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Chemistry and biosynthesis pathways of plant oleoresins: Important drug sources

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Abstract

Oleoresins are potential sources of many drugs. However, still comprehensive review articles on oleoresins are still very rarely found in the literature. Oleoresins are terpenoides thought to be produced in specialized epithelial secretory cells. The long-lived trees like conifers have potent defense mechanisms against insects and fungi by producing oleoresins. Ethnopharmacological studies of oleoresins indicate many activities that are still not fully understood through pharmacological experiments. Also, the activities of the isolated compounds do not explain the strong activities of crude oleoresins. This review summarizes the literature on biochemical activities of oleoresins which includes mechanism of oleoresins formation, biosynthesis pathways, extraction techniques, quantitative analysis, essential oils, biological activities and uses.

Key words: Oleoresins, Biosynthesis Pathways, Biological Activities, Essential Oils, Extraction

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1. Introduction

Oleoresins are terpenoides thought to be produced in specialized epithelial secretory cells that surround the extracellular storage space of resin ducts or resin blisters that are part of the bark or wood of trees stems, roots or needles [1, 2]. Terpenoides are the largest class of plant secondary metabolites, at least 50,000 structural variants [3]. The large number of structurally diverse plant terpenoides are known or assumed to have specialized functions associated with interactions of sessile plants with other organisms in the context of reproduction, repellants, anti-feedants, toxins or antibiotics [4]. Oleoresin consists mainly of monoterpenes (C_{10}) and diterpene resin acids (C_{20}) as well as smaller amounts of sesquiterpenes (C_{15}) compounds which may constitutes both the volatile and nonvolatile components [5]. They may be solid or semi-liquid, although always water insoluble. If percentage of volatile component is high, the substance will be more liquid and may be labeled as oleoresin or wood oil. Volatile terpenoides and related compounds occurring with no non-volatile fractions are termed essential (aromatic or volatile) oils. A variety of oleoresins are extracted from various trees like Aguaribay (*Schinus molle spp.*), Agarwood (*Aquilaria spp.*), Cinnamon (*Cinnamomum spp.*), Dipterocarp (*Dipterocarpaceae spp.*), Pine (*Pinus spp.*) and Copaiba (*Copaifera spp.*) [6].

A number of studies for evaluation of antimicrobial activities of extracts and essential oils of medicinal and aromatic plants have been increased with the search of new compounds along with their biological activities. The interest in use of essential oils and oleoresins as functional ingredients in foods, drinks, toiletries and cosmetic has been increased in recent years because many potentially harmful synthetic additives have been replaced by using them [7]. In food preparation, the usage of one of the constituents of different spices is widely known at present [8]. As well as the plant derived products to repel or kill domestic insect pests have been known worldwide [9]. Oleoresin obtained by extraction with solvents is a mixture of volatile oils. The addition of these oleoresins to the food causes aroma and flavor. A wide range of studies on the biological activities of oleoresins of several plant species such as black pepper [10] aguaribay, aquilaria, pine and copaifera have been mentioned in literature for several years.

An American tree, Aguaribay (*Schinus molle* L.) belonging to the family Anacardiaceous, is widely spread in the centre and south of America [11]. It is also known as Gualeguay or Molle [12]. Due to rustic nature it is resistant to cold and dry weather conditions and grows rapidly. Its fruit is called pink pepper. A very mild flavor and aroma, slightly pungent is the characteristics of its grain. The highly

toxic resin obtained from the trunk of the tree having purging characteristics. Much type of the varnishes could be produced from the Aguaribay resin. Throughout the tropics, indigenous people have been used *Schinus sp.* as medicine [13].

Gaharu or agarwood (aloeswood, eaglewood) from the Thymelaeceae family is resinous, fragrant and highly valuable heartwood of *Aquilaria species*. It is indigenous in India, Bangladesh, China, and Burma and extends through Southeast Asia to the Philippines [14]. The best known species that produce gaharu resin are *Aquilaria malaccensis* and *Aquilaria crassna* [15]. This wood is in high demand for incense and perfume across Asia and the Middle East. It is also used pharmaceutically as an anti-emetic, sedative, and digestive in oriental medical treatments. All agarwood-producing plants are timber species which take considerably long time to grow and the resinous portion is formed inside of the wood. The fragrant compounds of agarwood [16-18] sesqui-terpenoides and phenyl-ethyl chromone derivatives are the principal compounds in the oleoresin of agarwood.

Cinnamon from the family Lauraceae is a valuable spice. It is native to India, Malaysia, Singapore, China, Sri Lanka, Taiwan, Sumatra and Japan. The application of a cinnamon in the pharmaceutical, perfumery and flavoring industry is well known. The oleoresin extracted from the bark of this tree along with essential oil is very useful in the perfumes, soaps, beverages and essences. The essential oil and oleoresin extracted from *cinnamon* bark has antioxidant activities as well [19]. The forests of Southeast Asia are famous for producing main timber families like *Dipterocarpaceae* (also known as diesel tree) that forms a large canopy of the forest [20]. The oleoresins are extracted from the many species of *Dipterocarps* (locally called as Gurjan). The oleoresins of *Dipterocarpus* contain α-gurjunene as the major sesquiterpene [21]. The oleoresins from species like *Dipterocarpus alatus* and *Dipterocarpus grandiflorus* used to produce Gurjan oil. This oil is very useful in the treatment of various ulcer and ailments. The industrial application of the resin includes anti-corrosive coatings and as varnish. The *Hopea* species produces a very hard solid resin called rock dammar is used for making boats and handicrafts [22]. High contents of sesquiterpenoid essential oils [23] found in the oleoresin extracted from *Dipterocarpus* trees are used in the fragrance of cosmetics and soaps as fixative.

