the author was unable to shed light on the species due to lack of reproductive parts. On contrary, Anderson (1980) clarified that *A. malaccensis* is rarely available in Sarawak. His observation was based only on a single herbarium specimen, which was collected in Marudi, East of Sarawak. Subsequently, Tawan (2004) reviewed the herbarium specimen and identified it as *A. beccariana*.

Current international effort focuses on combining multiple checklist datasets to reexamine the genus identity. One such effort is led by the Royal Botanic Gardens

and Kew and Missouri Botanical Garden, which brought into being The Plant List in 2010. From the latest release, version 1.1, in May 2012, 21 out of 47 names were accepted (note: Tropicos recorded that the orthography for *A. banaense* was corrected to *A. banaensis* (Hô 1992)). As taxonomy solely depends on the morphological characteristics of the plant itself, probability of misidentification cannot be avoided. It will be a continuous effort to identify the correct species name and exclude the synonyms from time to time. Cooperation between experienced botanist and ecologist is required to reassessed the natural populations and review the type specimens to reduce the error of identification.

1.6 Domestication of the Genus

As the agarwood business is deemed lucrative, many individuals, entrepreneurs, and government agencies have ventured into *Aquilaria* plantations. Several species have been mass cultivated as plantation species in climate-suitable countries including *A. crassna* (widely spread), *A. malaccensis* (Peninsular Malaysia, West Indonesia, East India), *A. microcarpa* (Borneo region), *A. sinensis* (China), *A. subintegra* (South Thailand and Peninsular Malaysia), *A. filaria* (home gardens of East Indonesia), and *A. hirta* (home gardens of Peninsular Malaysia and West Indonesia) with the intention to sustainably produce agarwood in a short period of time. Interestingly, although *Aquilaria* is considered a highly out-crossing tree (Tangmitcharoen et al. 2008), yet, there is no formal records on hybrids in the field. There have been instances where individuals maintained that they breed for hybrid species; however, none has been scientifically supported. Perhaps the information is treated with discreet.

When it comes to species selection for planting, many farmers do not have the knowledge on which species to choose. They are often influenced by sellers of the planting materials. Most of the time, sellers rely on personal perception when recommending the species of superior growth and agarwood yield. These unfortunately are biased to the sellers, and most importantly are not corroborated with scientific evidence. It has been proven that different species produce different chemical compounds that make the agarwood scent unique to each species. In addition, the type of inducers also affects the outcome.

In general, one has to consider several criteria when selecting a plantation species:

(a) Trade market

The primary focus is targeted toward the trade market one wishes to penetrate. Different importing countries have different specific uses of the agarwood and preferences in species of origin. For example, consumers from the Middle East and India prefer agarwood from *A. malaccensis* source for perfumery and religious traditions; China regards *A. sinensis* agarwood as having medicinal properties; Korea acknowledges only *A. malaccensis* as true agarwood; and

Japan prefers agarwood from *A. crassna* for meditation purposes. However, other *Aquilaria* species possess a smaller-scale demand in perfumery, ornamental carvings, personal accessories, and cosmetics.

(b) Species adaptability

Although *Aquilaria* species are from the tropical regions, there are still possibilities that exotic species brought into as plantation species may not survive in the new planting environment. Most of the local planters cultivate native species to ensure low percentage of mortality. Furthermore, there were informal reports claiming that trees from other regions, which was proven prone to agarwood formation, actually did not produce the expected agarwood quality even after the same inoculation treatment was carried out. This could be explained by the phenotypic changes occurring in the tree, influencing it to be non-susceptible toward agarwood formation. It was suggested that such risk can be reduced by matching the seed source with similar ecological conditions to the planting site.

