



REVIEW

Biomolecules of Interest Present in the Main Industrial Wood Species Used in Indonesia-A Review

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ABSTRACT

As a tropical archipelagic country, Indonesia's forests possess high biodiversity, including its wide variety of wood species. Valorisation of biomolecules released from woody plant extracts has been gaining attractive interests since in the middle of 20th century. This paper focuses on a literature review of the potential valorisation of biomolecules released from twenty wood species exploited in Indonesia. It has revealed that depending on the natural origin of the wood species studied and harmonized with the ethnobotanical and ethnomedicinal knowledge, the extractives derived from the woody plants have given valuable heritages in the fields of medicines and pharmacology. The families of the bioactive compounds found in the extracts mainly consisted of flavonoids, stilbenes, stilbenoids, lignans, tannins, simple phenols, terpenes, terpenoids, alkaloids, quinones, and saponins. In addition, biological or pharmacological activities of the extracts/isolated phytochemicals were recorded to have antioxidant, antimicrobial, antifungal, anti-inflammatory, anti-diabetes, anti-dysentery, anticancer, analgesic, anti-malaria, and anti-Alzheimer activities. Aside from these remarkable characteristics of woody plant extractives, further studies concerning the valorisation of these extractives in the fields of nutraceutical, cosmetic, bio-control, bio-stimulation, and other advanced applications would be of interest.

KEYWORDS

Bark; by-product; bioactivity; extractive; Indonesia; industry; molecule; valorization; wood species

1 Introduction

The use of bioactive compounds derived from nature to promote human health and treat various diseases has been attracting considerable attention. Based on numerous ethnomedicines that commonly used for centuries, intensive research to uncover some bioactive chemicals responsible for these green medicines have been developed since the middle of the 20th century. Inherently separated from their sources, a large part of these bioactive compounds come from forests. In Asia-Pacific, forests and trees are an indispensable part of its regional economies due to their diverse economic, cultural, environmental, and social values. The relationship between the society and the forests encounter important changes,



especially in terms of demand for forests. The total forest area in the Asia-Pacific region was estimated at 740 million ha or approximately 18.3% of the global forest area. Indonesia, Australia, China, and India, as the four largest countries in Asia-Pacific, contributed for about 71% of the forest area (Fig. 1). Myanmar, Papua New Guinea, Japan, Malaysia, Lao PDR and Thailand collectively contributed for another 18%, with the final 11% located in the remaining 23 countries and territories [1]. Trade is an important factor of forestry change in the Asia-Pacific region due to the enormous value traded. The import values of primary wood products increased from about US\$ 27.1 billion in 1990 to US\$ 63.3 billion in 2008. Meanwhile, Asia and the Pacific's share of global forestry exports grew from US\$ 12.6 billion in 1990 to US\$ 33.7 billion in 2008. A major forest product exporting subregion in Asia-Pacific came from Southeast Asia, with the total export values of the forest products reported in 2008 was US\$13.7 billion. Contributing for 90% of these exports, Thailand (13.4%), Malaysia (27.9%), and Indonesia (48.7%) are the largest exporting countries in this subregion [1].

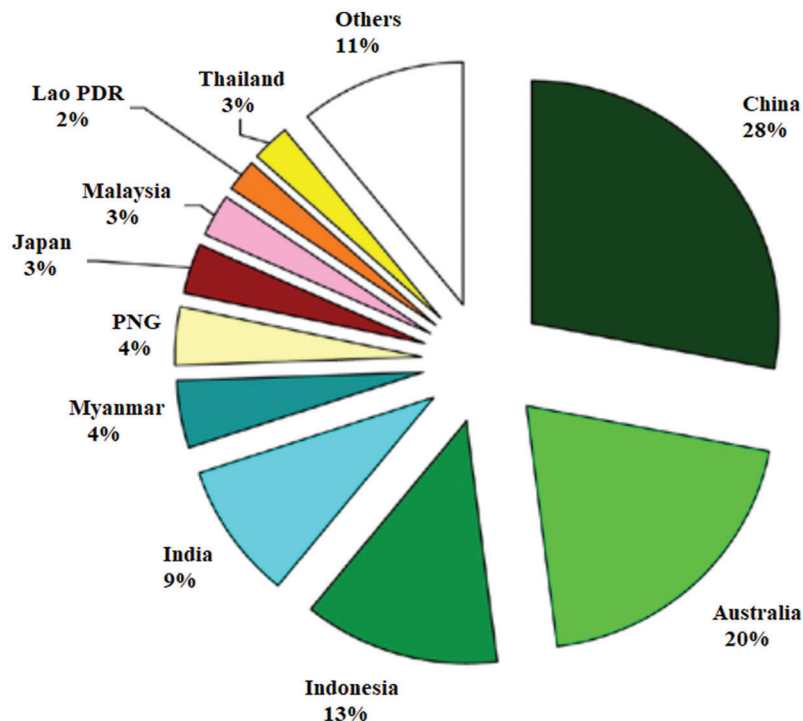


Figure 1: Distribution of forest area by country [1]

Indonesia as one of the countries with the largest forest area remains a major contributor to export activities in the forestry sector. Indonesian forests cover more than 49.81% of the national territory with an area of approximately 93.52 million ha. The export value of forest products in Indonesia increased from about US\$ 6.61 billion in 2014 to US\$ 12.13 billion in 2018 [2]. Log productions of timber culture establishments are spread throughout the islands of Indonesia. In 2018, Sumatra island is the largest region log production with production volume reaching 33,733.64 thousand m³, equivalent to 81.56% of total production. After Sumatra, Borneo island is placed as the second highest producer of logs from these culturing activities [3]. However, these highest log production capacities would be consistent or even increase if sustainable management of forest resources is well implemented, realizing action towards sustainable forestry. As an effort to achieve this, the development of forest products by means of

practicing the whole-tree utilization or recycling the wood wastes derived particularly from industrial activities should be well established and executed.

Being a tropical archipelagic country, Indonesia's forests possess high biodiversity, bestowing the nation to have a wide variety of wood species. Around 4000 species of wood have been registered, consisting of 785 genera in 106 families [4]. Among these species, 400 species are commercially used. Indonesia's forests are also known to have more than 400 species (70%) of the largest meranti (family Dipterocarpaceae) in the world which then recognized as excellent tropical wood species. The wealth of plant diversity can also be shown particularly by the wealth of the Borneo forests [5]. In order to maintain and protect the ecosystem and its biodiversity, Indonesian Ministry of Forestry have established a number of units of marine and terrestrial conservation, consisting of national parks, nature tourism parks, grand forest parks, game hunting parks, natural reserves, and wildlife sanctuaries [6].

The Indonesian Forestry Law Number 41 Year 1999 (Article 6) stated that based on the main functions, Indonesia's forest areas are classified into three categories: production forest, conservation forest, and protection forest [7]. In terms of the production forest, its total areas consisted of primary forest, secondary forest, plantation forest, non-forested land, and area with no data. The primary forests were located in Papua and Kalimantan islands, while the secondary forests were located in Sumatra and Kalimantan islands. Plantation forest was dominantly located in Java, followed in Sumatra and Kalimantan islands. Among various wood species that already existed in the production forest, there are twenty wood species either from natural or from plantation forest that widely commercialized for various wood products. These wood species consist mainly of teak (*Tectona grandis* L.f.), merbau (*Instia spp.*), camphor (*Cinnamomum camphora*), mahogany (*Swietenia spp.*), ebony (*Diospyros spp.*), light red meranti (*Shorea spp.*), bangkirai (*Shorea laevis*), sonokeling (*Dalbergia latifolia*), ulin (*Eusideroxylon zwageri* Teijsm. & Binnend.), kempas (*Koompassia malaccensis* Maingay ex Benth), nyatoh (*Palaquium spp.*), keruing (*Dipterocarpus* Gaertner f.), kapur (*Dryobalanops spp.*), agathis (*Agathis dammara* / *A. loranthifolia* / *A. celebica* / *A. alba*), and jelutung (*Dyera costulata* Hook) from the natural forest, whereas the wood species from plantation forest consist of pines (*Pinus spp.*), sungkai (*Peronema canescens*), sengon (*Paraserianthes falcataria* / *Albizia falcataria*), jabon (*Anthocephalus cadamba*), and acacia (*Acacia mangium* Willd). The annual share production of the wood logs of some of them has also been recorded in Tab. 1, according to the statistics of forestry production [8]. The teak as most popular species also comes from plantation forest. With relatively good physical, mechanical, and/or biological durability properties, the wood species from natural forest are commonly used for construction materials, whereas the wood species from plantation forest are commonly used for light construction, panel wood, pulp paper, and fuel wood. The teak, either comes from natural or plantation forest, is usually used for construction and furniture materials.

Although the utilization/processing of these wood species has been optimally practiced following the destined applications, the utilization of forest product residues, such as leaves, barks, roots, flowers, to become highly value-added by-products remains very limited. As an effort to solve this matter, numerous extensive researches have been conducted or even applied, such as valorisation of bark [9–11], leaves [12–14], including intensive analysis of the woody plant extracts for their chemical constituents as well as their biological and pharmacological properties. Correspondingly, it is known that some wood extractives have been reported to present several biological properties like antimicrobials, antibacterial, antifungals, insecticidal, antioxidants [15–17], and could be used as traditional or alternative medicines [18]. In terms of medicinal plant, there were around 1300 kinds of medicinal plants existed in Indonesian tropical forest [19]. As a country with rich plant diversity, Indonesia has become an exporter for the medicinal plants, aromatics, and herbs with the increased revenue from about US\$ 299.79 million in 2012 to US\$ 601.23 million in 2018 [3]. A lot of traditional knowledge, relating to the use of medicinal plants from various ethnicities living in the forest ecosystem, has been adopted and developed by the

herbal and pharmaceutical industries into herbal products. Accordingly, related to the whole-tree utilization, this later case could become a precious contributor in developing the value-added by-products as a source of bioactive molecules for pharmaceutical, cosmetic, nutraceutical, or other advantageous applications.

Table 1: Annual production of the wood logs by type per quarter in 2015 [8]

Logs type	Year 2015 (m ³)				Total (m ³)
	Quarter 1	Quarter 2	Quarter 3	Quarter 4	
Teak (<i>Tectona grandis</i> L.f.)	78,757.13	148,865.84	151,403.67	134,351.45	513,378.09
Merbau (<i>Instia spp.</i>)	29,547.30	31,889.73	101,583.45	102,903.11	265,923.59
Camphor (<i>Cinnamomum camphora</i>)	8,693.97	12,467.43	12,020.36	45,955.50	79,137.26
Mahogany (<i>Swietenia spp.</i>)	41,883.68	71,185.85	89,152.03	93,517.72	295,739.28
Light red meranti (<i>Shorea spp.</i>)	678,855.70	1,121,840.20	1,445,344.24	1,225,802.44	4,471,842.58
Bangkirai (<i>Shorea laevis</i>)	16,471.29	36,485.23	31,188.15	30,618.98	114,763.65
Sonokeling (<i>Dalbergia latifolia</i>)	10,118.14	9,662.54	11,658.28	9,976.72	41,415.6
Nyatoh (<i>Palaquium spp.</i>)	1,016.55	9,352.51	3,995.32	6,703.24	21,067.62
Keruing (<i>Dipterocarpus Gaertner f.</i>)	48,596.46	106,417.85	89,535.61	86,145.40	330,695.32
Agathis (<i>Agathis dammara</i>)	2,962.57	5,959.56	5,940.92	2,775.74	17,638.77
Pines (<i>Pinus spp.</i>)	54,689.62	44,017.18	67,552.21	66,677.46	232,936.46
Sungkai (<i>Peronema canescens</i>)	67.51	142.82	81.90	383.80	676.03
Sengon (<i>Paraserianthes falcataria</i>)	709,353.73	698,099.24	618,586.12	557,937.81	2,583,976.89
Jabon (<i>Anthocephalus cadamba</i>)	4,803.80	10,303.09	7,974.20	5,742.37	28,823.47
Acacia (<i>Acacia mangium</i> Willd)	5,792,622.69	6,274,780.37	4,918,074.59	5,920,401.25	22,905,878.90

The objective of this review is to present the knowledge already available in the literature on the structure and properties of the existing bio-molecules of wood extracts from tropical wood species exploited industrially in Indonesia.

2 Chemical Composition and Properties of Some Woody Plant Extracts Derived from the of Main Industrial Wood Species in Indonesia

2.1 Teak (*Tectona grandis* L.f.)

Teak (*Tectona grandis* L.f.), a well-known tropical hardwood species in Indonesia, belongs to the family Verbenaceae. Teak is one of the most valuable tropical timber species. Due to its excellent properties (texture, physical and biological durability), it is commonly used industrially for shipbuilding, outdoor equipment, and furniture. Teak grows naturally in South and South-East Asia, mainly in Bangladesh, India, Laos,

Myanmar, Indonesia, and Thailand. The Indonesian teak mostly comes from plantation forests in Java island, and the others come from natural or coppice forest on Sulawesi island. The heartwood colour is golden brown and clearly distinct from the yellowish-white sapwood. Darmawan et al. [20] reported that heartwood portion of the teak aged of 10 years was 40%, whereas the teak at the age of 40 years was 80%. The specific gravity of the wood is 0.62–0.75 [4]. Rizanti et al. [21] reported that a long rotation teak (contains less juvenile wood and higher heartwood content) contained slightly more holocellulose, cellulose, and hemicellulose contents than a short rotation teak (contains more juvenile wood and higher sapwood content) (68.53%, 49.18%, and 19.35%; 67.50%, 48.80%, and 18.70%, respectively), but the lignin content was lower (32.19%; 35.53%, respectively). This lignin content is much higher compared to the lignin content in hardwood in general. In general, heartwood contains more lignin compared to sapwood [22]. Rizanti et al. [21] also reported that long rotation teak contained higher contents total of extractives than short rotation teak (8.0% and 3.7%, respectively). Long rotation teak has higher extractives contents than short rotation teak due to higher heartwood content and also has less proportion of juvenile wood. In the previous study, Miranda et al. [23] reported that the extractive content of teak aged 50–70 years was 12.7%. Later on, Moya et al. [24] reported that some influential factors such as growth location, the type of solvent, and extraction techniques could affect differences in this extractive content.

Teak wood contains anthraquinones (tectoquinone, 2-methyl quinizarin, 1-hydroxy-2-methylanthraquinone, pachybasin), naphthoquinones (lapachol, deoxylapachol, 5-hydroxylapachol), naphthoquinone derivatives (tectol, dehydrotectol, α -dehydrolapachone, β -dehydrolapachone), and squalene, β -sitosterol, betulinic acid, trichione, and obtusifolin [25]. Several extractives of teak wood improved teak wood's ability to resist against biological attacks. These are predominantly quinone derivatives, like lapachol and tectoquinone (Fig. 2). Tectoquinone is the main component responsible for the wood natural durability against termites. Meanwhile, deoxylapachol has been found to have a strong anti-termite activity compared to lapachol reported to exhibit a weak anti-termite activity [26]. Tectoquinone and deoxylapachol are active compounds against *Aspergillus niger* [27]. GC-MS analysis of dichloromethane extract (yield: 5.7%–9.06%) of the heartwood shows that squalene is the major component for this solvent [23,28]. The high nonpolar fraction in the heartwood was reported responsible for this teak durability [23]. The dichloromethane, acetone, and toluene-ethanol extracts of long rotation teak wood contain tectoquinone as the main substance identified with a percentage ranging from 4.5 to 14.5% [21]. Windeisen et al. [29] reported that some other substances were found in the acetone extract such as 2-hydroxymethylanthraquinone, and 2-tert-butylanthraquinone. Lukmandaru et al. [26] also reported that extraction using toluene-ethanol and ethanol-benzene solvent has allowed them to extract palmitic acid and squalene, respectively. Squalene might contribute towards durability in the form of a hydrophobic barrier to toxic triterpene compounds [29]. In pharmacology, Goswami et al. [30] reported that many parts of teak wood have been used for several treatments. Root contained lapachol, tectoquinone, β -sitosterol, tectol, 1-hydroxy-2-methyl anthraquinone, dehydrotectol, β -lapachone, dehydro- α -lapachone, new diterpene, tectograndinol, non-structural carbohydrates, pachybasin, obtusifolina, and betulinic acid that are used in the treatment of anurea and urine retention. Bark contained tannin (7.14%), 5-hydroxy-1,4-naphthalenedione (juglon), obtusifolina, desidro- α -lapachona as astringent and useful for treatment of bronchitis. The wood is acrid, sedative, anthelmintic, expectorant, and useful in the treatment of gravid uterus, dysentery, headache, piles, leucoderma, and burning pain over the liver region. Meanwhile, the ashes of the wood are applied to swollen eyelids.