Pines belonging to the kingdom plantae are trees in genus *Pinus* in the family Pinaceae. Northern Hemisphere is place where pine originates and now introduced subtropical and temperate zones of the world. Pines have specialized structure of resin ducts and a considerable amount of oleoresin obtained from it [24]. The oleoresin of pine obtained from the pine bark chipping is an important commercial product. The oleoresin consists of monoterpenes and sesquiterpenes also includes acidic and neutral diterpenes [25]. Volatile compounds and diterpenes are obtained from the steam distillation of oleoresin. Pine oleoresin is used in pharmaceutical, disinfectant, fragrance and flavoring industry. It is also used in food gums, coatings, printing inks, adhesives and cleaners [26]. Monoterpenes, sesquiterpenes and resin acids present in oleoresin in different pine species have been used as chemotaxonomic indicators and biochemical markers of provenances [27, 28].

Copaifera belonging to the family Leguminosae. The western parts of Africa, the savannas of central Brazil and many Amazon rain forests of America are among the places where *Copaifera* species found. Many communities around the world including Brazil use a natural product commonly known as Copaiba oleoresin obtained from the *Copaifera* tree which has a commercial importance both as an economic and social benefit [29]. The sesquiterpenes [30, 31] and diterpenes [32, 33] are present in copaiba oleoresin. Many antibacterial and antimicrobial [34-36] anti-inflammatory [37], scarring and anti-rheumatic properties present in the extracts of the oleoresin have been used to treat many ailments including sores, cuts, influenza and tonsillitis [38]. The oleoresin also has properties like analgesic [39, 40], anti-helminthic [41], gastroprotective, healing [42], antitumoral [43] and tripanomicide activities. In addition, the oleoresin also acts as antiseptic and healing product, mainly of the upper air and urinary tracts [41].

2. Mechanism of Oleoresin Formation

The long-lived trees like conifers have potent defense mechanisms against insects and fungi by producing resins [44]. Resin duct system injury leads toward the accumulation of oleoresins at the injury site [45], a physical barrier against boring insects is formed, which can also act as vectors of pathogenic fungi. Various environmental factors control resin flow which is a defense response [46]. An array of factors can affect the potential flow of oleoresin from wounds. The thin walled epithelial cells in the wood parenchyma tissue synthesized the oleoresin. Specialized structures of ducts which appear as a network of radial and longitudinal form at high pressure have oleoresin in it. When there is an injury or cut occur at a site, transport this oleoresin to that place. The stimulation of oleoresin occurs when a pathogen or herbivore attacks the tree and in this response secondary metabolites of various kinds become activated and utilizes the resin ducts. There are several ways in which a tree creates defense mechanism against pathogens and herbivores. The response may be: (i) a constitutive; (ii) a preformed oleoresin response and (iii) an induced oleoresin response that develop simultaneously and complement each other [47]. Several components such as

monoterpenes and phenolic acids present in trees are responsible for the defense mechanism [2, 48-50]. The mycelial growth due to fungi which cause infection is inhibited by monoterpenes [51-54]. Monoterpenes are considered to be toxic to fungi. The coniferous trees contain such components like fatty acids, terpenes, waxes, phenolics and tannins which protect the tree against insect pests and diseases and act as energy reserves. The concentration of the induction of oleoresin may change due to mechanical stress, deficiency of water and several pollutants present in the atmosphere.

3. Biosynthesis Pathways

Biosynthetic pathways responsible for oleoresin constituents are currently unknown however as a model of plants producing oleoresins, conifers have been used to study the mechanisms by which the resin forms, including biosynthesis of terpenoides. The biosynthesis of oleoresin, agnate all other terpenoides, eventuates with the synthesis of isopentenyl diphosphate (IPP) (**1**) *via* the mevalonic acid pathway or the methylerythritol phosphate pathway [55]. The five-carbon building blocks of terpenoides IPP (**1**) and its isomer, dimethylallyl diphosphate (DMAPP) (**2)** are gone through consecutive condensation reactions to produce the larger intermediates geranyl diphosphate (GPP; C_{10}) (**3)**, farnesyl diphosphate (FPP; C_{15}) (**4)**, and geranylgeranyl diphosphate (GGPP; C_{20}) **5**. These terpene diphosphate intermediates are in turn the forerunners of monoterpenes, sesquiterpenes and diterpenes, respectively, as well as many larger products (Scheme 1). The first step of terpenoid biosynthesis of the MEV and MEP pathways occur in the cytosol/endoplasmic reticulum and plastids, respectively. PT and TPS enzymes of the central terpenoid pathway are also commenced in the cytosol and in plastids. In general, mono- and di-terpenoides are preferentially formed in plastids using ushers from the MEP pathway, while sesquiterpenoid are preferentially made in the cytosol using ushers from the MEV pathway. P_{450} enzymes engrossed in the modification of mono-, sesqui and di-terpenoides are associated with the endoplasmic reticulum [56]. In next step enzymes catalyzing the condensations of IPP (**1**) and DMAPP (**2**) to GPP (**3**), FPP (**4**) and GGPP (**5**) are ascribed to conjointly as short-chain isoprenyl diphosphate synthases (IDSs), members of a large enzyme class known as prenyltransferases [5, 57-59]. IDSs have been mostly studied because they direct flux into different branches of terpenoid biosynthesis and so control product distribution. GPP (**3**), FPP (**4**) and GGPP (**5**) are each formed by a specific, short-chain IDS: GPP (**3**) synthase condenses DMAPP (**2**) with one molecule of IPP (**1**); FPP (**4**) synthase condenses DMAPP (**2**) successively with two IPP molecules and GGPP (**5**) synthase condenses DMAPP (**2**) successively with three IPP (**1**) molecules [60-65]. During these repeated condensations, the intermediate prenyl diphosphates are normally bound and not released by the enzymes. The PaIDS1 protein is believed to act like a GGPP (**5**) synthase, but it releases a significant portion of the GPP (**3**) formed as an intermediate. The remainder of the GPP (**3**) is converted directly to GGPP (**5**) without release of FPP (**4**). OPP indicates a diphosphate group.