(c) Availability of planting resources

Like many other agriculture plants, *Aquilaria* flowers and fruits almost annually. However, the fruiting season varies among populations and tends to be inconsistent. *Aquilaria* trees are rare in the wild, numbers of mother trees that are likely prone to agarwood formation are limited; hence, it is difficult to obtain large amount of seeds suitable for plantation purposes. To ensure that the planting resources are sufficient and provide promising end products, getting seeds and planting materials from reliable sources, such as an established seed orchard or breeding center, is much recommended; however, their availability is scarce.

(d) Establishment of R&D and silviculture practices

As planting *Aquilaria* is a long-term investment, an optimal plantation management system is required to ensure planters get to harvest before anything goes wrong. Alongside with the planting, research on a suitable inoculation is indeed a crucial step to produce agarwood. To date, most of the modern inoculation techniques focus onto only a single *Aquilaria* species; therefore, planters need to be aware of their planting material beforehand. Established planting techniques, land use management, and pest and disease controls for the species of interest are also important factors for planters to select their desired planting materials. Reducing the risk of plantation investments by involving research-associated authorities will help planters to obtain firsthand information to manage their plantations.

1.7 Description of Cultivated *Aquilaria* Species

For *Aquilaria* in general, species recognition relies much on their reproductive parts, especially the fruit and calyx characteristics (Tawan 2004). Vegetative characteristic such as the leaves shape remains subjective as phenotypic changes may occur, causing alteration due to environment adaptation. From our own experience, one cannot tell the species with certainty by relying on the leaf morphology, except

for *A. hirta*, because of its distinctive puberulous leaf abaxial and leaf petiole. To aid planters in identification, the vegetative and reproductive characteristics of five commonly planted *Aquilaria* species are compiled here (Table 1.3). This description is not meant for taxonomical purposes but for field workers to help identify the species. Descriptions were from field observations and published references: *A. crassna* from Schmidt and Nguyen (2004), *A. subintegra* from Ding Hou (1964), *A. malaccensis* and *A. hirta* from Ding Hou (1960), and *A. sinensis* from Flora Reipublicae Popularis Sinicae (1991).

The simplest approach to identify the species of cultivated *Aquilaria* trees in plantations is by referring to their fruit structure, also known as capsule. Typical differences of the capsule structure include the size, the shape of the fruit apex and base, the surface texture, and the size and shape of the calyx lobe (Fig. 1.2). Therefore, species identification for common plantation species can be easily carried out during their fruiting seasons. The common flowering and fruiting

Table 1.3 Vegetative and reproductive characteristics of cultivated *Aquilaria* species

	A. crassna	*A. subintegra*	*A. malaccensis*	*A. sinensis*	*A. hirta*
Size	Big tree	Shrub	Big tree	Shrub	Small tree
Leaf shape	Elliptic	Elliptic-oblong or slightly obovate-oblong	Oblong-lanceolate, caudate-acuminate	Orbicular, elliptic-oblong, obovate	Elliptic to elliptic-oblong
Leaf texture	Leathery	Papery	Papery	Leathery	Semi-leathery,
Leaf surface	Smooth	Almost smooth	Smooth	Smooth	Smooth above, Hairy beneath
Capsule shape	Round, obovoid	Ellipsoid-oblong	Obovoid or obovoid oblong	Ovoid	Oblanceolate acute
Capsule base	Slight cuneate	Cuneate	Cuneate	Cuneate	Cuneate
Capsule apex	Round	Round	Round	Narrow or round	Sharp
Capsule texture	Heavily wrinkled	Slightly wrinkled	Smooth	White silky or smooth	Hairy
Calyx lobe	Broad-ovate or –obovate, 12–15 mm long, spreading or occasionally reflexed	Ovate-oblong, 3.5–5 mm long	Ovate-oblong, 2–3 mm long, spreading or reflexed	Spreading or occasionally reflexed	Ovate and obtuse, 2–3 mm long
Calyx tube	Bell-shaped	Bell-shaped	Bell-shaped	Bell-shaped	Cylindrical
Flower length	0.38 cm	0.75–1.1 cm	2.5 cm		2.5 cm