2.2 Merbau (*Intsia spp.*)

Merbau (*Intsia spp.*) is a tropical hardwood belonging to the family Caesalpiniaceae. The wood has a coarse-textured and a yellowish to orange-brown until reddish brown colour [4]. Merbau consists of nine species with different local names in different countries. Merbau is also commonly known as “kwila” or

“ipil” in Papua New Guinea, “moluccan ironwood” in Philippines, and “Borneo teak” in United Kingdom. The most widespread species are *Intsia bijuga* and *Intsia palembanica*. Other known species are *Intsia plurijuga*, *Intsia bakeri*, *Intsia puberula*, *Intsia amboinensis*, *Intsia retusa*, and *Intsia rhomboidei*. The range of specific gravity is 0.63–1.04 for *Intsia bijuga* and 0.52–0.97 for *Intsia palembanica*. The chemical compositions of merbau consist of cellulose 46.9%, lignin 22.6%, pentosan 17.1%, ash 0.9%, and silica 0.2% [4]. The wood is generally used for structural furnishings such as windows, framing, flooring and doors due to its favourable physical and mechanical properties (especially excellent tensile strength) and its termite resistance properties [31].

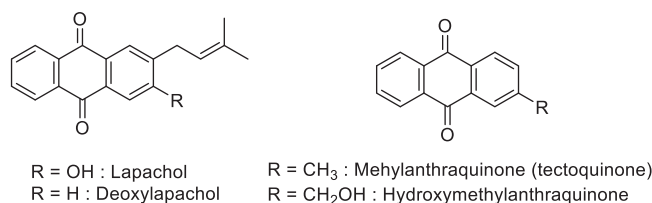


Figure 2: Predominantly quinone derivatives of teak wood

In the heartwood of merbau, robinetin is the main polyphenol compound with smaller amounts of 3,5,4'-tri and 3,5,3',4' tetra-hydroxystilbene, dihydroxymyricetin, myricetin and naringenin. According to Hillis et al. [32], the yellow crystalline in the heartwood of merbau is identified as pure robinetin (Fig. 3). *Intsia palembanica* has a higher proportion of robinetin than *Intsia bijuga*. The pure robinetin is formed throughout the length of vessels [33]. Merbau also contains large amounts of water-soluble extractives, including leucocyanidin. The high-water solubility of these extractives is responsible for some disadvantageous discolouration, which is manifest as blackish-lined, dark-coloured flecks on the surface. Even though robinetin is the principal compound in heartwood, it does not have high fungal toxicity [34]. Bark contains leucocyanidins, polyphenols, stilbenes, polysaccharides, and water-soluble polymers [35]. Hasan et al. [36] reported that the ethyl acetate extract of Merbau has a potent antioxidant characteristic. The effective concentrations (EC₅₀) for DPPH scavenging are $7.9 \pm 0.01 \mu\text{g/mL}$ and $4.5 \pm 0.02 \mu\text{g/mL}$ for the extract and standard antioxidant (Trolox), respectively. Whilst, the inhibitory concentrations (IC₅₀) for inhibition of tertbutylhydroperoxide is $1.26 \mu\text{g/mL}$, in comparison to the standard antioxidants, Trolox (IC₅₀ = $3.98 \mu\text{g/mL}$) and alpha-tocopherol acetate (IC₅₀ = $1.58 \mu\text{g/mL}$). The extract of Merbau has potent activity to be used for human health to prevent some diseases involving free radical and oxidative damage. In Madagascar, a decoction of the bark of *Intsia bijuga* is used in traditional medicine for diarrhea [37]. In Vanuatu, the inner bark of *Intsia bijuga* is used as remedy for asthma, meanwhile the leave of inner bark is used as remedy for diabetes and to relieve infections [38].

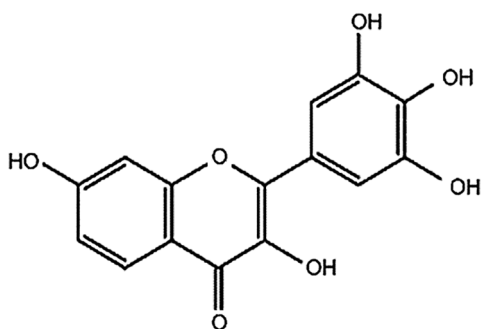


Figure 3: Robinetin

2.3 Camphor (*Cinnamomum camphora*)

The commercial Camphor comes only from *Cinnamomum camphora* (fam. Lauraceae) and *Dryobalanops camphora* (fam. Dipterocarpaceae). Camphor is widely planted in southern China, Vietnam, Japan, and Borneo. It is an evergreen tree species that grows to a great size, many-branched, flowers white, small, and clustered. Camphor wood is rigid and insect-resistant structural material that commonly used for luxury architecture and furniture. A considerable amount of valuable volatile chemical compounds such as camphenone, camphor, campherenol, nerolidol, and 1,8-cineole are contained in camphor trees [39]. Pandey et al. [40] also reported that camphor extracts contain α -terpineol, linalool, eucalyptol, safrole, etc. Camphor is a typical marker of camphor wood (Fig. 4). Camphor is commonly detected from all the camphor wood. Camphor is a natural product obtained through a steam distillation and purification by sublimation [41]. Camphor has been used in traditional and modern medicines, such as for the treatment of fibrous tissue inflammation, neuralgia, pruritic skin diseases, and influenza [42].

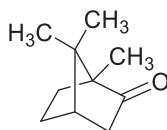


Figure 4: Camphor

Camphor is a colourless or white crystalline powder with a strong aromatic odour and volatile at room temperature. Camphor is slightly soluble in water (solubility of 0.12 g/100 mL at 25°C) and soluble in ethanol, chloroform, carbon disulphide, ether, and volatile or non-volatile oils [43]. The volatile gas of camphor can kill many types of harmful bacteria. The chemical components of extractives in camphor including their insecticidal and antimicrobial activities have been reported [44,45]. On the other hand, Kamariah et al. [46] investigated the oils from the leaves and seed of *Dryobalanops aromatica*. The leaf oil contains 84 compounds representing 92% of the total oil. α -terpineol (16%), terpinen-4-ol (15%), globulol (8%) and α -pinene (7%) are the major constituents. Meanwhile, the seed oil contains 31 compounds representing 100% of the total oil, with the major constituents being α -pinene (41%), α -thujene and β -pinene (13% each), sabinene, limonene and bicyclogermacrene (6% each), and myrcene (5%). The camphor extractives have been more commonly used in the form of the essential oil, which can be obtained from the trunk, leaves, and twigs by steam distillation or extraction using various solvents [47]. The camphor extract is used not only for medicinal application but also as an antibacterial agent for animals and plants against pathogenic bacteria, such as *Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*, etc. Camphor can also be used for food flavorings or preservatives due to its bacteriostatic and insecticidal activities that could restrain the growth of microbes [15,17].

2.4 Mahogany (*Swietenia spp.*)

Mahogany is a tropical hardwood species from the family Meliaceae. It consists of three species, *Swietenia macrophylla* king, *Swietenia mahogany* L. Jacq. and *Swietenia humulis* Zucc. The most widespread species are *S. macrophylla* and *S. mahogany*. *S. macrophylla* is native species to Central and South America and distributed from Mexico to Peru, Bolivia et al. [48]. *S. macrophylla* is used for many purposes such as furniture, ship building, panelling, etc. *S. mahogany* is mainly planted in southern Asia (Sri Lanka, India, and Bangladesh), in the Pasific (Indonesia, Malaysia, Philippines, and Fiji), and presented into cultivation in West Africa. *S. mahogany* is prospective to be applied for large scale timber production plantations, especially in dry areas, due to the excellent timber quality. Moreover, the plant is also used for soil improvement in agroforestry [49]. *S. macrophylla* and *S. mahogany* have specific

gravity of 0.53-0.67 and 0.56-0.72, respectively. Mahogany contains cellulose 46.8%, lignin 26.9%, pentosan 16.4%, ash 0.6%, and silica 0.1% [4].

S. macrophylla contains alkaloids, flavonoids, saponins, phenols, triterpenoids, anthraquinones, phospholipid, tannins, sterols, glycoside, resins, volatile oils, and long chain unsaturated fatty acid [50]. The major fatty acids are linoleic (37.50%-39.21%), oleic (18.82%-22.03%), stearic (16.75%-17.65%), and palmitic (14.62%-15.47%) [51]. Mootoo et al. [52] reported there are fifteen limonoids isolated from *S. macrophylla*: 7-deacetoxy-7-oxogedunin, andirobin, and thirteen bicyclononanolides. Eleven of the latter are the known compounds, swietenine, proceranolide, swietenolide, 6-O-acetylswietenolide, 3,6-O-diacetylswietenolide, khayasin T, and swietemahonins E-G that all recently reported from *S. mahagoni*, 2-hydroxyswietenine, and 6-deoxyswietenine (febrifugin). On the other hand, study on the leaves of the plant has successfully isolated limonoid of phragmalin type named swietenine J with nine compounds such as methyl-6- β -hydroxy angolensate, 1-O-acetylkhayanolide A, khayanolide E, khayalactone, khayanone, 1-O-acetylkhayanolide B, 1-O-deacetylkhayanolide E, khayanolide A, khayanolide B [13]. Fig. 5 shows the new limonoid, swietemacrophin. *S. macrophylla* is used for treating wound infection and skin condition [53]. In addition, *S. macrophylla* can also be used for treatment or prevention of various inflammatory diseases [54].

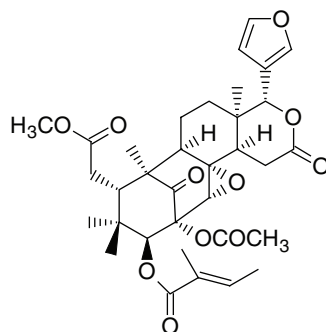


Figure 5: Swietemacrophin

S. mahagoni contains alkaloids, saponins, tannins, polyphenols, steroid, and triterpenoids [55]. Chen et al. [56] found two novel limonoids from *S. mahagoni* (Fig. 6).

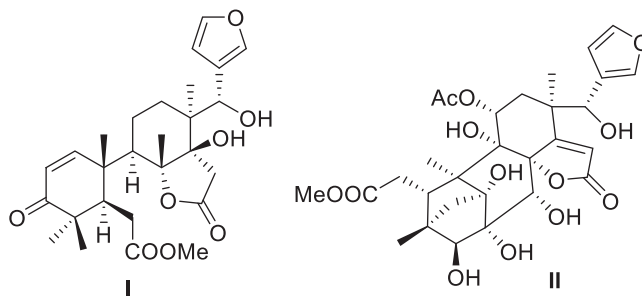


Figure 6: Swiemahogins A (I) and B (II)

Limonoids have been isolated from twigs and leaves. Swiemahogins A (1) and B (2) are the first examples of andirobin and phragmalin types of limonoids with a rare γ -lactone ring fused to the C-ring at C-8 and C-14 instead of the usual D- ring δ -lactone. Saad et al. [57] also reported that the extract

obtained from the stem bark of the plant has three novel ring-D opened limonoids corresponding to the phragmalin 8,9,14-orthoacetate with the addition of methyl 2,30-orthoacetate or a propionate, swietenialides A, B, C and two ring-D opened phragmalin type 1,8,9-orthoacetates, swietenialides D and E are isolated together with one known mexicanolide, 2-hydroxyswietenin. The extract from the seed contains 18 tetranortriterpenoids consisting of five swietenins (B-F), three acylswietenolides, seven swietemahonins (A-G), swietemahonolide, mahonin, and secomahoganin [58]. The seeds are traditionally used for leishmaniasis and abortion medicine by the Amazonian Bolivian ethnic group [59] and for the treatment of hypertension, diabetes, and malaria in Indonesia [58].

2.5 Ebony (*Diospyros spp.*)

The genus *Diospyros* belongs to the family Ebenaceae. Brummitt [60] has divided the family into three genera: *Diospyros*, *Euclea*, and *Tetraclis*. *Euclea* and *Tetraclis* are small numbers of species, existing only in eastern and southern Africa and Madagascar. The most widespread species is *Diospyros*. *Diospyros* contains about 400 species mostly native to the tropics (Madagascar, Africa and Malaysia), and two natives to the United States. Ebony is a member of genus *Diospyros*. Macassar ebony (*Diospyros celebica*) which natives to Indonesia, Ceylon ebony (*Diospyros ebenum*) which natives to Sri Lanka and southern India, and Gabon ebony (*Diospyros crassiflora*) which natives to western Afrika are certain species of ebony. The heartwood is dark brown to black, while sapwood is white to a greyish brown. The average specific gravity of Macassar ebony is 1.09. Chemically, the wood contains cellulose 46.5%, lignin 28.5%, pentosan 18.4%, and ash 1.7% [4]. *Diospyros spp.* has many sources for naphthol and naphthoquinones. The structural elucidation of *Diospyros spp.* produced diospyrol (I), mamegakinone (II), isodiospyrin (III) (Fig. 7) and bisisodiospyrin [61].

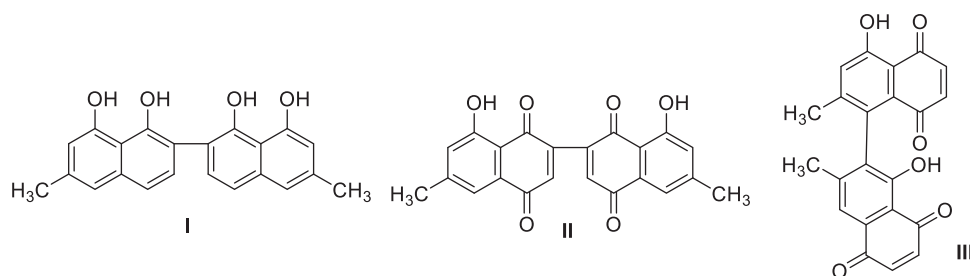


Figure 7: Compounds elucidated from *Diospyros spp.*

The extract obtained from the bark of the plant contains diosquinone, crassiflorone, plumbagin, cyclocanaliculatin and gerberinol [62,63]. In Macassar ebony (*D. celebica*), the heartwood contained Macassar II, Macassar III (the principal aromatic extractive derived from naphthol), and betulin [64]. Further, two β -naphthaldehydes and betulinic acid were isolated from the *Diospyros ebenum* [65]. On the other hand, other compounds such diospyrin and isodiospyrin are isolated from the heartwood of *D. mespiliformis*. Betulin, lupeol, plumbagin (2-methyljuglone), elliptinone are isolated from the bark of *D. elliptifolia* [66]. Diomelquinone, isocelebaquinone, o-naphthoquinone, celebaquinone, diosindigo B and its dihydro-derivative are isolated from the heartwood of *D. celebica* [67]. Dinaphthofuran 3,5'-O-cyclodiospyrin, 8'-hydroxydiospyrin, 2'- and 3'-chlorodiospyrin, 3'-chloro-2'-hydroxydiospyrin, the chromenone ester and acid are isolated from the heartwood and the bark of *D. montana* [68]. 4-hydroxy-5,6-dimethoxy-2-naphthaldehyde, 5,6,8-trimethoxy-3-methyl-1-naphthol, 4,8-dihydroxy-5-methoxy-2-naphthaldehyde, 4-hydroxy-5,8-dimethoxy-2-naphthaldehyde, and 4-hydroxy-5-methoxy-2-naphthaldehyde are isolated from the heartwood of *D. kaki* [69]. Isodiospyrin, bisisodiospyrin, 7-methyljuglone, shinanolone, taraxerol, lupeol, betulin, and betulinic acid are isolated from the root of *D. Japonica* [70]. Ehretione is isolated from the heartwood of *D. ehretiodes* [71].

In pharmacology, the anticancer activity of diospyrin, a bisnaphthoquinone, which presents in the heartwood of many species of Diospyros plants, has been investigated including its derivatives/analogues [72]. An antibacterial activity of a n-hexane, ethyl acetate, and ethanol extracts of the ebony bark against *Staphylococcus aureus* and *Escherichia coli* bacteria has also been investigated by Sumitriasih et al. [73]. This n-hexane extract contains only steroid compounds, the ethyl acetate extract contains alkaloids and tannins, while the ethanol extract contains flavonoids, alkaloids, and tannins. The ethyl acetate extract provides the highest inhibition towards the gram-positive bacteria (*S. aureus*), while ethanol extract provides the highest inhibition against the gram-negative bacteria (*E. coli*). Another study reported that the aqueous extract of *D. mespiliformis* bark has potential benefit for a neuropharmacological activity as a natural depressant. It is evidence that the extract can promote pentobarbital-induced sleep [74]. In addition, human health components analysis of the *D. celebica* extract by means of PY-GC-MS, TDS-GC-MS, and GC-MS has been investigated as well as the medicinal functions related to the obtained molecules through reviewing the literature. The study revealed that some of the obtained compounds have medicinal value as antiangiogenic, antioxidant, anti-inflammatory, anti-thrombosis and hypolipidemic. These compounds can protect the pancreatic B cells against the toxicity of alloxan, playing a role in endothelial dysfunction in uremic patients as well as repairing wound and reducing endothelial progression. The compound also has a protective effect on acetaminophen-induced necrosis of renal tissue, and antimicrobial activity against NCIM 2501 and NCIM 5021 [75]. On the other hand, anti-termite activities of the root extract of *D. sylvatica* and its four quinones (plumbagin, isodiospyrin, microphyllone, diospyrin) isolated from the chloroform extract of the root has been inquired, revealing that the toxic property of the extract as well as the tested quinones and showing high mortality of the subterranean termite *Odontotermes obesus* workers after 48 h on forced exposure [76].