Both (-)-α-pinene (**6**) and (-)-β-pinene (**7**), in a fixed 2:3 ratio, from geranyl pyrophosphate (**3**) *via* a common cationic intermediate, are produced by principal wound-inducible monoterpene cyclase of resinous' tree stem [66]. The principal (-)-abietic acid (**14**) [67] has been shown to originate by cyclization of corresponding C_{20} isoprenoid precursor, geranylgeranyl pyrophosphate (**5**), to (-)-abieta-7(8),13(14)-diene (**11**), followed by sequential oxidation of the A-ring a-methyl of the olefin to a carboxyl function involving two distinct cytochrome P_{450}-dependent hydroxylases and an aldehyde dehydrogenase (Scheme 2) [68]. Most other common resin acids show double-bond positional isomers of abietic acid and are thought to be originated by changes on same biogenetic theme including formation of different parent olefins followed by similar oxidation sequences. The pre-dedicated step of resin acid biosynthesis is catalyzed by abietadiene synthase. This inducible diterpene cyclase, like the monoterpene cyclases of pine, is an operationally soluble enzyme. Although the enzymatic cyclization sequence from geranylgeranyl pyrophosphate to (-)-abieta-7(8),13(14)-diene (**11**) almost certainly involves the production of copalyl pyrophosphate and a pimaradiene as stable intermediates, no evidence for separation of the corresponding partial activities has been obtained [69].

Agarwood contains a great variety of fragrant sesquiterpenes and a study using cultured cells of Aquilaria showed the production of sesquiterpene (α-guaiene (**25**), α-humulene (**19**), and δ-guaiene (**23**)) to be induced by treatment with methyl jasmonate (MJ) [70, 71]. Guaiane-type sesquiterpenes are thought to be formed via two cyclization reactions, the first constituting a C_1-to-C_{10} cyclization, yielding a macrocyclic germacrene like intermediate, and the second cyclization event occurring between C_2 and C_6 to generate the guaiene product as shown in scheme 3 [72].

4. Methodology of Oleoresin Extraction from the Plant

The injury or cut or any attack on the tree causes the flow of oleoresin which needs to be removed. In order to remove the oleoresin from the exposed surface several methods are available. The timber which contains oleoresin when placed in a boiling solution of salt, oleoresin can be removed. The function of the salt solution that removes oleoresin will be stimulating in nature [77]. The drawback of this method is that it cannot remove all the oleoresin present on the timber. There are some residues (oleoresin) left behind. There is a need to search such chemical

compounds that can act as stimulating agent and are able to remove oleoresin effectively. The oleoresins from Aguaribay *(Schinus molle* L.), *Aquilaria* (*Thymelaeceae*), Chinese cassia (*Cinnamomum cassia Blume*), Dipterocarpaceae, Copaiba trees (*Copaifera sp., Fabaceae*) are obtained by using stimulating agents.

Bark chipping is a method used for production of oleoresin in pines. In this method, bark strips are removed about 5 cm wide along the tree's one third circumference. There are some cups like containers attached to the injured area in order to collect the oleoresin. The production of the oleoresin can be enhanced by the application of a mixture of sulfuric acid along with a plant growth regulator *Ethephon*. When this mixture is applied on the wounded area, the duration of the resin flow also enhance. The resin is continuously removed from the surface so that more oleoresin could be got. Due to limitations of this method, some alternative methods are used. The borehole method of oleoresin tapping is one of them [73]. Volatile components are collected through a closed container. The plastic bags are used to collect the oleoresin. The oleoresin obtained from the trees then subjected to the hydro-distillation (by using Clevenger apparatus) and other techniques like steam distillation and solvent extraction and the extracted oil.

5. Quantitative Analysis

Resinous samples were taken from the trunks of trees from different sites. Each sample consisted of a mixture of equal proportions of freshly flowing resin (obtained immediately after the wounding process) from individual trees submitted to same treatment. Immediately after harvest, all samples are frozen in liquid nitrogen and kept as such until storage in an ultra-freezer (80°C) in completely sealed vials before use. Extractions and analyses are done in triplicate. For quantification of resin, standard curves were generated through using the authentic standard monoterpenes, sesquiterpene (Sigma, USA). Therefore, Gas chromatography (GC) and gas chromatography coupled with mass spectrometry (GC-MS) are preferably used today for monitoring the composition and quality of oleoresins and essential oils. Compound identification was based on comparison of retention indices (determined relatively to the retention times of a series of *n*-alkanes) and mass spectra with those of authentic samples and with literature data [74].