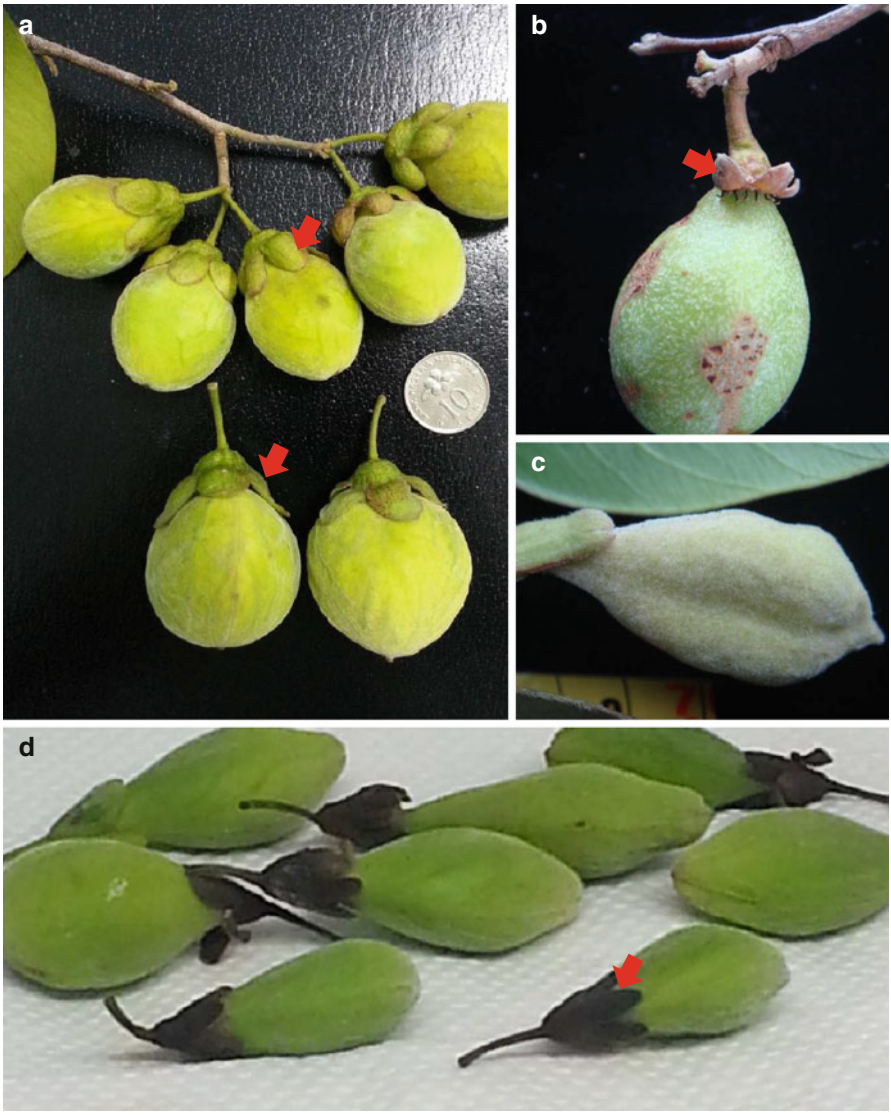

Fig. 1.2 Fruits of five commonly cultivated *Aquilaria* species. (**a**) *A. subintegra* capsule (*top*) is egg-shaped, generally smaller compared to *A. crassna* (*bottom*), which is spherical and wrinkly, while both have broad calyx lobes pointing toward the capsule base; (**b**) *A. malaccensis* is round at the apex while slender at the base, with tiny calyx lobes recurving outward; (**c**) *A. hirta* is a bit flattened, elongated, and pointy at the apex, covered with fine hair; and (**d**) *A. sinensis* is diamond-shaped or sometimes oval with a narrow base, with calyx lobe similar to *A. crassna*, only narrower. *Arrows* point to calyx lobes. Photos: (**b**) and (**c**) Salleh Endot