2.6 Pine (*Pinus spp.*)

Pine, a trade name of *Pinus spp.*, is a conifer in the family Pinaceae. Pinaceae contains eleven recognized genera and 225 species. Pine is classified into two major lineages, subgenus *Pinus* and subgenus *Strobus* [77]. Pine is mainly distributed in the Northern Hemisphere and widely distributed across many forest types in Europe, Asia, North Africa, North America, and Central America. Pine species are important components of boreal, temperate, sub-tropical and tropical forests. Pine species are highly valuable for the industry due to their fast-growing, easily cultivated, and suitable for industrial plantations, agroforestry, and community forestry. *P. merkusii* is the most widely spreading across the south equator. *Pinus merkusii* is an important plant used on plantation Indonesia. The main purpose of pine plantation forest is to produce oleoresin. The unproductive pine trees and then felled to produce wood. Its wood is used for the wood-working and pulp-paper industries. Its oleoresin, obtained through tree-tapping, contains high quality of rosin and turpentine oil [78]. Martawijaya et al. [4] reported the range of specific gravity of *P. merkusii* wood was 0.40–0.75. *P. merkusii* is chemically composed of cellulose 54.9%, lignin 24.3%. This lignin content is lower compared to the lignin content in softwood in general. pentosan 14.04%, ash 1.1%, and silica 0.2%.

From the genus *Pinus*, there are more than 280 compounds have been isolated, including phenols, terpenoids, lignans, flavonoids, and some other compounds. Li et al. [18] reported there are 35 triterpenoids isolated from *Pinus* plants, 18 seratane-types were mainly obtained from *P. armandii* and *P. monticola*, and 17 lanostane-types obtained from *P. monticola*. Diterpenoids are the main metabolites of Pines. Diterpenoids divided into three types, i.e., pimarane, labdane, and abietane types. Isodextropimaric acid type is an example of diterpenoids in *P. armandii*. Sesquiterpenoids and monoterpenoids are the main compounds found in oleoresins.

Chemical compositions of *Pinus merkusii* turpentine, oils, gum oleoresins, and rosins have been investigated by means of GC-MS. The neutral fraction of gum oleoresins and turpentine oils dominantly

consists of α -pinene (Fig. 8), Δ -3-carene, and β -pinene [78,79], whereas the major constituent of the acidic fraction and rosins are identified as sandaracopimeric acid, isopimeric acid, palustric acid, dehydroabietic acid, abietic acid, neoabietic acid, and merkusic acid [78]. Similar study was also performed by Song [80] identifying the chemical components of several Pines oleoresins by GC-MS method on different pines. They find two sesquiterpenoids (longifolene and caryophyllene) and six common monoterpenoids (α -pinene camphene, β -pinene, α -myrcene, limonene, and α -terpinene). Flavonoids mainly occur in *P. morrisonicola* and *P. armandii*, while biflavones and triflavone are found in *P. Sylvestris*. Type of lignans are also found in Pines such as benzodioxanes, lignanoides, tetrahydrofurans, benzofurans, oligomeric diepoxy lignan, aryl naphthalenes, and dibenzocyclooctene. Related to this study, steroid (e.g., stigmast-4-en-3-one; β -sitosterol) and triterpenoid (e.g., 3 β -methoxyserrat-14-en-21-one; 3- α ,21 β -dimethoxy- Δ 14-serratene; serrate-14-en-3 β ,21 β -diol) are identified as dominant lipophilic compounds in the inner bark of the *P. merkusii* whereas monoterpenes and sesquiterpenes are recorded in minor quantities either in inner or in outer bark [81,82].

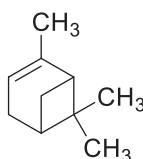


Figure 8: α -pinene of *Pinus merkusii*

Pinus merkusii knots and stemwood have also been investigated for their phenolic and lipophilic extractive constituents as well as their antioxidant properties. The study has disclosed that knotwood extract contain mainly lignans, nortrachelogenin, stilbenes and resin acids, whereas heartwood extracts are constituted mainly of stilbenes, particularly pinosylvin monomethyl ether, pinosylvin and pinosylvin dimethyl ether, and of flavonoid such as pinocembrin. Acetone knotwood extract presents higher antioxidant activity using DPPH method, while acetone heartwood extract possesses higher antifungal activities against the two tested fungi *Trametes versicolor* and *Poria placenta* [83]. Another study reported that the leaf extract of the plant also presents significant antioxidant property using the similar method [84]. The leaf oil of *P. merkusii* mainly contains α -pinene, Δ -3-carene, β -pinene, limonene, camphene, and β -phellandrene [85].

Pines have been used in traditional medicine, especially in China. *P. tabulieformis* and *P. massoniana* in Chinese medicine are used as herbal antirheumatic, analgesic, and anticancer [18]. Antibacterial activity of the essential oil obtained by means of hydro-distillation of *P. merkusii* leaves from Samosir, Indonesia, has been studied, presenting potent activity against *S. aureus* at concentration 0.25% and *Pseudomonas aeruginosa* at concentration 0.1% [86]. Meanwhile, antibacterial activity of the leaves extract of *P. merkusii* against *Enterococcus faecalis* has given minimum inhibitory concentration at 1.56% [87]. Antibacterial and antioxidant activities of the resin and essential oil of *P. merkusii* have also been investigated, disclosing that the resin-derived essential oil and the resin extracts could inhibit *S. aureus*, but not for *E. coli*. All the samples used has less potential antioxidant activity [88]. On the other hand, larvicidal activity of ethanol leaf or bark extract of *Pinus merkusii* on *Aedes aegypti* larvae has also been studied, revealing that this ethanol extract presents highest larvae mortality, promoting this extract can used for new bioinsecticides [89,90]. In addition, *P. merkusii* grown naturally in Indian Himalayas has various pharmacological values as follows: The alkaloids/phenolic such as stilbene, pinocembrin, lignans, miserotoxin, tannin, xanthotoxin have anti-cancerous properties, whereas, the essential oils have been used for antiseptic, diuretic, rubefacient, and vermifuge [91].

2.7 Sungkai (*Peronema canescens*)

Sungkai, a local name of *Peronema canescens*, belongs to the family Verbenaceae. Sungkai is one of the important types of wood in plantation forest. Sungkai has very diverse potential in the furniture industry (furniture), plywood with a beautiful and smooth texture. *P. canescens* is common in secondary forests. In industrial operation, the supply of sungkai has not been able to exceed teak, although both types are from the same family (Verbenaceae). Sungkai is distributed across Malaysia, Sumatra, Thailand, Java and Kalimantan [92]. The specific gravity of *P. canescens* is 0.52–0.73. *P. canescens* contains cellulose 48.6%, pentosan 16.5%, ash 1.6%, and silica 0.4%. The leaves of *P. canescens* contain β -sitosterol, phytol, β -amyrin, and several diterpenoids, namely peronemin compounds. Fig. 9 shows the structure of peronemins, consisting of peronemin B2 (1, 0.04% from the dried leaves), A2 (2, 0.005%), B1 (3, 0.01%), C1 (4, 0.04%), B3 (5, 0.03%), A3 (6, 0.01%), and D1 (7, 0.003%) [12].

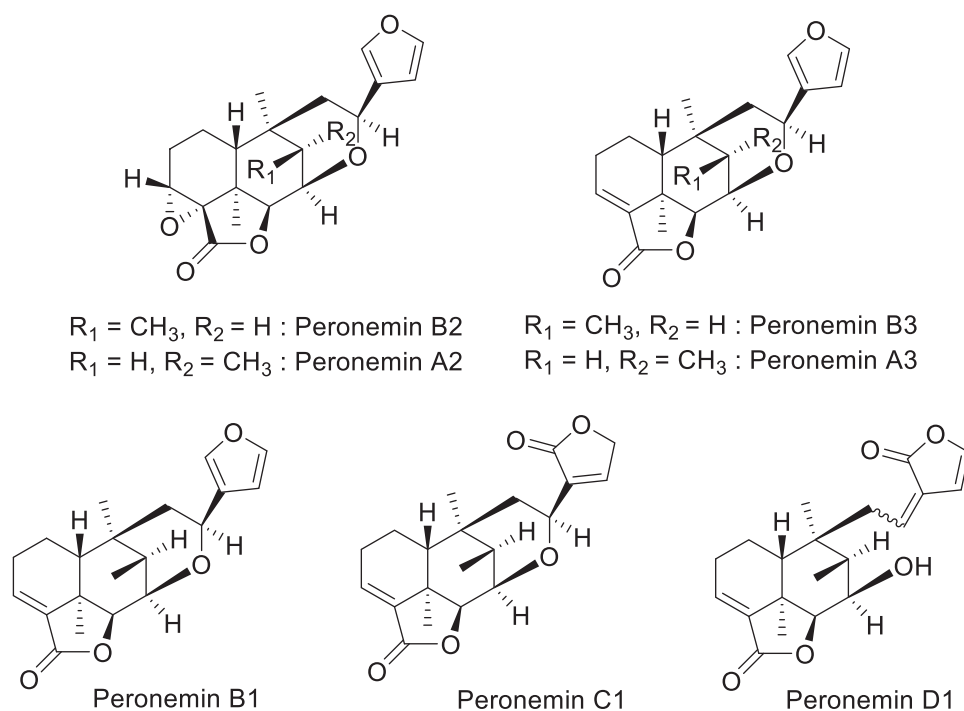


Figure 9: Structure of Peronemins

The plant of the family Verbenaceae contains essential oils, lantaden terpenoid A compounds, lantaden B, lanthanolic acid, lantat acid, and class of lantonin alkaloids [93]. The crude extracts of methanol and ethyl acetate fractions are reported to contain alkaloid, terpenoids-steroids, flavonoids, and tannin compounds [94]. In addition, *P. canescens* bark contains several compounds: Quinic acid, guaiacol, hydroquinone, isovanillic acid, genkwanin, catechol, and benzoic acid that are categorized as phenolic compounds and owning strong antioxidant activity [95]. In traditional medicine, the young leaves of *P. canescens* are used for treatment of colds, fever, and ringworms. It was also used as a water for taking a bath of the woman after delivery and as a gum toothache prevention [96]. Whilst, the decoction of the leaves has been used for treatment of malaria [97].

2.8 Light Red Meranti (*Shorea spp.*)

Shorea is the largest and economically most important genus in the family Dipterocarpaceae. *Shorea* is classified into the white meranti, yellow meranti, red meranti, and balau. Light red meranti, a trade name for

red meranti, is the most commercially available. The light red meranti consists of 70 species of the genus *Shorea*. The main sources of light red meranti species are *Shorea parvifolia* and *Shorea leprosula*. Light red meranti is used mainly for plywood, while the heavier one is used for light construction purposes. It is one of the major export products of Malaysia and Indonesia. The average specific gravity of *Shorea leprosula* was 0.52. The chemical compositions of *Shorea parvifolia* and *Shorea leprosula* consist of cellulose 50.70% and 50.76%, lignin 33.0% and 30.6%, pentosan 12.16% and 12.74%, ash 0.24% and 0.68%, and silica 0.19% and 0.29%, respectively [4].

The active compounds contained in the extracts of family Dipterocarpaceae include phenolic compounds such as oligostilbenoid, flavonoids, phenylpropanoid, and phenolic acid derivatives, as well as non-phenolic compounds, i.e., triterpenoids [98,99]. The heartwood extractives of light red meranti contain resveratrol oligomers (Fig. 10) and a small amount of phenolic acids gallic and ellagic acids (Fig. 11). The chemical structures of resveratrol oligomers are very complex and have many isomers.

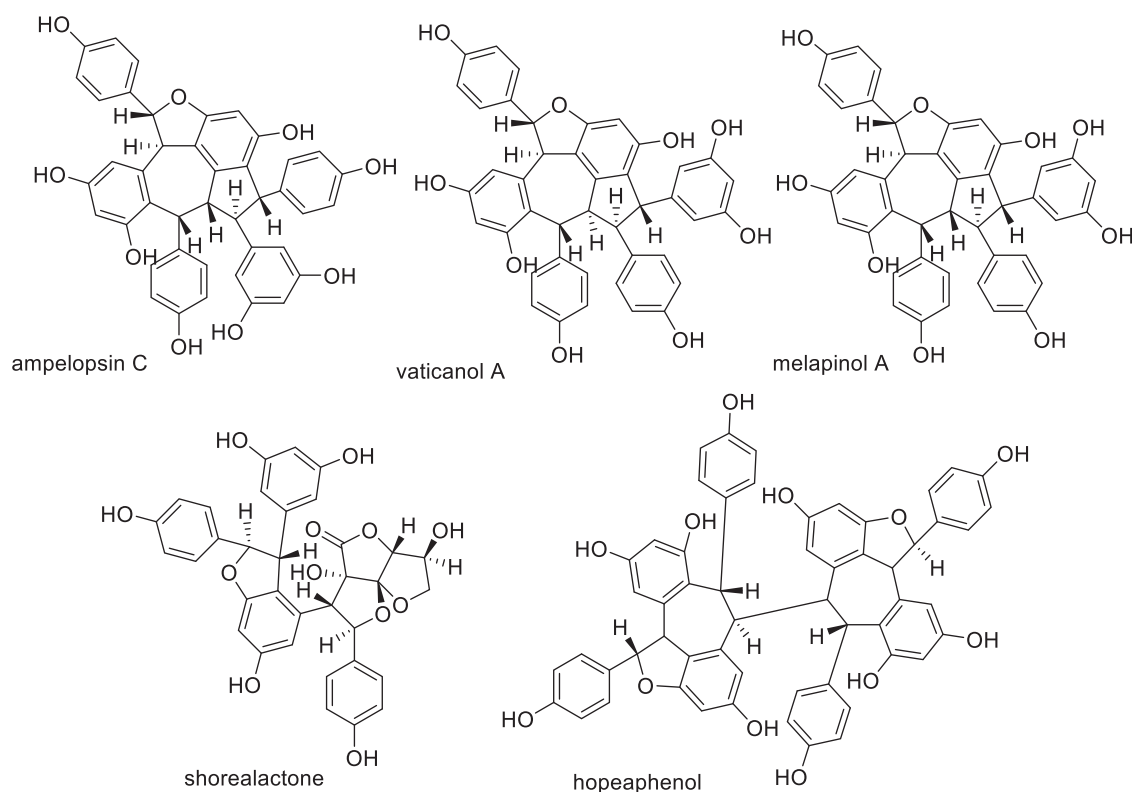


Figure 10: Resveratrol oligomers isolated from the heartwood of meranti. Gallic acid (3,4,5-trihydroxybenzoic acid) is a simple phenolic acid which commonly found in tea leaves, oak bark, and other plants as a constituent of tannins

The wood and resin of Dipterocarpaceae contain stilbenoid compound [100], monomers and oligomers of resveratrol [101–103]. The leaves of *Shorea leprosula* have potent activity as antibacterial agents against pathogenic bacteria. GC-MS analysis has identified the methanol fraction of the leaves extract, composing of 2-benzenedicarboxylic acid (65.77%), eicosanoic acid (9.82%), 2-pentadecenone (6.53%), tricosane (5.86%) and hexanedioic acid (4.13%) [94]. The derivative of oligomeric stilbene compound which is identified as α -viniferin (trimer stilbene) has been isolated from acetone extract of stem bark of *Shorea ovalis* Blume [104]. Acuminatol, a new resveratrol dimer, and other antioxidative resveratrol oligomers (laevifonol,

(+)- α -viniferin, shoreaketone, vaticanol B and (-)-hopeaphenol), have also been identified from the acetone extract of the stem bark of *Shorea acuminata* [105]. In addition, it was also reported that stilbenoid compounds and resveratrol have effective biological activities such as their cytotoxic to cancer cells, anti-fungal, anti-inflammatory, antioxidant, therapy of skin allergies, diarrhea, dysentery, and astringency [16,106].

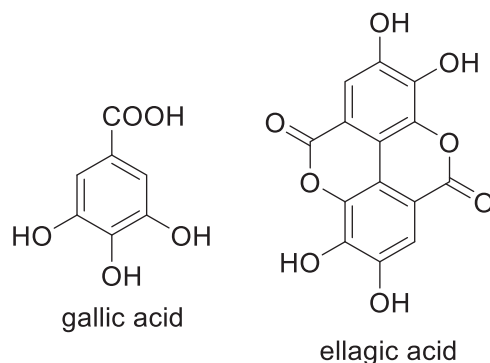


Figure 11: Phenolic acids isolated from the heartwood

2.9 *Bangkirai (Shorea laevis)*

Bangkirai, a local name of *Shorea laevis*, is a hardwood species of the family Dipterocarpaceae. Bangkirai is widely distributed in Burma, Thailand, Sumatra, Peninsular Malaysia, and Borneo. Bangkirai is classified as high-quality wood suitable for construction due to its high mechanical and biological durability properties. The range of specific gravity of bangkirai was 0.60–1.16. The wood is composed of cellulose 52.9%, lignin 24.0%, pentosan 16.8%, ash 1.0%, and silica 0.4% [4]. This family of Dipterocarpaceae contains terpenoids, flavonoids, phenylpropanoids and oligomer resveratrol. Similar to the light red meranti, bangkirai contains oligomer resveratrol compound that can be isolated from the bark or the stem of the plant. The basic structural unit of resveratrol is trans-3,5,4'-trihydroxystilbene (Fig. 12).