6 Phytochemicals of Oleoresins

Aguaribay (*Schinus molle spp.*) tree has active substances, such as terpenes, tannins, alkaloids, flavonoids, essential oils, and oleoresins [75]. The chemicals found in the Aguaribay oleoresin are long: piperine (**26**), α-pinene (**6**), β-pinene (**7**), amyrin, behenic acid, sabinene (**27**), bergamont, bicyclogermacrene, myrcene (**28**), bourbonene, α-phellandrene (**29**), cadinene, cadinol, calacorene, calamenediol, calamenene, camphene, car-3-ene (**8**), carvacrol, limonene (**31**), β-caryophyllene (**32**), cerotic acid, copaene, croweacin, cubebene, cyanidins, cymene, elemene, elemol, elemonic acid, eudesmol, fisetin, gallic acid, geraniol butyrate, germacrene, germacrone, guaiene, gurjunene, heptacosanoic acid, humulene, laccase, lanosta, linalool, linoleic acid, malvalic acid, masticadienoic acid, masticadienonalic acid, masticadienonic acid, muurolene, muurolol, nerol hexanoate, octacosanoic acid, oleic acid, paeonidin, palmitic acid, pentacosanoic acid, phellandrene, phenol, pinene, piperitol, protocatechuic acid, quercetin, quercitrin, raffinose, sitosterol, spathulene, terpinene, terpineol, terpinolene, and tricosanoic acid (shown in Fig. 1) [76, 77].

The first chemical components of agarwood were investigated in 1935. In *Aquilaria spp.* few analyses of the volatile components of aloes wood has been made. According to reports the principal compounds in the oleoresin of agarwood are sesquiterpenoids, sesquiterpene alcohols, oxygenated compounds and phenylethyl chromone derivatives [16, 18, 78-80]. Analysis made in Switzerland revealed agarofuranoids and sesquiterpenoids of eudesmane, eremophilane, valencane and vetispirane type as the main components [81]. Similar chemical studies were conducted on gaharu from *A. agallocha* and other species of *Aquilaria spp.* in Malaysia. *A. agallocha* has contained Jinkoh-eremol (**33**), (-)-10-epi-γ-eudesmol (**34**), α- and β-agarofuran (**35**), Nor-ketoagarofuran (**36**), Kesunol (**37**), Jinkohol (**38**), Jinkohol II (**39**), α-guaiene (**25**), α-humulene (**19**), δ-guaiene (**23**), Flindersiachromone (**40**), Oxo-agarospirol, Dihydroagarofuran, Agarospirol, Agaroterol AH_1 (**41**) and its derivatives (**42**-**47**) major constitutes as shown in Fig. 2, 3 [82]. The results from the study suggest that gaharu of different origins of Malaysia are distinguished chemically from Switzerland. Agarwood is the most famous fragrance in Japan. The salicylic acid (SA), methyl jasmonate (MJ), and *β*–glucan sesquiterpenoids fragrant compounds were investigated [83-87].

The active compounds of cinnamon oleoresin have been reported, such as water-soluble polyphenol type-A polymers (**48**-**49**) [88, 89], cinnamic acid [90], cinnamaldehyde [91] its several derivatives including 2′-hydroxycinnamaldehyde(**50**), 2′-benzoyloxycinnamaldehyde (**51**) as shown in Fig. 4 [101]. The main constituents of cinnamon oleoresin are eugenol, spathulenol, bicyclogermacrene, β-caryophyllene (**68**) and δ-elemene, (*E*)-cinnamaldehyde, coumarin, δ-cadinene, α-copaene, (*Z*)-cinnamaldehyde, *ortho*-methoxy cinnamaldehyde and β-bisabolene along with several other components obtained from India [19, 92-94] and main constituents obtained from Sri Lankan cinnamon oleoresins are 1,8-Cineole, camphor, linalool, terpinol, cinnamaldehyde, cinnamyl acetate and eugenol [95]. In both studies, major chemical constituent

cinnamaldehyde is found in cinnamon oleoresin and its percentage is high in leaf oil (70-80%) as compared to bark oil (60-65%).

Hopea is one of the main genus of Dipterocarp is known to produce a variety of Resveratrol (**52**) and its oligomers as dimmer (e-viniferin (**53**), trimer (Stemonoporal A (**29**) and tetramer resveratrol (Vaticanol B (**55**)) as depicted in Fig. 5 and Fig. 6. The distribution of the other oleoresin compounds particularly the sesquiterpenes derived from humulene (**56**) and Caryophyllene (**57**), Caryophyllene oxide (**58**), α-Gurjunene (**59**), γ-Gurjunene (**60**), Adoaromadendrene (**61**), Calarene (**62**), crystallisable acid, gurjunic acid ($C_{22}H_{34}O_4$) and dipterocarpol devoid of resinous characters as shown in Fig. 7 [96-99]. The presence of Dipterocarp oleoresin canals and multiseriate wood rays, also characterize in Asian which has dammaranic triterpenes and sesquiterpenes constitutes. The triterpenes derived from the skeleton "epoxyde of squalene" (precursor of sterols) constitute a familial feature for *Dipterocarpaceae sensu* Sricto. *Dipterocarpus hispidus* oleoresin of Sri Lanka contained dipterocarpol, dammarenediol and ocotillone.