Fig. 1.3 Inflorescence of several *Aquilaria* species. (**a**) *A. malaccensis* is bell-shaped and yellowish, (**b**) *A. hirta* is cylindrical, long, and fine haired, and (**c**) *A. sinensis* is bell-shaped and light green and has long petals. Photo: (**c**) Y. Yang

period for *Aquilaria* trees is between May and August (Fig. 1.3). Eventually, fruiting frequency is greatly influenced by the climate and geographical differences where the tree is populated (Soehartono and Newton 2001). *Aquilaria* fruit produces 1–2 seeds in a capsule, and seeds are important resources for cultivation (Fig. 1.4). *Aquilaria* seeds are classified as recalcitrant seeds, which are very sensitive to desiccation and cannot be kept for a long period. Under room temperature, the storage period for a successful germination is at maximum 3 days, after which the germination rate drops. When kept under −10 °C, it can be stored for a maximum of 25 days with promising survival rate (Aroonrungsikul et al. 2009; Aroonrungsikul and Wongsatain 2010; Saikia and Khan 2012; Tabin and Shrivastava 2014).

Planting materials are often young saplings ranging from 6 months to 2 years old. Species identification on young saplings is a difficult task as reproductive parts are absent. In such scenario, effective identification can only be carried out through leaf morphology. Except for *A. hirta* which has hairy leaves, all the remaining com-