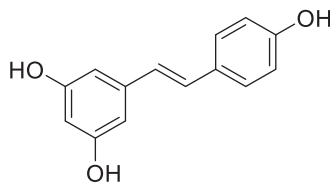


Figure 12: The basic monomer of resveratrol

The resveratrol units are joined together by phenolic oxidative coupling reactions resulting in the formation of oligoresveratrol to form a resveratrol derivative [99]. Resveratrol (trans-3,4',5-trihydroxystilbene), a phytoalexin presents in grapes, has been reported to have cytotoxic activity against cancer cell, possessing chemo preventive and chemo therapeutic activities. Resveratrol has potential use for many chronic diseases such as inflammation. It was also reported that resveratrol has antioxidant activity and can be effective for diet treatment [107].

2.10 *Ulin (Eusideroxylon zwageri Teijsm. & Binnend.)*

Ulin/Belian, also known as Ironwood, belongs to the family Lauraceae. Ironwood forest is a characteristic type of forest in the lowlands of Borneo, Sumatra, and Southern Philippines [108,109]. Due to very slow growth, the Bornean ironwood is known as the hardest and most durable timber in South-East Asia and commonly used in marine work, boatbuilding, heavy construction, etc. [110]. It is also

used for making a blowpipe of dart poison, poles, and beam by local “Dayak” in Borneo [111,112]. Due to high demands on this wood species and depletion of its availability in nature, Indonesia and the state of government of Sarawak has restricted this majestic wood for export trading. In terms of main chemical constituent of this plant extract, Hobbs et al. [113] found a small quantity (0.05%–0.08%) of a crystalline solid, namely eusiderin A ($C_{22}H_{26}O_6$), as a fractionation product of oily material extracted from the shredded timber with boiling light petroleum. Eusiderin, a neolignane compound, is a possible by-product of lignin synthesis in *E. zwageri*. Further study reported that there were found two other lignans isolated with other known compounds, eusiderin A and eusiderin from Ulin wood. These two new lignans were determined to be (2R,3R,4S)-2,3-dimethyl-6,7-dimethoxy-4-ethoxy (3',4',5'-trimethoxybenzene)-1,5-dihydroxytetralin and (2R,3S,4S)-2,3-dimethyl-6,7-dimethoxy-4-ethoxy(3',4',5'-trimethoxybenzene)-1,5-dihydroxytetralin (Fig. 13) [114].

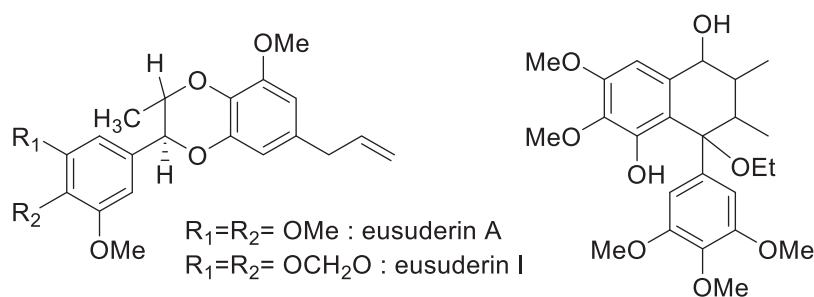


Figure 13: Eusiderin A, Eusiderin I and new lignans

Later on, eusiderin A, which can be found out in leaf, bark and root, has potential activity as an organic insecticide due to its antifungal and antifeedant properties towards some horticultural pests [115]. Study on the modification of allylic moiety of this compound *via* hydroboration-oxidation, Dess Martin, and Osmium tetroxide oxidation have increased its hydrophilicity, enhancing its antifeedant activity, 3–4 times higher than the original compound [115]. Another study reported that eusiderin I (at 3, 4, and 5 ppm concentration in chloroform as solvent) has potent antifungal activity against three plant pathogenic fungi, *Fusarium oxysporum f.sp. lycopersici*, *Sclerotium roefsii*, and *Rhizoctonia solani* [116]. Other antifungal study using dichloromethane and methanol crude extract of *E. zwageri* revealed that both crude extracts are toxic to *Trametes versicolor*, *Gloeophyllum trabeum* and *Chaetomium globosum*. GC-MS analysis showed that hexanedeconic acids, 2-4-di-ter-butylphenol, methyl hexadecanoate, methyl octadecanoate, γ -muurolene, α -cadinol and myristicin are among the expected compounds responsible to this fungal activity [117]. Antifungal activity against white-rot fungi, namely *Pycnoporus coccineus* and *Schizophyllum commune*, is also confirmed using acetone crude extract. 5-octadecene, palmitic acid and 4-tetradecanol, vanillin, 1-nitro-3,5-dimethoxyphenyl-ethylene, 2,4-dimethoxy-5,6-dimethylbenzaldehyde, benzenamine and 5-allyl-1,2,3-trimethoxybenzene are the compounds found after fractionation of this acetone crude extract. Further, cytotoxicity test against brine-shrimp, *Artemia salina*, disclosed that the extractives are toxic, giving a LC_{50} value at 0.8 $\mu\text{g/mL}$ [118].

Due to variation of phytochemical compounds (alkaloid, flavonoid, saponin, tannin, sterol-triterpenoid) contained in *E. zwageri*, this plant has been used as traditional medicine by Kutai people in East Kalimantan [119]. The seed of *E. zwageri* is used as traditional medicine for rheumatism, diabetes, gout, and hair treatment [120]. Further, scientific study disclosed that methanol extract of *E. zwageri* (yield: 33.8%) has potential effects as anti-melanogenesis to reduce hyperpigmentation in the skin [120]. The study showed that this methanol extract can inhibit (100%) melanin formation at 300 $\mu\text{g/mL}$ extract and has DPPH radical-scavenging activity (80%) at 100 $\mu\text{g/mL}$ extract. Further, an ethanolic extract of the stem bark

(yield 8.62%) have given the IC_{50} values of antioxidant activity of the extract in DPPH and superoxide radical scavenging mechanisms of 44.90 $\mu\text{g/mL}$ and 30.47 $\mu\text{g/mL}$, respectively. With the same extract, phytochemical analysis revealed that the extract has the total phenolic, total proanthocyanidin, and total flavonoid contents of about 31.28 GAE/g extract (mg), 183.3 PE/g extract (mg), and 30.48 CE/g extract (mg), respectively. In antidiabetic assay, this extract has IC_{50} value of 58.45 $\mu\text{g/mL}$ in α -glucosidase inhibition, and 9.04 $\mu\text{g/mL}$ in α -amylase inhibition. Quercetin, an antidiabetic activity-having flavonoid, presents IC_{50} values 2.00 $\mu\text{g/mL}$ and 4.04 $\mu\text{g/mL}$ in α -glucosidase and α -amylase inhibitory assays, respectively [121]. Besides these medical uses, *E. zwageri* wood powder extract can also be used as a dyeing agent for fabric [122].

2.11 Kempas (*Koompassia malaccensis* Maingay ex Benth)

Kempas belongs to the family Leguminosae. There are three known species of *Koompassia* wood, *K. malaccensis* (kempas), *K. excelsa* (tualang), and *K. grandiflora*. Kempas is widely distributed in the southern parts of Thailand and Malaysia, and in Sumatra and Borneo. The heartwood of kempas is reddish-brown to light yellowish-brown sapwood, grain interlocked, texture coarse to very coarse, and parenchyma bands visible to the naked eye. Kempas is used for charcoal, fuelwood, rafters, pallets, window frames, furniture, while some preservative-treated ones can be used for railway sleepers, beams, joists, piling, etc. Kempas is chemically composed of 47% cellulose, 29% lignin, 17% pentosan, 0.7% ash and 0.1% silica. The solubility is 3.1% in alcohol-benzene, 1.1% in cold water, 2.4% in hot water and 9.0% in a 1% NaOH solution [123]. Extraction of the stem part with methanol (yield, 1.9%) provides total phenol content $\pm 38\%$ μg gallic acid per mg dry extract, flavonoid $\pm 40\%$ μg quercetin per mg dry extract, and tannin $\pm 77\%$ μg BSA per mg dry extract [124]. On the other hand, kempas has been studied for its termite resistance in-ground and the result has supported for its moderately durable wood species according to in-ground natural durability ratings [125]. However, this species is classified as a high resistance class against white-rot fungus [126]. Kempas wood belongs to durability class III–IV (low class, non-durable). Its resistance to dry-wood termites belongs to class (low class, non-durable), while the resistance to wood-rotting fungi belongs to class II–III (moderate class) [127].

In medicinal application, kempas has been used traditionally for treatment of dysentery [128]. A stilbeno-phenylpropanoid namely Kompasinol A (Fig. 14), together with betulinic acid (a triterpene), 4-hydroxy-2',4'-dimethoxychalcone (a phenylpropanoid), vicoside lactam (an indole alkaloid glycoside), and (+)-catechin 3-O- α -L-rhamnopyranoside (a phenolic glycoside) have been isolated [129]. Kompasinol A (yield, 0.002%), a pale-yellow amorphous solid, is isolated from the ethyl acetate-soluble portion of the bark, partitioned from the methanol extract of the bark. An antimicrobial activity against *Streptococcus sobrinus* and an inhibitory activity against glucosyltransferase (GTase) of 50% ethanol extract of the heartwood are also investigated, providing a natural anticariogenic agent for dental caries [130]. The study reported that taxifolin and three flavanone rhamnoside isomers, neoastilbin, astilbin, and isoastilbin are isolated and identified as its bioactive compounds in this case. Study on anti-acne and tyrosinase inhibition properties of these bioactive compounds is also conducted, reporting that there is no antimicrobial activity against *Propionibacterium acnes* from these four compounds. However, *P. acnes* lipase inhibitory activity is only worked on isoastilbin, with IC_{50} about 1.36 $\mu\text{g/mL}$. At the concentration of 10 $\mu\text{g/mL}$, taxifolin, neoastilbin, astilbin, and isoastilbin show antioxidant activity for about 31.16, 25.64%, 28.47%, and 31.01% respectively. All compounds provide tyrosinase inhibition at concentration 1 mg/mL for about 11%–24% (monophenolase) and 5%–9% (diphenolase) [131].

2.12 Nyatoh (*Palaquium* spp.)

Nyatoh, a trade name for *Palaquium* species, belongs to *Sapotaceae* family. The genus *Palaquium* comprises of about 110 species, distributed from western India and Sri Lanka to southern China and east

to Polynesia (Samoa). Nyatoh is a light to medium-weight timber, moderately hard to hard timber, and rated as moderately durable wood against fungi, but susceptible against termites. The heartwood is pinkish-brown. Nyatoh is generally used for furniture, decorative doors, veneers, panelling, flooring, partition, household appliance, musical instruments, etc. Chemically, *P. microphyllum* contains 52% cellulose, 22% lignin, 17% pentosan, 1.0% ash and 0.05% silica. The solubility is 3.2% in alcohol-benzene, 1.4% in cold water, 5.4% in hot water and 14.8% in a 1% NaOH solution. Gutta-percha, a latex from *Palaquium* trees, is used as material for insulation and its imperviousness to water [123]. In medicinal application, gutta-percha is the best material for root canal filling [132]. The dominant chemical components of gutta-percha (from *P. Oblongifolium*) consists of 2-methyl-1,3 butadiene (24.61%) (Fig. 15), geranyl linalool isomer, solanesol (polyisoprene), limonene (16%), β -elemene, γ -elemene (monoterpenes), farnesene, and nerolidol (sesquiterpene and its derivatives) based on pyrolysis-GC analysis [133]. In addition, previous chemical identification from Mariposa gutta obtained from *Palaquium leiocarpum* has been conducted by Heilbron et al. [134], isolating a compound “lupeol”, a monohydric alcohol, $C_{20}H_{50}O$.

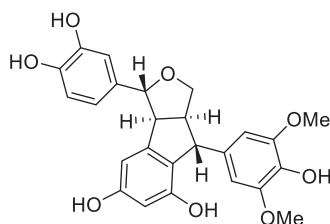


Figure 14: Kompasinol A

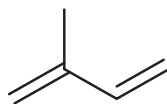


Figure 15: 2-methyl-1,3 butadiene

Extraction of the bark and timber of some identified *Palaquium sp* using benzene and methanol followed with separation using chromatography columns and tin layer chromatography (TLC), and analysed by means of infra-red and NMR, yield various main chemical components, such as β -amyrin (Fig. 16), β -amyrin acetate, β -amrenone, α -spinasterol, ursonic acid, and betulinic acid [135]. On the other hand, analysis of a dichloromethane extract from the leaves of *P. luzoniense*, results indicated the following compounds: lupenone, lupeol acetate, lupeoyl- 3β -O-cinnamate or lupeol cinnamate, oleanone, β -amyrin, β -amyrin cinnamate, ursenone, α -amyrin, spinasterol, squalene, and lutein [136].

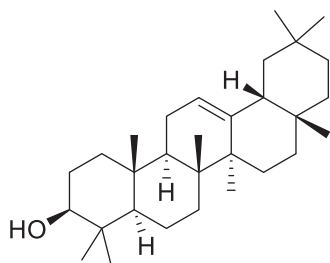


Figure 16: β -amyrin

In addition, the analysis of methanol extracts from the bark (yield: 10.30%), heartwood (yield: 9.24%), and sapwood (yield: 4.73%) of *P. hispidium* revealed that the extracts have antioxidant activity as 50% inhibition concentration (IC₅₀) and total phenol content of 9.64 µg/mL, 27.86 µg/mL, 23.81 µg/mL and 37.09%, 24.48%, 31.73%, respectively. Antifungal activities against *Gloeophyllum trabeum* and *Pycnoporus sanguineus* disclosed that inhibition activities toward both fungi are only effective at the heartwood extract [137]. On the other hand, antifungal activities against *Schizophyllum commune* and *Pleurotus ostreatus* from a methanol extract of the heartwood of *Palaquium sp.* have shown that the chloroform partition (yield: 5.12%) presents higher inhibition activity against those fungi with IC₅₀ of 56 ppm (*S. commune*) and 55 ppm (*P. ostreatus*). Further, a bio-active molecule found from this chloroform partition is identified as 2,3-dihydroxypentadecanoate [138].

2.13 Keruing (*Dipterocarpus Gaertner f.*)

Keruing belongs to the family Dipterocarpaceae. Dipterocarpus comprises of about 70 species, spreading from Sri Lanka, India and Burma, through Indo-China, southern China and Thailand towards western Malesia (found in Peninsular Malaysia, Borneo, Sumbawa, Bali, Java, Sumatra, the Philippines and intervening islands). It is a moderately heavy to heavy hardwood [139]. The heartwood is greyish-brown to red-brown, while the sapwood is yellowish to greyish-brown. *D. gracilis* contains 51% cellulose, 19% lignin, 17% pentosan, 0.9% ash and 0.6% silica. The solubility is 11.7% in a 1% NaOH solution, 3.9% in alcohol-benzene, 3.2% in hot water, and 0.3% in cold water. In addition, the essential oil fraction (yield: 38%–40%) obtained from the water distillation of *D. gradiflorus* results in the chemical compositions, as follows: copaene, α-gurjunene, β-gurjunene, β-elemene, caryophyllene, alloaromadendrene, α-humulene, germacrene D, and γ-gurjunene [140]. Keruing is classified as moderately durable wood, and generally used for construction, furniture, tools, board, household materials, etc. [123].

In medicinal use, *Dipterocarpus alatus* crude extracts (bark, leaves, twig, wood, and oleo-resin) were examined for antibacterial activity and wound healing effect against methicillin-resistant *Staphylococcus aureus* in a superficial skin infection in mice. The study revealed that oleo-resin, *D. alatus* wood extract, as well as α,β-gurjunene and dipterocarpol isolated from the oleo-resin significantly reduce the number of MRSA. Moreover, *D. alatus* dipterocarpol and its twig extract can be used to heal the infected wounds at rates comparable to the non-infected control group [141]. Other medicinal uses of *Dipterocarpus* species have been reviewed such as for treating a rheumatism, liver diseases, diaphoretic and antiseptic, hysteria, dysmenorrhoea, ulcer treatment, antiseptic for gonorrhoea and urinary disease, ringworm and skin diseases, anti-inflammatory. *D. obtusifolius* Teijsm ex Miq is one of the important species for its therapeutic function against AIDS. The bark of *Dipterocarpus* is presumed to be the most active for these medicinal functions. Moreover, it has also been described, to contain sesquiterpenes, triterpenes, oligostilbenoids, coumarin compounds, resveratrol compounds [e.g., diptoindonesin A (Fig. 17)], phytosterol [142]. In addition, the hexane extract of *D. costatus* wood shows cytotoxicity activity against breast cancer (MCF-7) and small cell lung cancer (NC-H187), in conjunction with potent anti-malarial activity against *Plasmodium falciparum* K1 strain). With the same extract, some 30 terpenoids are found which contain 12 triterpenes, such as 2 nordammaranes, 5 norlupanes, 3 dammaranes, and 2 seco-dammaranes. Cytotoxicity of these isolated compounds against four human cancer cell lines (PC3, MDA-MB-231, HT-29 and HCT116) was evaluated. Among these compounds, norlupane, a molecule possessing an endoperoxide group, provides a strong anti-plasmodial activity associated with low cytotoxicity [143]. Inhibition activity against acetylcholinesterase (AChE), a potential target for treating Alzheimer's disease, has also been investigated using a stem wood extract of *D. alatus*. Four new oligostilbenoids, as dipterocarpol, and two known resveratrol oligomers, hopeahainol and hopeafuran, has been separated and identified. Dipterocarpol A and hopeahainol A present moderate AChE inhibitory activity, with IC₅₀ 8.28 µM and 11.28 µM, respectively [144].