Monoterpenes, sesquiterpenes, neutral diterpenes and resin acids are the main components of Pine oleoresin. On average, the composition of the oleoresin is: 28.7% of monoterpenes, 2.5% of sesquiterpenes, 1.5% of neutral diterpenes and 62.8% of resin acids. Total of the detected components counts for 95% of the total mass of oleoresin analysed. The most abundant compounds among monoterpenes are α-pinene (**6**), β-pinene (**7**), α-phellandrene and limonene, (**31**), β-phellandrene (**9**) and among sesquiterpenes, longifolene and β-caryophyllene. Among the neutral diterpenes, abienol, isoabienol, isopimaral, pimaral and 11,13-labdien-8-ol was found in concentrations lower than 2%. The most abundant resin acids are palustric, levopimaric, neoabietic, abietic, isopimaric, pimaric and dehydroabietic [100]. Two compounds with a molecular weight of 302 have been tentatively assigned to methyl esters of noracids [101]. The chemical structures of tricyclene (**63**), camphene (**64**), sabinene (**27**), 3-carene (**65**), myrecene (**28**), limonene borneol, bornyl acetate and enantiomeric pairs of seven chiral monoterpene and sesquiterpene hydrocrbons are also studied in Pine oleoresin (Fig. 8) [102, 103].

The chemical composition of *Copaifera spp.* oleoresin is well known, and more than 40 different constituents have been identified [104]. The oleoresin of copaiba has been characterized mostly by the presence of sesquiterpenes [105, 106] and diterpenes. Sesquiterpenes that have been reported to occur in oleoresin of copaiba are α-curcumene, β-caryophyllene (**66**), caryophyllene oxide (**58**) α-humulene (**19**), γ-cadinene (**67**), α-cadinol (**68**), α- and β-selinene, β-elemene (**69**), α-copaene (**70**), α-selinene (**71**), β-selinene (**72**), β-bisabolene (**73**), *trans*-α-bergamotene (**74**) and α-cubebene (**77)** (Fig. 9 and Fig. 10).[62, 107-114] The most commonly diterpenes found in copaiba oleoresins are copalic acid (**76**), kaurenoic acid (**78**), polyalthic acid (**79**), hardwickiic acid (**80**), together with their derivatives 3-hydroxy-copalic, 3-acetoxy-copalic, and *ent*-agathic acid (**77**) as shown in Fig. 11) [33, 106, 115-117]. Some quantitative and qualitative differences among the volatiles are analyzed. A further identified three sesquiterpenes were identified: seline-3,7(11)-diene, α-calacorene and gleenol from hydro-distillation of *C. langsdorffi* and *C. martii* oleoresins [104, 118, 119]. However, the major constituent α-copaene of samples of *C. paupera* and *C. piresii* oleoresins was collected in Acre and Rondônia [119], and was also the major constituent in the samples of *C. martii* oleoresins collected in Pará, by hydro-distillation [118]. Meanwhile, β-bisabolene was the major constituent in several samples of *C. duckei* and *C. reticulata* collected in Pará [30, 120]. In general the oleoresins from C. *reticulata* harvested at Para showed a lower percentage of β-caryophyllene as compared with the oleoresins from Amapá [31, 121]. The preponderance specimens are studied from Para which showed oils rich with β-bisabolene and trans-α-bergamotene. An important qualitative difference of oleoresins was the absence of selinenes in two samples from Belterra in Para. One natural component caiyophyllene oxide of oleoresins of copaiba was found only in the two samples from Curionópolis in high amount. Humulene epoxide II was absent in all samples from Amapá, and in the some samples from Para. The present study is revealed a great compositional variation in the oleoresins of C. *reticulata* which agrees with a previous study on *Copaifera* where the oleoresin collected at different times was analyzed [121].

7. Essential Oils

An essential oil is a concentrated hydrophobic liquid containing volatile aroma compounds from different trees. The essential oil also known as volatile or ethereal oils or simply as the "oil of" the tree material from which they were extracted. It carries a distinctive scent or essence of the tree. Essential oils are multi-component chemicals; they do not as a group needs to have any specific chemical properties in common, beyond conveying characteristic fragrances. They are not to be confused with essential fatty acids. The mixture of oil compounds that constitute the essential oil comprises polar and non-polar compounds [122-124].

The chemical composition of the essential oil of *Schinus molle. Spp.* consists of mainly monoterpene hydrocarbons (α-pinene (**6**), β-pinene (**7**), sabinene (**27**), terpinen-4-ol), some sesquiterpenes such as (+)-spathulenol, germacrene-D [125] limonene, α-ocimene, γ-cadinene, δ-cadinene, epi-byciclosesquiphelandrene (18.6%) [126, 127].