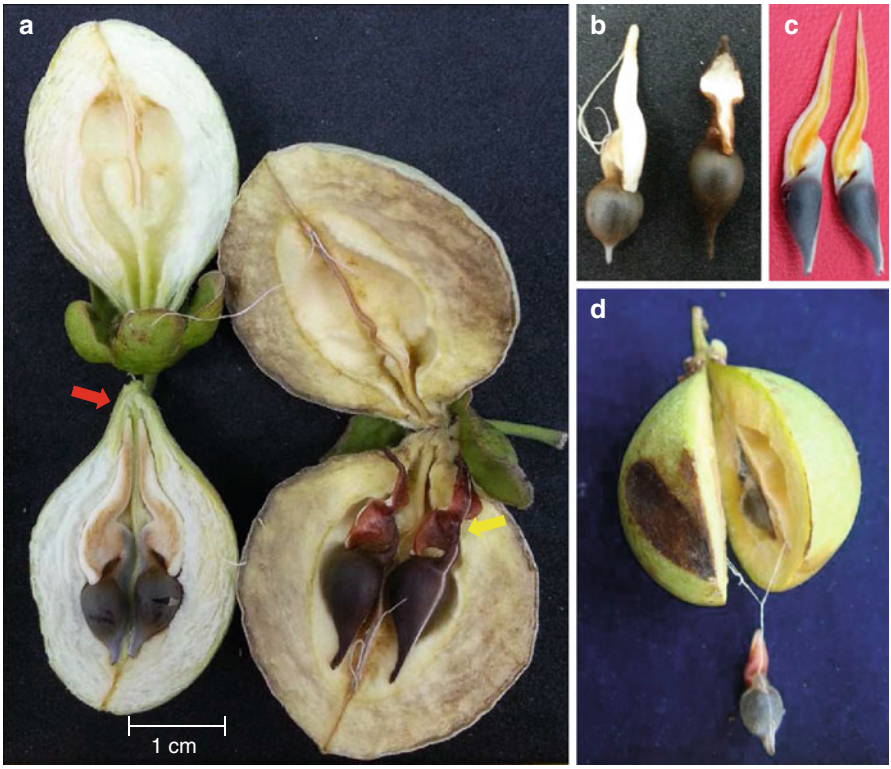

Fig. 1.4 Capsules and seeds of five commonly cultivated *Aquilaria* species. (**a**) Capsule of *A. subintegra* (*left*) and *A. crassna* (*right*); the latter is round in shape, while the former is oblong with a cuneate or triangle base (*red arrow*); (**b**) seed of *A. crassna* (*right*) is reddish brown, with a wrinkled appendage, which is clearly seen in the previous photo (*yellow arrow*) and is bigger than *A. subintegra* seed (*left*); (**c**) seeds of *A. sinensis* have long and slender appendages; and (**d**) *A. malaccensis* seed is small and round and has a reddish short appendage. Capsules (**a**) and (**d**) are on the same scale. Photo: (**d**) Salleh Endot

monly cultivated *Aquilaria* species have similar leaf characteristics at young age. A study on the vegetative description of three *Aquilaria* species in Malaysia was carried out by describing distinctive vegetative characteristics of the saplings. Although it could be done, *Aquilaria* saplings identification remains a challenging job for inexperienced individuals (Lee et al. 2013). At present, identification efforts can be supported using molecular approaches such as DNA markers. Unlike conventional identification, molecular-based identification does not require a professional or experienced personal to identify tree morphology. Armed with simple laboratory procedures and basic facilities, which are available at any descent research institutions, species identification can be accomplished in a rapid manner and most importantly with confidence. A well-optimized molecular technique can be an effective tool to ascertain species identity and potentially contributes in breeding programs for *Aquilaria* (Lee et al. 2011).

In Indonesia, *Aquilaria* planting is carried out at a small to medium scale, and the trees of choice are "filaria" and "malakensis." However, this grouping does not indicate a specific species; rather it was a general trade name that distinguishes agarwood from the eastern and western regions of Indonesia, respectively, and may include *Gyrinops* species. *Gyrinops* is a closely related agarwood-producing tree under the same family that populates the same region as the *Aquilaria* (Takeuchi and Golman 2002). Planters could misidentify and wrongly reported their planting materials to the authorities, thus causing incorrect evaluation of the preferred plantation species in the region. Due to the ambiguity of the planted species, we have excluded them from this section.

1.8 Brief Notes on *Gyrinops*, a Closely Related Genus

Together under the same subfamily Aquilariodeae, the genus *Gyrinops* is the nearest tree to *Aquilaria*. These two genera are taxonomically different only by the number of stamens: *Aquilaria* has eight to twelve stamens, while *Gyrinops* has five. The first *Gyrinops* was recorded in the year 1791 by Joseph Gaertner; *Gyrinops walla* was the type specimen.

With a total of nine accepted species name under the genus *Gyrinops*, seven were found distributed in the southeast of Indomalesia regions, namely, Indonesia and Papua New Guinea (Table 1.4). Those that are endemic to Indonesia are *G. decipiens*, *G. moluccana*, *G. podocarpa*, and *G. versteegii*, while *G. caudata* is endemic to Papua New Guinea. Two other species, *G. ledermannii* and *G. salicifolia*, are found in both countries. Further north in the Indomalesia region, *G. vidalii* has been reported endemic to Laos and *G. walla* to Sri Lanka.

Similar to *Aquilaria*, the *Gyrinops* is also classified as agarwood-producing trees. To date, only three species are known agarwood producers: *G. ledermannii*, *G. versteegii*, and *G. walla* (Hou 1960; Ng et al. 1997; Compton and Zich 2002; Subasinghe et al. 2012). The genus *Gyrinops* was listed under Appendix II of CITES in 2005 together with the genus *Aquilaria* as a conservation effort; however, it was not included in the IUCN Red List perhaps because the exploitation of its natural population was not as alarming as *Aquilaria*.