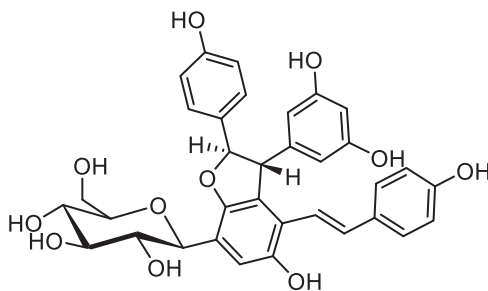


Figure 17: Diptoindonesin A

2.14 Kapur (*Dryobalanops*)

Kapur, a trade name of *Dryobalanops* wood species, belongs to the family Dipterocarpeaceae. *Dryobalanops* comprises of 7 species distributed in Peninsular Malaysia, Sumatra, Borneo, and intervening islands. Kapur is moderately heavy timber. The colour of the sapwood is yellowish-brown, whereas the heartwood is rose-red to dark reddish-brown. Kapur is used for heavy and light construction in the location free of termites, furniture, joints and beam, and extensively used for plywood. The fruits of kapur is edible. *D. sumatrensis* contains 60% cellulose, 27% lignin, 16% pentosan, 0.8% ash and 0.6% silica. The solubility is 2.7% in alcohol-benzene, 2.6% in cold water, 3.9% in hot water and 12.9% in a 1% NaOH solution [123]. Camphor, a crystalline solid yielded from the wood cavities or as an oil from holes cut in the trunk, has been used for medicinal purposes [145].

The chemical components of the hexane or diethylether extracts from the heartwood and sapwood of *D. aromatica* contains some compounds as follows: hydroxydammarones-11 (dipterocarpol), kapurone, β -sitosterol, dryobalanone, terpinylhydrate, w-hydroxyfatty acid ferulate, and unresolved fraction [146]. Malaysianol A, a new trimer resveratrol oligomer from the acetone extract of the stem bark of *D. aromatica* has been isolated, along with five known resveratrol oligomers: laevifonol, ampelopsin, α -viniferin, ϵ -viniferin, diptoindonesin A, and bergenin. Cytotoxic activities of the compounds against several cell lines showed that α -viniferin strongly inhibits the growth of HL-60 cell line (human leukemia) [147]. Further, methanol extract of the stem bark of *Dryobalanops beccarii* provides a new trimeric oligostilbene, malaysianol D and galloylglucoside, malaysin A, together with 12 known compounds. Among these compounds, vaticanols C is found to be moderately active against human lung adenocarcinoma epithelial (A549) cell line while other compounds show weak or not active [148]. On the other hand, a new oligostilbenoid tetramer, malaysianol B is found from the acetone extract of the stem bark of *D. lanceolata*, together with other oligostilbenoids tetramers; hopeaphenol, stenophyllol, nepalensinol B, vaticanol B, vaticanol C, upunaphenol D, and flexuon A. It was suggested that resveratrol in upunaphenol D and flexuon A is the active site of the compounds to have antibacterial activities against Gram-positive strains, *Staphylococcus epidermidis*, *S. aureus* and *S. xylosus* [149]. Further, with different fractionation techniques of the same acetone extract from the bark of *D. lanceolata*, another study found a new tetramer oligostilbenoid possessing tetrahydrofuran ring, malaysianol C, together with four known oligostilbenoids nepalensinol E, ϵ -viniferin (Fig. 18), laevifonol, and ampelopsin. Among these compounds, only ϵ -viniferin and laevifonol show cytotoxic activity against human lung adenocarcinoma epithelial (A549) and breast cancer (MCF7) cell lines [150].

An essential oil obtained by steam distillation method (Yield: 0.12%) from the leaves of *D. lanceolata* showed that the extract inhibits the growth of microorganism *Staphylococcus aureus* and *Candida albican* and has a potency to inhibit the free radical (DPPH) at concentration 25–100 ppm [151]. Further, with the same essential oil, it is also active against *Streptococcus sobrinus* and *Streptococcus mutans*. Through GC-MS analysis, the major compounds identified in this oil are eugenol (28.73%), γ -terpinene (15.60%),

2- β -Pinene (9.80%) and 1-Limonene (8.09%) [152]. Other study used hydro-distillation to obtain the essential oil of the leaves and seed of *D. aromatica*. Eighty-three compounds are identified from the leaf oil with the main compounds composed of oxygenated bicyclic sesquiterpene (globulol 8%), bicyclic monoterpene (α -pinene 7%), and oxygenated monocyclic monoterpenes (α -terpineol 16%, terpinen-4-ol 15%). Whilst, there are 31 components identified in the seed oil with the major compounds consist of acyclic monoterpene (myrcene 5%), monocyclic monoterpene (limonene 6%), bicyclic monoterpenes (α -pinene 41%, α -thujene and β -pinene 13% each, sabinene 6%), and bicyclic sesquiterpene (bicyclogermacrene 6%) [46]. Fractional distillation method to obtain essential oil (yield: 7.58%) from the exudate of *D. aromatica* was also demonstrated, yielding 30 compounds that were identified by GC-MS. About 97.56% of total essential oil compositions are identified as sesquiterpenes, monoterpenes, oxygenated monoterpenes, and oxygenated sesquiterpenes, as well as borneol [153].

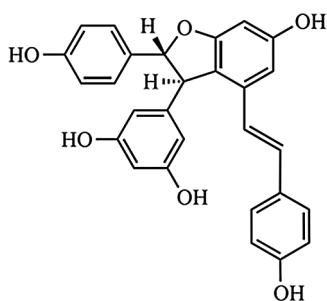


Figure 18: ϵ -viniferin of *D. lanceolate*

2.15 Sengon (*Paraserianthes falcataria*/Albizia falcataria)

Sengon/Jeung jing (Indonesia) is local name of *Paraserianthes falcataria* L. Nielsen belongs to the family Fabaceae. It is native to Indonesia, Papua New Guinea, Solomon Islands and Australia. Due to its fast-growing and can grow on a wide range of soils, its preferable silvicultural characteristic and has acceptable quality of wood for the panel and plywood industries, it is one of the tree species favoured for industrial forest plantations in Indonesia. Sengon is a lightweight and soft to moderately soft. The heartwood colour ranges from whitish to a pale pinkish-brown or a light-yellowish to reddish brown. It is not durable. It is commonly used as material for light constructions, matches, musical instrument, toys, and plywood [154]. Since the specific gravity of this wood is very low, there is no pulp and paper mill in Indonesia using sengon as raw material. The chemical compositions of sengon comprise of cellulose 52.5%, lignin 26.5%, hemicellulose 21.0% [155], while for alcohol-toluene solubility 1.3%–1.7%, 1% NaOH solubility \pm 15%, hot-water solubility \pm 3.7%, cold-water solubility \pm 3.6%, ash content 0.86%–0.96% [156].

Preliminary study towards secondary metabolites/extractive of this species was performed by means of GC-MS and ^1H NMR analysis to methanol extracts of the bark, sapwood, and heartwood of *P. falcataria*. The study identified that glycoside of syringaresinol is presented in the methanol extract of bark and sapwood, while syringaresinol (Fig. 19) is present in the methanol extract of the heartwood [157].

Other study reported that the hexane extract of the bark of *P. falcataria* affords some chemical groups rich with alkaloid, flavonoid, and triterpenoid. The study was then revealed that the purified triterpenoid group compounds are able to lower glucose concentration through *in vivo* test [158]. In addition, the acetone extract (yield: 0.74%) and the toluene/ethanol extract (yield: 1.16%) from the bark of this wood species show antioxidant (DPPH and Oxygen uptake inhibition method) and antifungal (*Coriolor versicolor* and *Poria placenta*) activities [159].

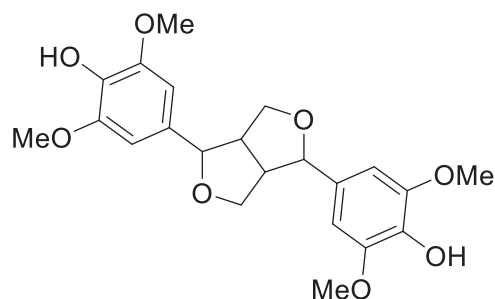


Figure 19: Syringaresinol

2.16 *Agathis* (*Agathis dammara*/*A. loranthifolia*/*A. celebica*/*A. alba*)

Agathis (Indonesia) belongs to the Araucariaceae family. The local name of *A. dammara*/*A. loranthifolia*/*A. alba* is damar, but it is usually called as agathis. It is native to Indonesia and Philippines, distributed in the Philippines (Palawan and Samar), Sulawesi island, and Java island. This species is an important source for its copal resin. There are two kinds of resin produced by agathis, a solid and a liquid resin. The solid resin is the evaporation product of the liquid resin. The solid resin does not have characteristic odour like the liquid resin. The wood is commonly used as material for pulp and paper with a high quality, besides it is used for construction. A very poor termite resistance against *Coptotermes curvignathus* of *A. dammara* obtained from the plantation sites, in West Java Indonesia has been reported [160]. Meanwhile, its resin products can be used as a material in plastic, textile, paint, ink, and matches industries. An adhesive property of the copal resin has been investigated, suggesting its potential to be used as a substitute agent owing biodegradable property for plastic-based coating for aluminium [161]. The copal resin contains agathic acid, agathalic acid, agatholic acid, and sandaracopimaric acid [162]. In addition, water distillation of the resinous exudate of *A. philippinensis*, known as Almaciga resin or Manila copal, yields oil rich in limonene (72%) and other minor compounds greater than 1% included α -pinene, p-cymene, terpinen-4-ol and α -terpineol [163]. Further, the acetone-methanol (9 : 1) extract of the copal from Sukabumi, a district in the West Java Indonesia, yields limonene (44%), ethylene oxide hexamer (11%), cis-limonene oxide (7%), toluene (5,25%), trans-carveol (5%), 2- sikloheksan-1-on (4%), trans-limonene oxide (3%), α pinene (2%), dan 2-pentanone (2%) [164].

On the other hand, the chemical component of the methanol extract from the leaves of *A. alba* contains a yellowish brown solid as a mixture of biflavones compounds, such as 7-O-methylagathisflavone, 7-O-methylcupressulflavone, 4''',7-di-O-methylagathisflavone, 7,7''-di-O-methylcupressulflavone [165]. Previously, it was also reported that the acetone extract of the light petrol extract from the leaves of *A. alba* contains 7-O-methylagathisflavone and 7,4''-di-O-methylagathisflavone [166,167].

In medicinal application, the methanol extract of *A. dammara* plant leaves has antimicrobial activity with the minimum inhibitory concentration (MICs) against *Escherichia coli* (250 μ g/mL), *Bacillus subtilis* (62.5 μ g/mL), *Staphylococcus aureus* (62.5 μ g/mL) and *Proteus vulgaris* (250 μ g/mL) [168]. Meanwhile, the essential oil obtained from the hydro-distilled fresh leaves of *A. dammara* has antibacterial activities with the lowest MIC against *S. aureus* and *B. subtilis* of about 1.25 mg/mL. The major components from 19 compounds identified are limonene (36.81%), β -bisabolene (33.43%), and β -myrcene (25.48%) [54]. A recent study reported that the bioflavonoids obtained from the leaves of *A. dammara* has an inhibitory activity against amyloid β_{40} aggregation in the brain that can cause Alzheimer diseases. These bioflavonoids of amyloid β consist of kayaflavone (Fig. 20); 7,4',7'',4'''-tetra-O-methylamentoflavone; 7-O-methylagathisflavone; 7,7''-di-O-methylagathisflavone; 7,4'''-di-O-methylagathisflavone; 7,7'',4'''-tri-O-methylagathisflavone; 7,7''-di-O-methylcupressulflavone; 7,4',7''-tri-O-methylcupressulflavone; 7,4',7'',4'''-tetra-O-methylcupressulflavone; and hinokiflavone [169].

On the other hand, antiplasmodial activity of the methanolic extract from the leaves of *A. borneensis* (*A. alba*/*A. dammara*) has been investigated, revealing that the obtained IC_{50} is $11.00 \pm 1.41 \mu\text{mL}$ [170].

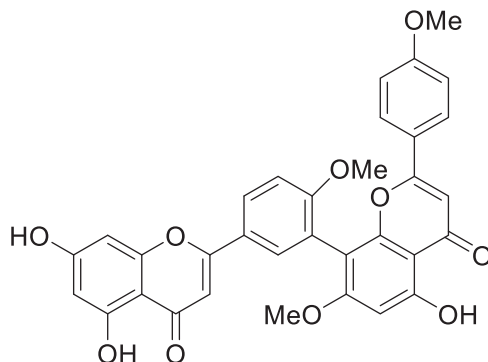


Figure 20: Chemical structure of kayaflavone

2.17 Jelutung (*Dyera costulata* Hook)

Jelutung (Indonesia)/jelutong (Malaysia), a local name of *Dyera costulata* Hook, belongs to the family Apocynaceae. It grows in Borneo, Sumatra, Malaysia, and Peninsular Thailand. It is grown commercially for timber production; besides it yields latex when it is tapped, used as material for chewing-gum. Aged heartwood colour is yellowish-brown, and it is not clearly distinguished from the sapwood. Jelutung wood is a nondurable regarding decay resistance [171], and susceptible against insect attack [172]. The jelutung wood is mostly used for pencil production. Besides its wood and latex products, jelutung plant can be an efficient phytoremediator for copper-contaminating soils [173]. In traditional medicine, leaves and bark have been used for treating pain, inflammation, and fever [174].

Alkaloid content isolated from the leaves of the *Dyera costulata* has been carried in 1982, yielding six alkaloids consisting of 18-dehydroochrolifuanine A (4% of total), ochrolifuanine A (9%) (Fig. 21), 18-dehydroochrolifuanine E(3%), ochrolifuanine E(5%), ochrolifuanine F (1.6%), 18-dehydroochrolifuanine F (2.7%) [175]. Pharmacologically, chloroform and n-butanol extract from the leaves of the plant exhibit EC_{50} values for DPPH radical scavenging activity of 79.8 ± 0.2 and $12.0 \pm 0.1 \mu\text{g/mL}$, respectively. Quercetin-3-O- α -L-rhamnopyranoside is isolated from the n-butanol extract, whereas, β -Amyrin and rhamnazin were isolated from the chloroform extract. Antioxidant activity (DPPH method) of quercetin-3-O- α -L-rhamnopyranoside shows EC_{50} value of $9.37 \pm 0.02 \mu\text{M}$, about 8 times higher than the common antioxidant, BHT (EC_{50} value of $80.78 \pm 0.01 \mu\text{M}$) (Subhadhirsakul et al. 2003). On the other hand, 5-O-caffeoylquinic acid (5-CQA) ($253 \pm 32 \text{ mg CGA/100g}$ samples fresh) is obtained from the methanolic extract of the plant leaves, giving an alternative source of chlorogenic acid [176].

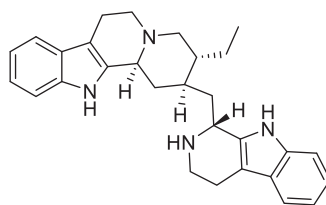


Figure 21: Ochrolifuanine A

In medicinal application, a butanol fraction obtained from the methanolic extract of jelutung latex has been examined for its allergic inhibitory activity in guinea pigs. Dimethylmyoinositol (inhibition rate: 34.2%) is identified as the main compound in the jelutung butanol extract (inhibition rate: 55.0%) having this allergic inhibitory activity [177]. Later on, an *in vitro* test of the methanolic extract from the leaves of the *D. costulata* revealed that the extract has a potent anti-trypanosomal activity with IC₅₀ values of 0.58 ± 0.01 µg/mL, promoting this plant as candidate for treatment of sleeping sickness [178,179]. In addition, leaf extracts of *D. costulata* does not have antiproliferative activity, but its DCM/MeOH and MeOH extracts has positive antiplasmodial activity against K1 (EC₅₀ < 10 µg/mL) and 3D7 (EC₅₀ < 5 µg/mL) strains of *Plasmodium falciparum*. The results also reported that the methanol crude extract of *D. costulata* has higher total phenolic content (319 ± 25 mg gallic acid/g) and radical-scavenging activity (377 ± 25 mg ascorbic acid/g) [180,181]. The effects of the chloroform extract from the leaves of the plant on nociceptive response using writhing, hot plate and formalin tests in mice and the antipyretic activity in yeast-induced fever in rats have also been investigated. Based on the results, the study suggested that plant extract has a marked analgesic but no antipyretic effect [182].