The study was carried out to find out the differences in composition of oils obtained from healthy, naturally infected and artificially screws wounds eaglewood (*Aquilaria agallocha* Roxb.) using gas chromatography mass spectrometry analysis. Natural healthy plants agar contained octacosane (19.83%), naphthalene, 1,2,3,5,6,7,8,8a-octahydro-1,8a-dimethyl-7-(1-methyl-ethenyl), [1R- (1.alpha.,7.beta.,8a.alpha.)] (12.67%), 5-isobutyramido-2-methyl pyrimidine (13.52%), caryophyllene oxide (11.25%) and (+)-cadinene (5.46%). Natural infected plants agar (super agar) contained cycloheptane, 4-methylene-1-methyl-2-(2-methyl-1-propen-1-yl)-1-vinyl (46.17%), caryophyllene oxide (**58**) (33.00%), 7-isopropenyl-4a-methyl-1-methylenedecahydronaphthalene (20.83%). Artificially screw injected plants agar contained diisooctyl phthalate (71.97%), 1H-cycloprop[e]azulen-4-ol,decahydro-1,1,4,7-tetramethyl-, [1ar- (1a.alpha., 4.beta., 4a.beta., 7.alpha., 7a.beta., 7b.alpha.)] (9.16%), hexadecanoic acid (7.05%), naphthalene,1,2,3,5,6,7,8,8a-octahydro-1,8a-dimethyl-7-(1-methylethenyl),[1R-(1.alpha., 7.beta., 8a.alpha.)] (6.45%) and aristolene (5.36%). This study showed a marked difference in the oil compositions among the treatments with regards to their quality [128]. Maheshwari et al., (1963) isolated three new sesquiterpenic furanoids of the selinane group from agarwood oil, obtained from the fungus infected plant and their structures and absolute configurations determined by degradative studies and physical measurements [156]. Varma et al., (1965) examined that degradative studies and physical measurements supported by an unambiguous synthesis of the derived ketone have led to the assignment of a novel spiro-skeleton to agarospirol, a sesquiterpene alcohol isolated from the essential oil of infected agarwood [157]. Paknikar and Naik (1975) reported that on hydrogenation of α-agarofuran and β-agarofuran the same dihydroagarofuran was obtained [87]. Thomas and Ozainne (1976) reported some naturally occurring dihydroagarofuran and iso-dihydroagarofuran to unequivocally show that the dihydroagarofuran found was indeed dihydro-β-agarofuran and iso-dihydroagarofuran was iso-dihydro-β-agarofuran; two separate compounds [129]. Pant and Rastogi (1980) and Bhandari et al, (1982) isolated a new sesquiterpene, agarol and a couinarinolignan, aquillochin, respectively from the oil of agarwood [130, 131]. Nagashima et al. (1983) further characterized the presence of two more sesquiterpene alcohols, jinkohol II (**39**) and jinkoheremol (**33**), from the Indonesia agar wood oil [132]. Nakanishi et al. (1984) again reported that a benzene extract of an Indonesian sample of 'Jinkoh' agarwood was found to contain α-agarofuran, 10-epi-γ-eudesmol (**34**) and oxoagarospirol [86]. Ishihara et al. (1991) characterized seven new sesquiterpenes based on the guaiane skeleton in a sample of agarwood oil [79]. Five new eudesmane sesquiterpenes and three other compounds further characterized by Ishihara et al. (1993) in a sample of agarwood extract produced in the laboratory from *A. agallocha* of Vietnamese origin [80]. Volatile oils of *Aquilaria malaccensis* (Thymelaeaceae) are obtained from Malaysia by hydro-distillation and analyzed by GC-FID and GC/MS to determine possible similarities and differences in their chemical composition in comparison with commercial oil. The major compounds identified are 4-phenyl-2-butanone (32.1%), jinkoh-eremol (**33**) (6.5%) and α-guaiene (**25**) (5.8%), while the major compounds in the commercial oil were α-guaiene (**25**) (10.3%), caryophellene oxide (**58**) (8.6%), and eudesmol (3.2%), β-agarofuran (**35**), α-bulnesene, jinkoh-eremol (**33**), kusunol (**37**), selina-3,11-dien-9-one, oxo-agarospirol and guaia-1 (**10**), 11-dien-15,2-olide. An analysis from Japan of essential oil obtained from aloes wood identified as originating from *Aquilaria*, using diethyl ether extraction of the highest quality aloes wood, revealed that oxygenated sesquiterpenes and chromone derivatives (**40**-**47**) are the main components of the essential oil [79, 80].

Through GC/MS analysis twenty-two volatile compounds (Ethyl alcohol, 1-Methoxy-2-propanol, 3-Methoxy-1,2-propanediol, 2-Nitro-ethanol, Benzenemeth-anol, Benzeneethanol, Glycerin, Cinnamyl alcohol, 4-Butylbenzyl alcohol, Acetaldehyde, Benzaldehyde, Benzylidenemalonaldehyde, 2-Methoxy-benzaldehyde, *trans*-Cinnamaldehyde, *o*-Methoxy-cinnamaldehyde, Dodecane, Acetic acid, Ethyl formate, Ethyl acetate, Isopropyl acetate, 1,1-Diethoxy-ethane, Coumarin) are detected in the essential oil of *C. cassia*. Other main components included 3-methoxy-1,2-propanediol, *o*-methoxy-cinnamaldehyde, coumarin, glycerin and benzene ethanol were also detected. The area percentages of the rest volatile compounds were lower than 1%. Nine alcohols were also found in essential oil of C. *cassia*, while the numbers of aldehydes, esters, carboxylic acids, alkanes and ketones were 6, 3, 1, 1 and 1, respectively [164].