In Papua New Guinea, where *A. filaria* and *G. ledermannii* can both be found, identification is compounded by them sharing the same morphology. Careful examination, however, revealed that *Gyrinops* contains the same number of stamens as the petals, while *Aquilaria* has twice the number of stamens to the petals. In terms of agarwood, no one genus is superior to the other. *Gyrinops* plantations were initiated as early as 1998 without prior information on its taxonomy. A thorough taxonomy study was then carried out in 2001 where the plantation species was identified as *G. ledermannii* (Subasinghe et al. 2012).

Because of very similar characteristics between the two genera, the idea to consolidate *Aquilaria* and *Gyrinops* became apparent. Hailier (1922) and Ding Hou (1960) acknowledged that both genera are highly similar in taxonomical characteristics, and the difference in number of stamens should not be the major factor for

Table 1.4 Accepted names and distribution of *Gyrinops* species

No.	Species name	Basionyms and Synonyms	Year first reported	Distribution
1	*Gyrinops caudata* (Gilg) Domke	*Aquilaria caudata* *Brachythalamus caudatus* *Gyrinops audate*	1932	Papua New Guinea
2	*Gyrinops decipiens* Ding Hou	–	1960	Indonesia
3	*Gyrinops ledermannii* Domke	–	1932	Papua New Guinea Indonesia
4	*Gyrinops moluccana* (Miq.) Baill	*Aquilaria moluccana* *Lachnolepis moluccana*	1946	Indonesia
5	*Gyrinops podocarpa* (Gilg) Domke	*Aquilaria podocarpus* *Brachythalamus podocarpus* *Gyrinops ledermannii* *Gyrinops podocarpus*	1932	Indonesia
6	*Gyrinops salicifolia* Ridl.	*Gyrinopsis salicifolia*	1916	Indonesia Papua New Guinea
7	*Gyrinops versteegii* (Gilg) Domke	*Aquilaria versteegii* *Brachythalamus versteegii*	1932	Indonesia
8	*Gyrinops vidalii* P.H.Hô	–	1987	Laos
9	*Gyrinops walla* Gaertn.	*Aquilaria walla*	1791	Sri Lanka

According to Version 1.1 of The Plant List (2013), http://www.theplantlist.org, assessed on 26 January 2016
– not available

natural segregation. Eurlings and Gravendeel (2005) conducted a phylogenetic analysis on both genera by comparing morphological characteristics such as the shape of the calyx tube, lobes and fruits, presence or absence of leaf indumenta, and prominence of leaf venation. These attributes seem to correlate better with molecular clades formed, rather than the number of stamens, which is highly homoplasious. With further research, it is perceivable that *Gyrinops* may be reduced into *Aquilaria* synonym as it can reflect natural resemblances better.

1.9 Conclusions

As an endangered genus, the understanding of *Aquilaria* botany and taxonomy is an essential step toward conservation in the wild. With its natural population spreading across more than ten countries, further deteriorated by its scarcity in numbers and thus being threatened to extinction, the work for conservation must be carried out with full cooperation from all authorities. New efforts to review *Aquilaria* taxonomy and systematics could be initiated by recollecting specimens of several species, starting with those that have not been updated recently. An example are the endemic species of the Philippines, whereby the latest record is from 1946. Furthermore, by

taking advantage of molecular data, it may aid in taxonomy work such as in the classification of *Aquilaria* species, identification of species origin of agarwood products, and resolution of issues regarding species affinities between *Aquilaria* and *Gyrinops*.

References

Anderson JAR. A checklist of the trees of Sarawak. Kuching: Forest Department, Sarawak; 1980.

Angiosperm Phylogeny Group. An ordinal classification for the families of flowering plants. Ann Mo Bot Gard. 1998;85(4):531–53.

Aroonrungsikul C, Karwsuwan U, Wongsatain W. Preliminary study of agarwood (*Aquilaria crassna*) fruit and seed storage. Proceedings of the 47th Kasetsart University Annual Conference, Kasetsart, 17–20 Mar 2009. Subject: Plants. Kasetsart University; 2009. p. 281–8.