2.18 Jabon (*Anthocephalus cadamba*)

Anthocephalus cadamba, also known as kadam, jabon (Java, Indonesia), belongs to the family Rubiaceae. It is native to the South Asia and Southeast Asia, including Indonesia. Jabon grows naturally in Australia, China, Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore, and Vietnam [183]. In Indonesia, there are two species of jabon, namely kadamba [*Anthocephalus cadamba* (Roxb) Miq] dan samama (*Anthocephalus macrophyllus* (Roxb)). However, only kadamba species that would be explained in detail in this review due to its most frequently planted in Indonesia. Jabon has several advantages including fast-growing, resistant to pests and diseases, and the wood has several uses. Jabon is lightweight hardwood. The heartwood is white and not clearly distinguished from the sapwood. The wood can be used for light construction materials, toys, pencils, beams, ceiling boards, material for the pulp and paper industry [184]. Besides its wood, its barks, fruits, leaves, roots, and seeds are commonly used for various medicinal applications.

The bioactive phytochemicals of *A. cadamba* have been reported and summarized by many review studies [185,186]. These phytochemicals are constituted of indole alkaloids, terpenoids, terpenes, steroids, saponins, sapogenins, fats and reducing sugars, glycoside, and flavonoids. Besides tannins, the stem bark of *A. cadamba* contains a new pentacyclic triterpenic acid, namely cadambagenic acid (18 α -olean-12ene-3 β -hydroxy-27,28-dioic acid). Quinovic acid and β -sitosterol are also isolated in the bark. The leaves contain glycosidic indole alkaloids; 3 α -dihydrocadambine (C₂₇H₃₄N₂O₁₀), cadambine (C₂₇H₃₂N₂O₁₀) (Fig. 22) [187], isodihydrocadambine (C₃₇H₄₄N₂O₁₅), and two related non-glycosidic alkaloids; cadamine (C₂₃H₂₃N₃O₄) and isocadamine.

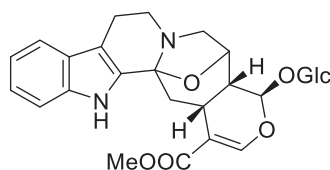


Figure 22: Cadambine

In addition, 3 β -dihydrocadambine and 3 β -isodihydrocadambine with molecular formula (C₃₇H₄₄N₁₅O₂) have been isolated from the leaves of the plant. A new saponin, saponin B (C₄₈H₇₆O₁₇) has also been identified in the stem bark of *A. cadamba* [188]. Chlorogenic acid (CGA) obtained from the leaves of the plant has been tested with *in vitro* and *in vivo* methods for its hepatoprotective activity [189]. In the bark

of the plant, it was disclosed that two novel triterpenoid saponins, namely phelasin A and phelasin B, have been isolated [190]. The bark was also identified, containing two triterpenoid glycosides, glycosides A and B which are defined as 3-O-(α -L-rhamnopyranosyl)-quinovic acid-28-O-(β -D-glucopyranosyl) ester and 3-O-(β -D-glucopyranosyl)-quinovic acid-28-O-(β -D-glucopyranosyl) ester, respectively [191]. Later on, it was also reported that the flower of the plant contains an essential oil that composes mainly of linalool, geraniol, geranyl acetate, linalyl acetate, α -selinene, 2-nonanol, β -phellandrene, α -bergamottin, p-cymol, curcumene, terpinolene, camphene and myrcene [185].

In pharmacology, *A. cadamba* is the well-known plant for its widely used as ethnomedicine in the treatment of anaemia, fever, uterine complaints, blood diseases, skin diseases, leprosy, dysentery, and for improvement of semen quality [192]. Numerous scientific studies about its medicinal potential have been conducted to date, among them, it was reported that the hydroethanolic extract of the flowering tops of *A. cadamba* at concentration of 400 mg/kg body mass demonstrates an effective antidiabetic (hypoglycaemic) property in alloxan-induced diabetic rats and is able to protect liver and brain from the oxidative damages caused by diabetes [193]. This antidiabetic efficacy can also be generated from the methanolic and aqueous extract from the root of the plant, causing significant reduction in the blood glucose level in both normoglycaemic and alloxan induced diabetic rats [194]. The study also reported that this methanol extract contains alkaloids, flavonoid, tannins, saponins, and sugars. Whilst, the aqueous extract also contains these compounds except alkaloids. Another study reported that the defatted ethanolic extract from the leaves of the plant possess the satisfactory significant activity as analgesic and anti-inflammatory agent in wistar rats, in comparison with aspirin and pentazocine as standards [195]. This anti-inflammatory activity can also be generated from the methanolic extract of the plant's bark which its anti-inflammatory activity is possibly backed by its antihistaminic activity [196]. In addition, an anti-diarrhoeal activity study of the hydroethanolic extract from the flowering tops of the plants have revealed that the extract generates not only a dose-dependent decrease in the total number of faecal dropping in castor oil-induced diarrhoea in mice but also a dose-dependent reduction in intestinal fluids accumulation and in the gastrointestinal transit [197]. Equally important, the chlorogenic acid (CGA) obtained from the leaves of the plant has been reported to have hepatoprotective activity tested by *in vitro* and *in vivo* methods using carbon tetrachloride as a model of liver injury [189]. Microbial and antioxidant activities of the *A. cadamba* has also been investigated using the whole part of the plant using successively different solvents, petroleum ether, acetone, chloroform, ethanol, and water. Results have revealed that the alcoholic and aqueous extract of the plant presented significant activity against almost all the organisms tested: *Micrococcus luteus*, *Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Proteus mirabilis*, and four *Candida albicans* fungi known as the systemic fungi (*Aspergillus flavus*, *Aspergillus niger*, and *Aspergillus nidulans*) and the dermatophyte fungi (*Trichophyton rubrum*). Besides having potent wound healing capacity, the extract also has potent antioxidant activity by inhibiting lipid peroxidation and increase in the superoxide dismutase (SOD) and catalase activity [198]. Moreover, the development of antimicrobial drug based on the fruit extract of the *A. cadamba* is also suggested as a potent antimicrobial activity of the extract towards gram-positive (*S. aureus*, *B. cereus*) and gram-negative (*E. coli*, *Salmonella abony*, *Shigella boydii*) bacteria [199]. Similar antimicrobial study plus antioxidant activity of the hot aqueous extract from the leaves of the plant has also been demonstrated by Khandelwal et al. [200]. Another study reported that the ethanolic extract from the flowering tops of the plant possess both analgesic and gastroprotective activity on treated mice [201]. This similar extract is also reported to have remarkable antioxidative function towards several testing methods [202]. Comparatively, similar antioxidant study including analysis of the existed bioactive compounds was also reported by using different extract fractions from the leaves of the plants [203]. Furthermore, an anticancer study was also investigated using bark extract of the plant and revealed that cadambine is the most potent inhibitor of cell line HCT116 (human colorectal) and

3-O-[α -L-rhamnopyranosyl]-quinovic acid 28-O-[β -D-glucopyranosyl] ester showed the maximum inhibitory activity against HepG2 (hepatocellular carcinoma) [204].

2.19 *Acacia (Acacia mangium Willd)*

Acacia mangium, also known as mangium, belongs to the family Fabaceae (the new family name of Leguminosae). It is native to Queensland in Australia, Papua New Guinea (PNG), and the Molucca island in the eastern Indonesia. Its rapid growth, good quality, and tolerance to a wide range of soils and environments might become alternative solution for the rampant deforestation in tropical areas. The heartwood of *A. mangium* is medium-brown coloured, hard, strong, and durable in well-ventilated conditions, but not in a ground-contact area. Its sapwood is narrow and light coloured. Its specific gravity ranges of 0.40–0.45 for timber obtained from the plantation and it is around 0.60 for the ones obtained in natural stands [205]. Chemically, *A. mangium* obtained from the Queensland has the highest cellulose (60.29%) content and the lowest lignin (21.29%) and extractive (3.36%) content than the ones obtained from PNG or eastern Indonesia provenance, supporting its potential as material for pulp and paper industry [206]. Besides pulp and paper, it is also prospective as material for particle board, wood chips, moulding, furniture, and veneer [207].

The heartwood extract of the *A. mangium* is dominated by three flavonoids, 2,3- trans-3,4',7,8-tetrahydroxyflavanone, teracacidin (Fig. 23), and 4',7,8,-trihydroxyflavanon [208]. Further, it was reported that 3,4',7,8-tetrahydroxyflavanone and teracacidin show antifungal activities against *P. noxius* and *P. badius*, which might contribute to the heart rot resistance commonly happened towards the heartwood. In addition, these compounds have strong DPPH radical scavenging activity and laccase inhibition, giving suggestion that the antifungal mechanism occurs through quenching the free radical produced from the extracellular fungal enzyme laccase [209]. On the other hand, the leaves of the plant are reported to contain several flavonol glycosides, consisting of 3-glucoside of quercetin, quercetin-3-diglucoside, kaempferol-3,7-dirhamnoside, kaempferol-7,4'-digalactoside, kaempferol-7-glucoside, and myricetin-3,7-diglucoside [210].

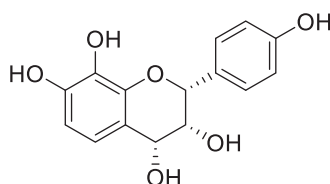


Figure 23: Teracacidin

In pharmacology, the plant is used traditionally for treating high fever [211]. The most recent study reported that the proanthocyanidins obtained from the ethanolic extract of the barks of *A. mangium* has a carbolytic enzymes inhibition activity towards α -amylase and α -glucosidase through *in-vitro* method, giving a potential as antidiabetic agent. In addition, the degree of polymerization of these proanthocyanidins enacts dominant role in this carbolytic enzymes inhibition activity [212]. On the other hand, the saponin compounds obtained from the pods extract of *A. mangium* has been reported can reduce the haemoglobin and haematocrit values of the *Oreochromis niloticus*, a wild fish competitor commonly found in the aquaculture of shrimp [213].

2.20 *Sonokeling (Dalbergia latifolia)*

Sonokeling (*Dalbergia latifolia*) belongs to the family Fabaceae (sub-family: Papilionaceae) and commonly known as East Indian rosewood or black wood. Sonokeling is native to tropical Asia, from Nepal to India and in Java (Indonesia). Sonokeling is an important and highly valuable commercial

timber, nationally and internationally. Due to its strength and durability, it is suitable for all kinds of construction works. The range of its specific gravity is 0.77–0.86. The wood composes of cellulose 53.8%, lignin 27.3%, pentosan 10.1%, ash 1.0%, and silica 0.6% [4]. The extract from the seed of the plant contains dalbinol as a new 12 α -hydroxyrotenoid and sisafolin coumarin [214]. Further, the bark contains dalbergichromene, lupeol, latifolin, and dalbergin (Fig. 24) [215]. The heartwood contains latinone, neoflavonoid dalcridon and latinone, a substituted phenanthrene-1, 4-quinone isolated from *Dalbergia latifolia* [216]. Sonokeling is a fragrant wood, rich in aromatic oils. In traditional medicine, sonokeling has various advantages such as for aphrodisiac, abortifacient, expectorant, anthelmintic, reducing obesity, treating leucoderma, dyspepsia, dysentery, eye and nose diseases, syphilis, stomach troubles, leprosy, antipyretic, appetizer, allays thirst, vomiting, burning sensation, skin diseases, ulcers, the blood disease, scabies, and ringworm [217].

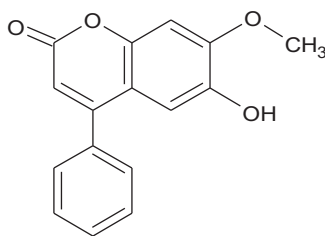


Figure 24: The structure of dalbergin

3 Results and Discussion

The use of bioactive compounds derived from nature to promote human health and treat various diseases has been attracting considerable attention. Based on numerous ethnomedicines that commonly used for centuries, intensive research to uncover some bioactive chemicals responsible for these green medicines has been developed since the middle of the 20th century. According to this literature review, numerous bioactive chemicals have been discovered in the Indonesian commercial wood species investigated in this study. These bioactive chemicals were in most case associated to ethnobotanical and ethnomedicinal knowledges. Summaries of the main compounds found in each wood species studied as well as their chemical families are presented in Tab. 2. Variabilities of these phytochemicals mostly depend on the type of plant species, part/sampling location within the plant, area/location where the plants grow, time/season of sampling, and the mode of extraction used. Among the varying extraction methods, water or organic solvent extraction was commonly practised. The use of different solvents for the extraction resulted in different yields and phytochemical constituents as well as their biological/pharmacological activities. Due to all these parameters used, phytochemicals in Tab. 2 might not represent totally all biomolecules potentially available in the plant, but at least some prominent biomolecules were identified. Among the common solvents used for the extractions (water, ethanol, methanol, chloroform, dichloromethane, acetone), methanol seemed the most effective solvent and was frequently chosen for the extraction in the works described in this review. Although a supporting study also confirmed that methanol was identified as the most effective solvent for obtaining higher extract yields as well as the highest content of phenolic, flavonoids, alkaloids, and terpenoids, which are known as the main chemical families of the phytochemicals [218], different solubilities of bioactive constituents might remain unextractable. Hence, exploration and identification for unknown bioactive compounds in the reviewed plant species are still challenging to date. According to Tab. 2, among the chemical families recorded in this review, phenolic-based compounds (e.g., flavonoids, stilbene, stilbenoid, lignans, phenylpropanoids) were the most abundant phytochemicals in the wood species studied followed with terpenes, terpenoids and alkaloids. Similar results were also reported in a other literature study indicating that phenolic-based

compounds dominated the plant secondary metabolites [219]. Data of the main chemical families with their corresponding wood species studied are presented in Tab. 3. Among the reviewed wood species, it seems that jaborite has almost all phytochemical families, supporting its advantages in the ayurvedic remedies that encouraged numerous intensive research since a couple of decades ago [185]. Even though not all of the reviewed wood species contained all phytochemical families, it is possible that other phytochemicals of interest exist in other parts of the plant not investigated up to now encouraging further research. Intra and inter specific variabilities have also been the subject of relatively few research works necessitating additional studies in case of valorization of given extracts or molecules.

Table 2: Main families and molecules of interest identified from industrial wood species used in Indonesia

Wood	Compartment	Molecules	Family	References
Teak	Heartwood	Lapachol, deoxylapachol, 5-hydroxylapachol, α -dehydrolapachone, β -dehydrolapachone, tectol, dehydrotectol, tectoquinone, 1-hydroxy-2-methylanthraquinone, 2-methylquinizarin, pachybasin and also obtusifolin, betulinic acid, trichione, β -sitosterol, and squalene	Naphthoquinones, naphthoquinone derivates, anthraquinones, phytosterol, terpenoid	[25]
	Root	Lapachol, tectol, dehydrotectol, tectoquinone, β -lapachone, dehydro- α -lapachone, β -sitosterol, tectograndinol, non-structural carbohydrates, 1-hydroxy-2-methyl anthraquinone, pachybasin, obtusifolina, and betulinic acid	Naphthoquinones, phytosterol, terpene, flavonoids, anthraquinone, carbohydrates	[30]
	Bark	Tannin, 5-hydroxy-1,4-naphthalenedione (juglon), obtusifolina, dehydro- α -lapachone	Polyphenol, Naphthoquinones, Anthraquinone	[30]
Merbau	Heartwood	Robinetin, 3,5,4'-tri and 3,5,3',4' tetra-hydroxystilbene, dihydromyricetin, myricetin and naringenin.	Flavonoid, Stilbenoid,	[32]
	Bark	Leucocyanidins, polyphenols, stilbenes, polysaccharides, and water-soluble polymers	Flavonoids, Polyphenols, stilbenes, carbohydrate	[35]
Camphor	Wood	Camphor, 1,8-cineole, nerolidol, campherenol, campherenone, α -terpineol, linalool, eucalyptol, safrole.	Terpenoids	[39]
	Leaf oil	α -terpineol, terpinen-4-ol, globulol, and α -pinene	Terpenoids	[46]
	Seed oil	α -pinene, α -thujene and β -pinene, sabinene, limonene and bicyclogermacrene, and myrcene	Terpenoids	[46]

(Continued)

Table 2 (continued).