The essential oil of *Dipterocarpaceae spp*. is obtained by the bark-chipped method and its oil indicated the presence of 7 major components, sesquiterpene, α–gurjunene (**59**), β-caryophyllene (**66**), α-humulene (**19**), adoraromadendrene (**61**), sesquiterpene and β-gurjunene [74]. Borneol compound is obtained through another analysis [133].

Lawrence and Reynolds [134] studied Scots pine essential oil and compared the amounts of main components in pine oil from: Austria, Russia (Caucasus and Siberia), France and Portugal. The more recent papers described essential oils of pine trees from different parts of Europe: Estonia [135], Slovakia [136], Lithuania [137, 138], Greece [173] and France [134]. All these investigation were conducted using GC and GC-MS and analyzed the main chemical constitutes tricyclene (**63**), α-thujene, α-pinene (**64**), camphene, sabinene, β-pinene(**7**), myrcene (**28**), β-phellandrene, 3-car-ene (**65**), α-terpinene, *p*-cymene, β-

phellandrene (**9**), limonene (**31**), 1,8-cineole, (Z)-β-ocimene, (E)-β-ocimene, γ-terpinene, terpinolene, myrtenol, γ-caurveol, *p*-mentha, 1,5-dien-8-ol, borneol, *p*-cymen-8-ol, terpinen-4-ol, β-guaiene, β-farnesene, *m*-cymen-8-ol, decan-2-one, α-terpineol, γ-patchoulene, β-citronellol, thymol emtyl ether, Linalyl actetate, deca-(2E,4E)-dienal, α-terpinen-4-yl acetate, boryl acetate, undecan-2-one, δ-elemene, neryl acetate, α-cubebene, geranyl acetate, α-ylangene, α-copaene, junipene, β-bourbonene, β-cubebene, β-elemene (**69**), longifolene, β-caryophyllene (**66**), β-copaene, aromadencrene, α-humulene (**19**), α-guaiene (**35**), α-cadinene, *cis*-muurola-4 (**14**), 5-diene, allo-aromadendrene, γ-gurjunene (**60**), β-gurjunene, γ-muurolene, δ-muurolene, β-guaiene, germacrene D, β-selinene, calanenene, *epi*-cubebol, bicyclogermacrene, α-muurolene, α-farnesene, β-bisbolene, γ-cadinent, δ-cadiene, cadina-1,4-diene, garmacra-1(10)E,5E-dien-4-ol, nerolidol, *trans*-cadina-1(2),4-diene, α-calacorene, β-calacorene, germacrene B, gobulol, caryophyllene oxide, hex-3(2)-enyl bezoate, spathulenal, germacrene D-4-ol, geenol, β-oplopenone, T-cadinol, T-muurolol, α-muurolol, α-cadinol, α-bisabolol, benzyl benzoate, aoietadiene and manoyl oxide of pine essential oil.

The Copaifera essential oil composed mainly of sesquiterpenes [139, 140]. The main components of copaifera essential oils are: δ-elemene, cyclosativene, α-copaene, β-elemene (**69**), α-gurjunene (**59**), *cis*-α-bergamotene, β-caryophyllene (**6**), *trans*-α-bergamotene, α-guaiene (**25**), aromadendrene, epi-β-santalene, α-humulene (**19**), (E)-β-farnesene, β-chamigrene, γ-gurjunene, 7-curcumene, β-selinene (**72**), α-selinene, (Z)-α-bisabolene, α-bulnesene, β-bisabolene, β-curcumene, β-sesqui phellandrene, (E)-7-bisabolene, caryophyllene oxide (**58**), epi-β-bisabolol and β-bisabolol [119].

8 Biological Activities

8.1 Antibacterial Activity

New compounds with biological activities result enhance in the number of studies on the evolution of antimicrobial activities of extract, oleoresin and essential oils of medicinal and aromatic plants (Aguaribay (*Schinus molle spp.*), Agarwood (*Aquilaria spp.)*, Cinnamon (*Cinnamomum spp.)*, Dipterocarp (*Dipterocarpaceae spp.)*, Pine (*Pinus spp.*) and Copaiba (*Copaifera spp*) [13, 141-147]. *Salmonella enteriditis, Enterococcus faecalis, Staphylococcus aureus, Staphylococcus epidermidis, Streptococcus mutans, Streptococcus salivarius, Streptococcus pyogenes, Listeria monocytogenes, Escherichia coli, E. coli* O_{157}*:* H_7*, Bacillus. cereus, Bacillus subtilis, Bacillus brevis, Bacillus spizizenii, Paenibacillus alginolyticus, P. pabuli, P. azotofixans, P. borealis, P. gluconolyticus, P. validus, P. thiaminolyticus* and *P. larvae* (Gram-positive bacterial strains), *Pseudomonas. aeruginosa, Klebsiella pneumonia, Proteus mirabilis, Shigella flexneri, Enterobacter cloacae, Enterococcus faecalis, Citrobacter freundi, Actinobacillus pleuropneumoniae* and *Haemophilus parasuis* (Gram-negative bacterial strains) are bacterial species used for the different antimicrobial assay [148-162]. The antimicrobial activity displayed by *S. molle.* against *S. pneumoniae* led to the identification of δ-cadinene as the principal active constituent which supports the traditional use of this plant for treatment of infectious diseases [163]. Cinnamaldehyde, carvacrol and eugenol have been reported in cinnamon oleoresin to possess antibacterial activity against a wide range of bacteria [19, 164-166]. The Hopea structures, stemnoporol and alpha-copalliferol are showed bacterial growth inhibitor of Dipterocarp [167-182]. The four labdane-type diterpenes [(-)-copalic acid (**76**), (-)-acetoxycopalic acid, (-)-hydroxycopalic acid, (-)-agathic acid, Hardwickiic acid (**80**) and sesquiterpenes β-caryophyllene (**66**) are active constitutes of copaiba oleoresin which responsible for antimicrobial activity [183-186].