Aroonrungsikul C, Wongsatain W. Seed quality of some cloning of agarwood (*Aquilaria crassna*) in Trad Province area. Proceedings of the 48th Kasetsart University Annual Conference, Kasetsart, 3–5 Mar 2010. Subject: Plants. Kasetsart University; 2010.

Browne FG. Forest trees of Sarawak and Brunei. Kuching: GPO; 1955. p. 370.

Compton JGS, Zich FA. *Gyrinops ledermannii* (Thymelaeaceae), being an agarwood-producing species prompts call for further examination of taxonomic implications in the generic delimitation between *Aquilaria* and *Gyrinops*. Flora Malesiana Bull. 2002;13(1):61–5.

CITES. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Consideration of proposals for amendment of Appendices I and II- *Aquilaria* spp. and *Gyrinops* spp. Thirteenth meeting of the Conference of the Parties, Bangkok, 2–14 Oct 2004.

CITES. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Resolutions of the Conference of the Parties. Ninth meeting of the Conference of the Parties, Fort Lauderdale, 7–18 Nov 1994.

Cronquist A. The evolution and classification of flowering plants. 2nd ed. Bronx: The New York Botanical Garden; 1988.

Domke W. Untersuchungen über die systematische und geographische Gliederung der Thymelaeaceen. Bibliotheca Botanische. 1934;27:1–151.

Don G. A general history of the dichlamydeous plants, vol. 2. London: J.G. and F. Rivington; 1832. 4.

Duke JA. Duke's handbook of medicinal plants of the Bible. Boca Raton: CRC Press; 2007.

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

Flora Reipublicae Popularis Sinicae. 1991. [http://www.eflora.cn]. Access date 3 Aug 2015.

Gilg E. Thymelaeaceae. In: Engler A, Prantl K, editors. Die Natürlichen Pflanzenfamilien III, 6a. Leipzig: Engelman; 1894. p. 216–45.

Hailier JG. Beiträge zur Kenntnis der Thymelaeaceen und ihrer natüralichen Umgrenz-ungen. Meded Rijaks Herb. 1922;44:1–31.

Hamilton F. Chapter 11. A commentary on the second book of the herbarium amboinense. In: Memoirs of the Wernerian Natural History Society, vol. 6. Edinburgh/London: Adam Black and Longman; 1836. p. 268–333.

Herber BE. Pollen morphology of the Thymelaeaceae in relation to its taxonomy. Plant Syst Evol. 2002;232:107–21.

Herber BE. Thymelaeaceae. In: Kubitzki K, editor. The families and genera of vascular plants, Flowering plants dicotyledons (Malvales, Capparales and Non betalain Caryophyllales), vol. 5. Berlin: Springer-Verlag Berlin Heidelberg; 2003. p. 373–438.

Heywood VH. Flowering plants of the world. London: B. T. Batsford Ltd; 1993.

Hô PH. *Aquilaria* (Thymelaeaceae). In: Morat P, editor. Flora of Cambodia, Laos and Vietnam, vol. 26. Parisin: Museum National d'Histoire Naturelle; 1992. p. 51.