Wood	Compartment	Molecules	Family	References
Mahogany	Seed	Linoleic, oleic, stearic, palmitic, 7-deacetoxy-7-oxogedunin, andirobin, bicyclononanolides, swietenine, proceranolide, swietenolide, 6-O-acetylswietenolide, 3,6-O,O-diacetylswietenolide, khayasin T, and swietemahonins E-G that all recently reported from <i>S.mahagoni</i> , 2-hydroxyswietenine, and 6-deoxyswietenine (febrifugin)., five swietenins (B-F), three acylswietenolides, seven swietemahonins (A-G), swietemahonolide, mahonin, and secmahoganin	Limonoids (triterpenoids), Terpenoid, fatty acid	[50,51,52,58]
	Leaf	Swietenine J with nine compounds such as methyl-6- β -hydroxy angolensate, 1-O-acetylkhayanolide A, khayanolide E, khayalactone, khayanone, 1-O-acetylkhayanolide B, 1-O-deacetylkhayanolide E, khayanolide A, khayanolide B.	Limonoids (triterpenoids) / Terpenoids	[13]
	Twig	Swiemahogins A and B that were the first examples of andirobin and phragmalin types of limonoids with a rare -lactone ring fused to the C-ring at C-8 and C-14 instead of the usual D- ring -lactone.	Limonoids (triterpenoids) / Terpenoids	[56]
	Stem Bark	Phragmalin 8,9, 14-orthoacetate with the addition of methyl 2, 30-orthoacetate, swietenialides A, B, C and two ring-D opened phragmalin type 1,8,9-orthoacetates, swietanialides D and E, were isolated together with one known mexicanolide, 2-hydroxyswietenin.	Limonoids (triterpenoids) / Terpenoids	[57]
Ebony	Heartwood	Macassar II, Macassar III (the principal aromatic extractive derived from naphthol), betulin, two β -naphthaldehydes and betulinic acid, diospyrin, isidiospyrin, diemelquinone, o-naphthoquinone, celebaquinone, isocelebaquinone, diosindigo B and its dihydro-derivative, dinaphthofuran 3,5'-O-cyclodiospyrin, 8'-hydroxydiospyrin, 2'- and 3'-chlorodiospyrin, 3'-chloro-2'-hydroxydiospyrin, chromenone ester and acid, 4-hydroxy-5,6- dimethoxy-2-naphthaldehyde, 5,6,8-trimethoxy-3-methyl-1-naphthol, 4,8-dihydroxy-5-methoxy-2-naphthaldehyde, 4-hydroxy-5,8-dimethoxy-2-naphthaldehyde, 4-hydroxy-5-methoxy-2-naphthaldehyde, and ehretione.	Naphthol, Triterpene, Triterpenoid, bisnaphthoquinones, naphthoquinones, cumarins, Naphthaldehyde	[64,65,67,68,69]

Table 2 (continued).				
Wood	Compartment	Molecules	Family	References
	Root	Isodiospyrin, bisidiospyrin, 7-methyljuglone, shinanolone, taraxerol, lupeol, betulin, and betulinic acid.	Naphthoquinones, Triterpenoids	[70]
	Bark	Diosquinone, crassiflorone, plumbagin, cyclocanaliculatin, gerberinol, betulin, lupeol, plumbagin (2-mathyljuglone), elliptinone.	Naphthoquinones, Triterpenoids, Bisnaphthoquinone,	[62,63,66]
Pine	Wood	Triterpenoids (seratane, lanostane), diterpenoids (labdane, opimarane and abietane), sesquiterpenoids (longifolene and caryophyllene), longifolene and caryophyllene, monoterpenoids (pinene camphene, pinene, myrcene, limonene, -teipinene, and Δ -3-carene), flavonoids (biflavones and triflavone), lignans (benzodioxanes, benzofurans, lignanolides, tetrahydrofurans, oligomeric diepoxylignan, aryl naphthalenes, and dibenzocyclooctene), the major constituent of the acidic fraction and rosins (sandaracopimeric acid, isopimeric acid, palustric acid, dehydroabietic acid, abietic acid, neoabietic acid, and merkusic acid).	Terpenoids, Flavonoids, Lignans, phenols, and some other compounds.	[18,78,79,80]
	Bark	Steroids (e.g., stigmast-4-en-3-one, β -sitosterol) and triterpenoids (e.g., 3 β -methoxyserrat-14-en-21-one, 3 α ,21 β -dimethoxy- Δ 14-serratene, serrate-14-en-3 β ,21 β -diol).	Steroids, Triterpenoids	[81,82]
	Knots	Lignans, nortrachelogenin, stilbenes, and resin acids	Lignans, Lactone, Stilbenes, Resin acids	[83]
	Leaf	α -pinene, Δ -3-carene, β -pinene, limonene, camphene, and β -phellandrene	Terpenes	[85]
	Heartwood	Stilbenes (particularly pinosylvin monomethyl ether, pinosylvin and pinosylvin dimethyl ether), flavonoid such as pinocembrin.	Stilbenes, Flavonoids	[83]
Sungkai	Leaf	β -sitosterol, phytol, β -amyrin, and several diterpenoids, named peronemin compounds (peronemins B2, A2, B1, C1, B3, A3 and D1), lantaden terpenoid A compounds, lantaden B, lanthanolic acid, lantat acid, and class of lantonin alkaloids	Phytosterol, Terpenoids, Terpenoids-steroids	[12,93]
	Bark	Quinic acid, guaiacol, hydroquinone, isovanillic acid, genkwanin, catechol, and benzoic acid	Cyclo-alkanoic acid, Phenolic, Flavonoid, Aryl carboxylate	[95]
Light Red Meranti	Heartwood and resin	Monomers and oligomers of resveratrol, gallic acid (3,4,5-trihydroxybenzoic acid), stilbenoid compound.	Oligostilbenoids, flavonoids, Phenyl propanoid and phenolic acid derivatives	[100,101,102,103]

(Continued)

Table 2 (continued).				
Wood	Compartment	Molecules	Family	References
	Leaf	2-benzenedicarboxylic acid, eicosanoic acid, 2-pentadecenone, tricosane and hexanedioic acid	Aryl carboxylate, Alkanoic acid, ketone,	[94]
	Bark	α -viniferin (trimer stilbene), acuminatol, laevifonol, (+)- α -viniferin, shoreaketone, vaticanol B and (-)-hopeaphenol	Stilbene, Resveratrol	[104,105]
Bangkirai	Wood, bark	Terpenoids, flavonoids, phenylpropanoids and oligomer resveratrol (trans-3,5,4'-trihydroxystilbene)	Oligostilbenoid, Terpenoids, Flavonoids, Phenylpropanoids	[99]
Ulin	Heartwood	Eusiderin A, Eusiderin I, (2R,3R,4S)-2,3-dimethyl-6,7-dimethoxy-4-ethoxy(3',4',5'-trimethoxybenzene)-1,5-dihydroxytetralin, (2R,3S,4S)-2,3-dimethyl-6,7-dimethoxy-4-ethoxy(3',4',5'-trimethoxybenzene)-1,5-dihydroxytetralin,...	Neolignans, Lignans	[113,114,115]
	Heartwood	1,2,3-trimethoxy-5-[(1E)-1-propenyl]benzene, 4-methoxy-6-(2-propenyl)-1,3-benzodioxole, α -panasinsen, cadina-3,9-diene, tetratetracontane, eicosane, isoelemicin, methyl elaidate, heneicosane,...	Phenylpropanoid, Terpenes, Fatty acid ester, Alkane	[117]
	Bark	Quercetin	Flavonoid	[121]
Kempas	Stem	Flavonoids, tannins	Flavonoids, Polyphenols	[124]
	Bark	Kompasinol A, betulinic acid, 4-hydroxy-2',4'-dimethoxychalcone, vincoside lactam, (+)-catechin 3-O- α -L-rhamnopyranoside	Stilbeno-phenylpropanoid, Terpenoid, Flavonoid, Indole alkaloid glycoside, Phynolic glycoside	[129]
	Heartwood	Taxifolin, rhamnoside isomers, neoastilbin, astilbin, and isoastilbin	Flavonoids, Favanonol rhamnosides	[130,131]
Nyatoh	Latex	2-methyl-1,3 butadiene, geranyl linalool isomer, solanesol (polyisoprene), d-limonene, β -elemene, γ -elemene, farnesene, d-nerolidol, lupeol	Terpenes, Terpenoids	[133,134]
	Bark, Heartwood	β -amyrin, β -amyrin acetate, β -amrenone, α -spinasterol, ursonic acid, betulinic acid, ...	Triterpenoids, Phytosterol	[135]
	Leaf	Lupenone, lupeol acetate, lupeoyl-3 β -O-cinnamate or lupeol cinnamate, oleanone, β -amyrin, β -amyrin cinnamate, ursenone, α -amyrin, spinasterol, squalene, lutein, ...	Triterpenoids, Phytosterol, Terpenoids	[136]
	Heartwood	2,3-dihydroxypentadecanote	Fatty acid	[138]

Table 2 (continued).				
Wood	Compartment	Molecules	Family	References
Keruing	Essential oil	Copaene, α -gurjunene, β -gurjunene, β -elemene, caryophyllene, allo-aromadendrene, α -humulene, germacrene D, γ -gurjunene	Terpenes	[140]
	Bark, Heartwood	Sesquiterpenes, triterpenes, oligostilbenoids, coumarin compounds, resveratrol compounds (e.g., diptoindonesin A), phytosterol	Terpenes, Stilbenoids, Coumarins, Phytosterol,	[142]
	Leaf	Dammaranes, norlupanes, nordammaranes, <i>seco</i> -dammaranes	Triterpenes	[143]
	Stem, Twigs	Dipterocarpol A, dipterocarpol B, dipterocarpol C, dipterocarpol D, hopeahainol, hopeafuran	Terpenoids, Oligostilbenoids, Resveratrol derivatives	[144]
Kapur	Heartwood, Sapwood	Hydroxydammarones-11 (dipterocarpol), kapurone, β -sitosterol, dryobalanone, terpinylhydrate, w-hydroxyfatty acid ferulate, unresolved fraction	Terpenoids, Phytosterol, Fatty acid	[146]
	Bark	Malaysianol A, laevifonol, ampelopsin, α -viniferin, ϵ -viniferin, diptoindonesin A, bergenin, malaysianol D, trimeric oligostilbenes, galloylglucoside, malaysin A, malaysianol B, vaticanols C, hopeaphenol, stenophyllol, nepalensinol B, vaticanol B, vaticanol C, upunaphenol D, and flexuoson A, malaysianol C, nephalensinol E, laevifonol, and ampelopsin	Resveratrols, Stilbenes, Oligostilbenoids	[147,148,149,150]
	Essential oil (leaf)	Eugenol, γ -terpinene, 2- β -Pinene, 1-Limonene, terpinen-4-ol, α -terpineol, α -pinene, globulol	Terpenes	[46,152]
	Essential oil (seed)	Myrcene, limonene, α -pinene, α -thujene, β -pinene, sabinene, bicyclogermacrene	Terpenes	[46]
	Stem exudate	Sesquiterpenes, monoterpenes, oxygenated monoterpenes, oxygenated sesquiterpenes (e.g., borneol)	Terpenes, Terpenoids	[153]
Sengon	Bark, Sapwood, Heartwood	Glycoside of syringaresinol, syringaresinol, alkaloids, flavonoids, triterpenoid	Lignans, Terpenoid, Flavonoids, Alkaloids	[157,158]
Agathis	Copal resin / Manila copal	agathic acid, agathalic acid, agatholic acid, sandaracopimaric acid, limonene, α -pinene, p-cymene, terpinen-4-ol, α -terpineol, cis-limonene oxide, trans-carveol, trans-limonene oxide, ...	Terpenoids, Terpenes	[162,163,164]

(Continued)

Table 2 (continued).

Wood	Compartment	Molecules	Family	References
	Leaf	7-O-methylgathisflavone, 7-O-methylcupressulflavone, 4''',7-di-O-methylgathisflavone, 7,7''-di-O-methylcupressulflavone, 7-O-methylgathisflavone, 7,4''-di-O-methylgathisflavone, kayaflavone, 7,7'',4'''-tri-O-methylgathisflavone, 7,7''-di-O-methylcupressulflavone, 7,4',7''-tri-O-methylcupressulflavone, 7,4',7'',4'''-tetra-O-methylcupressulflavone, hinokiflavone	Biflavonoids	[165,166,167,169]
	Essential oil (leaf)	Limonene, β -bisabolene, β -myrcene, 7,4',7'',4'''-tetra-O-methylamentoflavone, 7-O-methylgathisflavone, 7,7''-di-O-methylgathisflavone, 7,4''-di-O-methylgathisflavone, ...	Terpenes, Biflavonoids	[54]
Jelutung	Leaf	18-dehydroochrolifuanine A, ochrolifuanine A, 18-dehydroochrolifuanine E, ochrolifuanine E, ochrolifuanine F, 18-dehydroochrolifuanine F, Quercetin-3-O- α -L-rhamnopyranoside, β -amyrin, rhamnazin, 5-O-caffeoylquinic acid	Bisindole-alkaloids, Flavonoid, Terpenoid, Phenylpropanoid	[174,175,176]
	Latex (Stem)	Dimethylmyoinositol	Carbocyclic sugar	[177]
Jabon	Fruit, Leaf, Root, Seed	Indole alkaloids, terpenoids, terpenes, steroids, saponins, sapogenins, fats and reducing sugars, glycoside, flavonoids	Idem	[185,186,194]
	Bark	Cadambagenic acid (18 α -olean-12ene-3 β -hydroxy 27,28-dioic acid), Quinovic acid, β -sitosterol, saponin B (C ₄₈ H ₇₆ O ₁₇), phelasin A, phelasin B, phelasingenin, glycosides A and B, cadambine, 28-O-[[β -D-glucopyranosyl] ester	Triterpenic acid, Saponin	[185,188,190,191,204]
	Leaf	3 α -dihydrocadambine (C ₂₇ H ₃₄ N ₂ O ₁₀), cadambine (C ₂₇ H ₃₂ N ₂ O ₁₀), isodihydrocadambine (C ₃₇ H ₄₄ N ₂ O ₁₅), cadamine (C ₂₃ H ₂₃ N ₃ O ₄), isocadamine, 3 β -dihydrocadambine, 3 β -isodihydrocadambine (C ₃₇ H ₄₄ N ₁₅ O ₂), Chlorogenic acid	Indole alkaloids, Non-glycosidic alkaloids, Polyphenolic ester	[185,187,189]
	Essential oil (Flower)	Linalool, geraniol, geranyl acetate, linalyl acetate, α -selinene, 2-nonanol, β -phellandrene, α -bergamottin, p-cymol, curcumene, terpinolene, camphene, myrcene	Terpenes	[185]

Table 2 (continued).				
Wood	Compartment	Molecules	Family	References
<i>Acacia mangium</i>	Heartwood	2,3- trans-3,4',7,8-tetrahydroxyflavanone, teracacidin, 4',7,8,-trihydroxyflavanon, 3,4',7,8-tetrahydroxyflavanone	Flavonoids	[208,209]
	Leaf	3-glucoside of quercetin, quercetin-3-diglucoside, kaempferol-3,7-dirhamnoside, kaempferol-7,4'-digalactoside, kaempferol-7-glucoside, myricetin-3,7-diglucoside	Flavonol glycosides	[210]
	Bark	Proanthocyanidins	Polyphenol	[212]
	Pods	Saponin compounds	Saponin	[213]
Sonokeling	Seed	Dalbinol (C ₂₃ H ₂₂ O ₈), sisafolin coumarin	Flavonoid, Coumarin	[214]
	Bark	Dalbergichromene, lupeol, latifolin and dalbergin	Neoflavene/neoflavonoid, Terpenoid, Flavonoids	[215]
	Heartwood	Latinone (phenanthrene-1, 4-quinone)	Neoflavonoid	[216]

Table 3: Main chemical families with their corresponding wood species

Chemical family	Wood species
Alkaloid	Sungkai, Sengon, Jelutung, Jabon
Flavonoid	Teak, Merbau, Pine, Light red meranti, Bangkirai, Sonokeling, Ulin, Kempas, Sengon, Agathis, Jabon, <i>Acacia mangium</i>
Lignan	Pine, Ulin, Sengon
Stilbene / Resveratrol / Phenylpropanoid	Merbau, Pine, Light red meranti, Kapur, Bangkirai, Keruing, Jelutung, Kempas, Ulin
Phenolic / Tannin	Teak, Merbau, Sungkai, Kempas, <i>Acacia mangium</i>
Phytosterol	Teak, Pine, Sungkai, Nyatoh, Keruing, Kapur, Jabon
Terpene	Ebony, Pine, Ulin, Nyatoh, Keruing, Kapur, Agathis, Jabon
Terpenoid	Camphor, Mahagony, Ebony, Pine, Sungkai, Bangkirai, Nyatoh, Keruing, Kapur, Sengon, Agathis, Jabon
Saponin	Jabon, <i>Acacia mangium</i>

In terms of biological properties of the reviewed plant extracts or its isolated phytochemicals, [Tab. 4](#) presents data of the biological or pharmacological characteristics of the reviewed wood species. Among the wood species studied, the whole part of jabon possessed advantageous biological/pharmacological activities, confirming its ethnomedicinal functions. Even though there have been many studies conducted to investigate the biological/pharmacological effects of the reviewed wood species, not all of these studies isolated the main bioactive compounds related to their biological/pharmacological activities. Therefore, further specific inquiries for isolation and analysis of the corresponding bioactive compounds remain challenging to investigate. Related to this pharmacognosy, the main biological/pharmacological properties classification of the wood species as well as their phytochemical families is presented in [Tab. 5](#). According to [Tab. 5](#), it seems that the phenolic-based compounds roughly dominated almost all of these main biological/pharmacological properties of the plants; terpene/terpenoid roughly dominated as

anti-diabetes, anti-malaria, antibacterial, anti-fever; and alkaloids acted as an analgesic, anti-diabetes, anti-fever. Although all wood species have their own biological/pharmacological activities, some corresponding specific phytochemical families, as well as their compositions, have not been extensively investigated. In all cases, based on this preliminary study, further studies which concern on analysing the chemical compositions and quantities of the potential bio-sourced molecules would be crucial to be implemented. In addition, very limited studies of their valorisation in the fields of nutraceutical, cosmetic, bio-control, bio-stimulation, and other advanced applications have given attractive challenges towards green technology nowadays and perhaps in the future.