Hou D. Thymelaeaceae. In: Van Steenis CGGJ, editor. Flora malesiana series I, vol. 6. Netherlands: Wolters-Noordhoff Publishing; 1960. p. 1–48.
Hou D. Notes on some Asiatic species of *Aquilaria* (Thymelaceae). Blumea. 1964;12(2):285–8.
Hutchinson J. The genera of flowering plants, Dicotyledons, vol. 2. Oxford: Clarendon; 1967.
Ito M, Honda G. Taxonomical identification of agarwood-producing species. Nat Med. 2005;59:104–12.
Kiet LC, Kessler PJA, Eurlings MCM. A new species of *Aquilaria* (Thymelaeaceae) in Vietnam. Blumea J Plant Taxonomy Plant Geogr. 2005;50(1):135–41.
Lee SY, Weber J, Mohamed R. Genetic variation and molecular authentication of selected *Aquilaria* species from natural populations in Malaysia using RAPD and SCAR markers. Asian J Plant Sci. 2011;10(3):202–11.
Lee SY, Faridah-Hanum I, Mohamed R. Vegetative description of three *Aquilaria* (Thymelaeaceae) saplings in Malaysia. Pertanika J Trop Agric Sci. 2013;36(S):287–94.
Li T. Nguyen Cochinchina: southern Vietnam in the seventeenth and eighteenth centuries, vol. 23. Ithaca: Southeast Asia Program Publications; 1998.
Ng LT, Chang YS, Kadir AA. A review on agar (gaharu) producing *Aquilaria* species. J Trop Forest Prod. 1997;2(2):272–85.
Rautenbach M. *Gnidia* L. (Thymelaeaceae) is not monophyletic: taxonomic implications for *Gnidia* and its relatives in Thymelaeoideae, Doctoral dissertation, University of Johannesburg; 2008.
Ridley HN. Garu and chandan. In Royal Asiatic Society of Great Britain and Ireland Straits Branch. J Straits Branch R Asia Soc. 1901;35–36:73–82.
Royle JF. Illustrations of the botany and other branches of the natural history of the Himalayan mountains and of the flora of Cashmere, vol. 1. London: WM. H. Allen and Company; 1839.
Saikia P, Khan ML. Phenology, seed biology and seedling survival and growth of *Aquilaria malaccensis*: a highly exploited and red listed tree species of North East India. Indian Forester. 2012;138(3):289–95.
Schmidt LH, Nguyen XL. *Aquilaria crassna* Pierre. Seed Leaflet. 2004;100.
Society for the Diffusion of Useful Knowledge. The Penny Cyclopaedia of the Society for the Diffusion of Useful Knowledge, vol. 9. London: Charles Knight and Company; 1838.
Soehartono T, Newton AC. Reproductive ecology of *Aquilaria* spp. in Indonesia. For Ecol Manage. 2001;152(1):59–71.
Subasinghe SMCUP, Hettiarachchi DS, Rathnamalala E. Agarwood-type resin from *Gyrinops walla* Gaertn: a new discovery. J Trop Forestry Environ. 2012;2(2):43–8.
Tabin T, Shrivastava K. Factors affecting seed germination and establishment of critically endangered *Aquilaria malaccensis* (Thymelaeaceae). Asian J Plant Sci Res. 2014;4(6):41–6.
Takeuchi W, Golman M. The identity of Eaglewood (*Gyrinops*, Thymelaeaceae), a new economic resource for Papua New Guinea. SIDA Contributions Botany. 2002;20:261–7.
Tangmitcharoen S, Yongrattana P, Luangvirivasaeng V, Tasen W, Chantbep P, Saengtubtim S. Floral biology of *Aquilaria crassna* Pierre ex Lecomte. Thai J Forestry. 2008;27(2):1–13.
Tawan CS. Thymelaeaceae. In: Soepadmo E, Saw LG, Chung RCK, editors. Tree flora of Sabah and Sarawak, vol. 5. Kuala Lumpur: Forest Research Institute Malaysia; 2004. p. 133–484. 528 pp.
The Plant List. 2013. Version 1.1. [http://www.theplantlist.org/]. Access date 26 Jan 2016.
Tropicos. Missouri Botanical Garden. 2016. [http://www.tropicos.org]. Access date 27 Jan 2016.
Van der Bank M, Fay MF, Chase MW. Molecular phylogenetics of Thymelaeaceae with particular reference to African and Australian genera. Taxon. 2002;51(2):329–39.
Watt G. A dictionary of the economic products of India, vol. 1. Cambridge: Cambridge University Press; 2014.
Wyn LT, Anak NA. Wood for the trees: a review of the agarwood (Gaharu) trade in Malaysia. Traffic Southeast Asia; 2010.