Table 4: Main biological/pharmacological properties of the woody plant extracts or its isolated phytochemicals

Wood	Compartment	Biological or pharmacological properties	References
Teak	Wood	Treatment of gravid uterus, piles, leucoderma, dysentery headache and burning pain over liver region	[30]
	Root	Anurea and urine retention.	[30]
	Bark	Treatment of bronchitis	[30]
Merbau	Bark	Diarrhea, asthma, meanwhile the leave of inner bark is used as remedy for diabetes	[37,38]
Camphor	Leaf	Preservative, bacteriostatic, and insecticidal activities that could restrain the growth of microbes.	[15,17]
Mahogany	Seed	Leshmaniasis and abortion medicine by Amazonian Bolivian ethnic group and for the treatment of hypertension, diabetes, and malaria in Indonesia.	[58,59]
Ebony	Heartwood	Anticancer activity	[72]
	Wood	Antiangiogenic, antioxidant, anti-inflammatory, anti-thrombosis and hypolipidemic, can protect the pancreatic B cells against the toxicity of alloxan, playing a role in endothelial dysfunction in uremic patients as well as repairing wound and reducing endothelial progression, protective effect on acetaminophen-induced necrosis of renal tissue, and antimicrobial activity against NCIM 2501 and NCIM 5021.	[75]
	Bark	The activity is depressant in nature as evident by the ability of the extract to potentiate pentobarbital-induced sleep and antibacterial activity (<i>Staphylococcus aureus</i> and <i>Escherichia coli</i>).	[73,74]
	Root	Anti-termite activities (<i>O. obesus</i>)	[76]

Table 4 (continued).			
Wood	Compartment	Biological or pharmacological properties	References
Pine	Wood	Antirheumatic, analgesic, and anticancer medicine	[18]
	Leaf	Antibacterial (<i>S. aureus</i>), antioxidant, new bioinsecticides, diuretic, rubefacient, and vermifuge.	[86,87,89,90]
	Bark	Insecticide.	[89,90]
Sungkai	Leaf	Cold medicines, fever, ringworms, used as for women a bath after delivery and as a gum toothache prevention, malaria	[96,97]
Light Red Meranti	Stem Bark	Cancer cells, anti-fungal, anti-inflammatory, antioxidant, therapy of skin allergies, diarrhea, dysentery and astringency	[16,106]
Bangkirai	Bark	Chemo preventive and chemo therapeutic activities, anti-inflammation, anti-oxidant and can effective for diet	[107]
Ulin	Heartwood	Insecticide, antifeedant, antifungal, cytotoxic, anti-melanogenesis, antioxidant	[115,116,117,118,120]
	Seed	Rheumatism, anti-diabetes, gout, and hair treatment	[120]
	Bark	Antioxidant, anti-diabetes	[121]
Kempas	Heartwood	Antifungal, insecticide, antimicrobial, anticariogenic for dental caries, antioxidant	[125,126,130,131]
	Bark	Dysentery	[128,129]
Nyatoh	Heartwood	Antioxidant, antifungal	[137,138]
Keruing	Oleo-resin, Heartwood, Twigs	Antibacterial, wound healing against methicillin-resistant <i>Staphylococcus aureus</i> (MRSA)	[141]
	Unknown parts	Ethnomedicinal uses: Treatment for rheumatism, liver diseases, diaphoretic and antiseptic, hysteria, dysmenorrhoea, ulcer treatment, antiseptic for gonorrhoea and urinary disease, ringworm and skin diseases, anti-inflammatory.	[142]
	Leaf	Anti-malaria, anti-cancer	[143]
	Stem, Twigs	Potential for Alzheimer treatment	[144]

(Continued)

Table 4 (continued).			
Wood	Compartment	Biological or pharmacological properties	References
Kapur	Bark	HL-60 cell line inhibitor (anti leukimia), anti-cancer [human lung adenocarcinoma epithelial (A549) cell line], antibacterial (<i>Staphylococcus epidermidis</i> , <i>S. aureus</i> and <i>S. xylosus</i>), anti-cancer [breast cancer (MCF7) cell lines]	[147,148,149,150]
	Essential oil (leaf)	Antimicrobial (<i>S. aureus</i> , <i>C. albican</i> , <i>S. sobrinus</i> , <i>S. mutans</i>)	[152]
Sengon	Bark	Anti-diabetes, antioxidant, antifungal (<i>Corioliolus versicolor</i> and <i>Poria placenta</i>)	[158,159]
Agathis	Leaf & Essential oil (leaf)	Antimicrobial (<i>E. coli</i> , <i>B. subtilis</i> , <i>S. aureus</i> , <i>P. vulgaris</i>), amyloid β_{40} aggregation inhibitor (Alzheimer diseases), antiplasmodial	[54,168,169,170]
Jelutung	Leaf, Bark	Analgesic, inflammation, fever, antioxidant, antitrypanosomal, antiplamodial (<i>P. falciparum</i>)	[174,178,179,180,181,182]
Jabon	Latex (Stem)	Anti-allergic	[177]
	Unknown parts	Ethnomedicinal use: anaemia, fever, uterine complaints, blood diseases, skin diseases, leprosy, dysentery, and for improvement of semen quality	[192]
	Flower, Root	Antidiabetic (hypoglycaemic), anti-diarrhoeal, analgesic, gastroprotective, antioxidant	[193,194,197,202]
	Leaf	Hepatoprotective, analgesic, anti-inflammatory, antioxidant, antimicrobial	[189,195,200,203]
	Bark	Anti-inflammatory, anticancer (human colorectal and hepatocellular carcinoma)	[196,204]
	Whole part of the plant	Antimicrobial, antifungal, antioxidant, wound healing	[198]
	Fruit	Antimicrobial (gram-positive and gram-negative)	[199]
<i>Acacia mangium</i>	Heartwood	Antifungal (<i>P. noxius</i> and <i>P. badius</i>)	[209]
	Unknown parts	Ethnomedicinal use: treating fever	[211]
	Bark	Antidiabetic	[212]
	Pods	Haemoglobin and haematocrit redactor for <i>Oreochromis niloticus</i>	[213]
Sonokeling	Unknown parts	Aphrodisiac, abortifacient, expectorant, anthelmintic, reduces obesity, dyspepsia, dysentery, for diseases of the eye and nose, syphilis, stomach troubles, leprosy, antipyretic, appetizer, allays thirst, vomiting, burning sensation, leucoderma, cures skin diseases, ulcers, diseases of the blood scabies and ringworm	[217]

Table 5: Main biological/pharmacological properties classification of the wood species with their phytochemical families

Properties	Compartment	Phytochemical family
Anti-bacteria	Agathis Leaf, Oil Leaf	Terpene, Biflavonoids
	Ebony Bark, Wood	Naphthol, Triterpene, Triterpenoid, Bisnaphthoquinones, Naphthoquinones, Cumarins, Naphthaldehyde,
	Jabon Leaf, Whole Part, Fruit	Indole Alkaloids, Terpenoids, Terpenes, Steroids, Saponins, Sapogenins, Fats and Reducing Sugars, Glycoside, Flavonoids
	Kapur Bark	Resveratrol, Stilbene, Oligostilbenoid
	Kapur Leaf Oil	Terpenes
	Kempas Heartwood	Flavanoids, Favanonol Rhamnosides
	Keruing Oleoresin, Heartwood, Twigs	Terpenes, Stilbenoid, Phytosterol, Terpenoids, Oligostilbenoids, Resveratrol Derivatives
	Pine Leaf	Terpenes
Antifungal	Acacia Heartwood	Flavonoids
	Jabon Whole Part	Indole Alkaloids, Terpenoids, Terpenes, Steroids, Saponins, Sapogenins, Fats and Reducing Sugars, Glycoside, Flavonoids
	Kempas Heartwood	Flavanoids, Favanonol Rhamnosides
	Light Red Meranti Bark	Stilbene, Resveratrol
	Nyatoh Heartwood	Triterpenoids, Phytosterol
	Sengon Bark	Lignans, Terpenoids, Flavonoids, Alkaloids
Antioxidant	Ulin Heartwood	Neolignan, Lignans, Phenylpropanoid, Terpenes, Fatty Acid Ester, Alkane
	Bangkirai Bark	Oligostilbenoid, Terpenoids, Flavonoids, Phenylpropanoids
	Ebony Wood	Naphthol, Triterpene, Triterpenoid, Bisnaphthoquinones, Naphthoquinones, Cumarins, Naphthaldehyde
	Jabon Flower, Root, Leaf, Whole Part	Indole Alkaloids, Terpenoids, Terpenes, Steroids, Saponins, Sapogenins, Fats and Reducing Sugars, Glycoside, Flavonoids
	Jelutung Leaf, Bark	Bisindole-Alkaloids, Flavonoid, Terpenoid, Phenylpropanoid
	Kempas Heartwood	Flavanoids, Favanonol Rhamnosides
	Light Red Meranti Bark	Stilbene, Resveratrol
	Nyatoh Heartwood	Triterpenoids, Phytosterol
	Pine Leaf	Terpenes
	Sengon Bark	Lignans, Terpenoids, Flavonoids, Alkaloids
	Ulin Bark	Flavonoid
Ulin Heartwood	Neolignan, Lignans, Phenylpropanoid, Terpenes, Fatty Acid Ester, Alkane	

(Continued)

Table 5 (continued).		
Properties	Compartment	Phytochemical family
Anti-Inflammatory	Bangkirai Bark	Oligostilbenoid, Terpenoids, Flavonoids, Phenylpropanoids
	Ebony Wood	Naphthol, Triterpene, Triterpenoid, Bisnaphthoquinones, Naphthoquinones, Cumarins, Naphthaldehyde
	Jabon Leaf, Bark	Triterpenic Acid, Saponin, Indole Alkaloids, Non-Glycosidic Alkaloids, Polyphenolic Ester
	Jelutung	Alkaloid, Flavonoid, Terpenoid, Phenylpropanoid
	Keruing	Terpenes, Stilbenoid, Phytosterol
Insecticide	Light Red Meranti	Oligostilbenoids, Flavonoids, Phenyl Propanoid And Phenolic Acid Derivatives
	Camphor Leaf	Terpenoids
	Ebony Root	Naphthoquinones, Triterpenoids
	Kempas Heartwood	Flavanoids, Favanonol Rhamnosides
	Pine Leaf, Bark	Steroids, Triterpenoids
Anti-diabetes	Uline Heartwood	Neolignan, Lignans, Phenylpropanoid, Terpenes, Fatty Acid Ester, Alkane
	Acacia Bark	Polyphenol
	Jabon Root, Flower	Indole Alkaloids, Terpenoids, Terpenes, Steroids, Saponins, Sapogenins, Fats and Reducing Sugars, Glycoside, Flavonoids
	Mahoni Seed	Limonoids (Triterpenoids), Terpenoid, Fatty Acid
	Merbau Bark	Limonoids (Triterpenoids) / Terpenoids
	Sengon Bark	Lignans, Terpenoids, Flavonoids, Alkaloids
Anti-Dysentery	Ulin Seed Bark	Flavonoid
	Jabon	Triterpenic Acid, Saponin, Indole Alkaloids, Non-Glycosidic Alkaloids, Polyphenolic Ester, Terpenes
	Kempas Bark	Stilbeno-Phenylpropanoid, Terpenoid, Flavonoid, Indole Alkaloid Glycoside, Phynolic Glycoside
	Light Red Meranti Bark	Stilbene, Resveratrol
	Sonokeling	Neoflavene/Neoflavonoid, Terpenoid, Flavonoids
Anti-Fever	Teak Wood	Naphthoquinones, Naphthoquinone Derivates, Anthraquinones, Phytosterol, Terpenoid
	Acacia Mangium	Flavonoids
	Jabon	Triterpenic Acid, Saponin, Indole Alkaloids, Non-Glycosidic Alkaloids, Polyphenolic Ester, Terpenes
	Jelutung Leaf, Bark	Alkaloid, Flavonoid, Terpenoid, Phenylpropanoid,
Anticancer	Sungkai Leaf	Phytosterol, Terpenoids, Terpenoids-Steroids
	Ebony Bark	Naphthoquinones, Triterpenoids, Bisnaphthoquinone,
	Jabon Bark	Triterpenic Acid, Saponin

(Continued)

Table 5 (continued).		
Properties	Compartment	Phytochemical family
	Kapur Bark	Resveratrol, Stilbene, Oligostilbenoid
	Keruing Leaf	Triterpenes
	Light Red Meranti Bark	Stilbene, Resveratrol
	Pine Wood	Terpenoids, Flavonoids, Lignans, Phenols, and Some Other Compounds.
Analgesic	Jabon Flower, Root, Leaf	Indole Alkaloids, Terpenoids, Terpenes, Steroids, Saponins, Sapogenins, Fats and Reducing Sugars, Glycoside, Flavonoids
	Jelutung Leaf, Bark	Alkaloid, Flavonoid, Terpenoid, Phenylpropanoid,
	Pine Wood	Terpenoids, Flavonoids, Lignans, Phenols, And Some Other Compounds.
Antimalaria	Keruing Leaf	Triterpenes
	Mahagony	Limonoids (Triterpenoids) / Terpenoids
	Sungkai Leaf	Phytosterol, Terpenoids, Terpenoids-Steroids
Anti-Alzheimer	Agathis	Terpene, Biflavonoids, Terpenoid
	Keruing Stem, Twigs	Terpenoids, Oligostilbenoids, Resveratrol Derivatives
Anti-Rheumatic	Keruing	Terpenes, Stilbenoid, Phytosterol
	Pine Wood	Terpenoids, Flavonoids, Lignans, Phenols, And Some Other Compounds.
	Ulin Seed	Unknown
Anti-Diarrhea	Jabon Flower, Root	Indole Alkaloids, Terpenoids, Terpenes, Steroids, Saponins, Sapogenins, Fats and Reducing Sugars, Glycoside, Flavonoids
	Light Red Meranti Bark	Stilbene, Resveratrol
	Merbau Bark	Limonoids (Triterpenoids) / Terpenoids
Anti-Allergic	Jelutung Latex	Carbocyclic Sugar
	Light Red Meranti Bark	Phenolic Acid
Anti-Leukemia	Kapur Bark	Resveratrol, Stilbene, Oligostilbenoid
Antipyretic	Sonokeling	Neoflavene/Neoflavonoid, Terpenoid, Flavonoids

4 Conclusion

Based on this literature study, it appears that the Indonesian forest, through its secondary species exploited for timbers production, provides an abundant source of valuable bioactive molecules/ phytochemicals as demonstrated by their application as ethnomedicines. All phytochemical families such as phenolic-based compounds (flavonoids, stilbenes, stilbenoids, lignans, tannins, simple phenols), terpenes, terpenoids as well as alkaloids, quinones, or saponins are potentially available. Although almost

all the reviewed wood species have these phytochemical families in their structures, some characteristic phytochemicals have been identified in each wood species which support their bioactive functions, such as Teak has tectoquinone (quinone), Merbau has robinetin (flavonoid), Camphor has camphor (terpenoids), Mahogany has swietemahonins (triterpenoids), Ebony has Macassar II & III (naphthol) and diospyrin (naphthoquinones), Pine has seratane and pinene (terpenoids), Sungkai has peronemin compounds (diterpenoids), Light red meranti has ampelopsin C, vaticanol A, melapinol A, shorealactone, hopeaphenol (resveratrol oligomers), Bangkirai has trans-3,5,4'-trihydroxystilbene (resveratrol oligomer), Ulin has eusiderin A, eusiderin I (neolignane compounds), Kempas has kompasinol A (stilbenophenylpropanoid), Nyatoh has 2-methyl-1,3 butadiene, limonene, β -elemene (terpenes), Keruing has diptoindonesin A (resveratrol), Kapur has dipterocarpol (terpenoids) and malaysianol (resveratrol), Sengon has syringaresinol (lignan), Agathis has agathic acid (terpenoid), 7-O-methylagathisflavone (biflavones compound), Jelutung has ochrolifuanine A, E, F (bisindole-alkaloids), Jabon has cadambine, isocadamine, isodihydrocadambine (indole alkaloids), phelasin A, phelasin B (triterpenoid saponins), Acacia has 3-trans-3,4',7,8-tetrahydroxyflavanone, teracacidin, and 4',7,8-trihydroxyflavanon (flavonoids), while Sonokeling has dalbinol and dalbergin (flavonoids). In general, most of these extractives contributed remarkably to the technological properties of wood, especially its natural durability. Bactericidal, fungicidal, and insecticidal properties of these extractives can be used in the formulation of biopesticides which will be characteristically more environmentally friendly than synthetic biocides. According to the nature of the wood species, their particular activity properties as antioxidant, antimicrobial, antifungal, anti-inflammatory, anti-diabetes, anti-dysentery, anticancer, analgesic, anti-malaria, and anti-Alzheimer have given special interests in the fields of medicines and pharmacology. After all, as a part of the efforts towards the implementation of the whole-tree utilization, additional studies that concern on the valorisation of these extractives in the fields of nutraceutical, cosmetic, bio-control, bio-stimulation, and other advanced applications would be of interests.

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