8.2 Antifungal Activity

The antifungal efficacy of the volatile oil and oleoresin of *Schinus molle*., *Cinnamomum cassia*, *Dipterocarps spp*. and *C. multijuga* is determined by the pathogenic fungi (*Alternaria alternate, Microsporum gypseum, Trichophyton mentagrophytes, Trichophyton rubrum, Aspergillus niger, Aspergillus flavus, Aspergillus ochraceus, Aspergillus terreus, A. tamari, Fusarium moniliforme, Fusarium graminearum, Penicillium citrinum* and *Penicillium viridicatum* and *Penicillium italicum, Botrytis cinerea, Microsporum canis* and *M. gypseum*) [187-198]. The role of wounding and fungal infection in the formation of the aromatic base, agar, in the wood of the Agar tree (*Aquilaria spp.*) is studied. Inoculation without wounding using three fungal species (*Aspergillus spp*., *Penicillium spp*. and *Fusarium spp*.) is isolated from agar and strain of *Aspergillus niger* showing marked efficiency as compared to other strains [199-201]. The changes and decrease in the biochemical constituents as sugar, ascorbic acid, phenol and protein contents of *A. malaccensis* were investigated after inoculation with *Chaetomium globosum* and *Fusarium oxysporum* fungi but in healthy trees, the biochemical constituents increased [202]. It was inferred that formation of agar did not depend on the activity of a special fungus, as was previously believed, but is a general reaction of the host to injury or invasion. A diterpene (3α-hydroxy-kaurenoic) of copaiba oleoresin is presented higher fungi-toxic activity against *Botrytis cinerea* [203].

8.3 Anticancer Activity

The *Schinus spp*. *A. malaccensis*, *Cinnamomum cassia*, *Dipterocarps spp*. and copaiba oleoresin are showed interesting anticancer activity and act as anti-tumorous

agents [7, 32, 43, 98, 173, 204-216]. The active anticancer components, 1,3,dibehenyl-2-feruulyl glyceride and 12-O-*n*-deca-2,4,6-trienoylphorbol-13-acetate are isolated from *A. malaccensis*. Gunasekera et al., 2′-Hydroxycinnamaldehyde (HCA) (**50**) and its derivative 2′-benzoyloxycinnamaldehyde (BCA) (**51**) from the stem bark of *Cinnamomum cassia* [203, 206-208, 217], Hopea structures (**52-55**) from *Dipterocarpaceae* [173, 213] and β-Elemene (**69**) from copaiba oleoresin [107, 218-224] have a broad spectrum antitumor agent.

8.4 Anti-Inflammatory Activity

The anti-inflammatory activities of the *Schinus spp, Aquilaria sinensis* (Lour.), *Cinnamomum cassia*, *Dipterocarpaceae* and *Copaiba balsam* oleoresins are observed from an essential oil and a resinous fraction is used as folkloristic remedy in treatment of several inflammatory diseases [37, 159-162, 225-236].

8.5 Insecticidal Activity

The use of chemical insecticides has been a fundamental tool for pest control, but it has had serious consequences such as intoxication of people and animals, contamination of water, air, and soil, residues on food, high persistence in environment, resistance in pests, and impact on beneficial insects, among other effects [301, 302]. This has motivated the search for alternative pest controls without the negative effects of synthetic insecticides. Thus, botanical insecticides have become a more ecological and natural alternative for insect control. There are several reports on insecticidal, repellent and anti-mosquito activity of oleoresin and essential oils of *S. molle*., agarwood, cinnamon, *Dipterocarpus kerrii* and *Copaifera spp* [75, 77, 126, 141, 159-162, 237-244]. These trees are well known to resist biological attack from many sources. The resin of *Dipterocarpus kerrii* contains small quantities of four labile sesquiterpenoids, closely related to α-gurjunene (**59**), which are responsible for anti-insecticide agents.

8.6 Anti-Oxidant Activity

The essential oils and resinous fractions of *Schinus molle.*, *Aquilaria agallocha*, *Dipterocarpaceae* and *Copaiba balsam* have their antioxidant properties [145, 245-247]. They exhibited remarkable antioxidant activity with EC_{50}s less than 10 g ml^{-1}. Although, the chemical constituents of leaf and bark essential oils and oleoresin of cinnamon have been studied [19, 92-94, 248] but the potential antioxidant properties have yet not been studied and it seems that investigation on oleoresins are scarce. It is reported that resveratrol derivatives isolated from the stem bark of Dipterocarp consist of dimer, trimer and tetramer resveratrol (*trans*-3,4',5-trihydroxystilbene (**52-55**)) act as antioxidant [249].

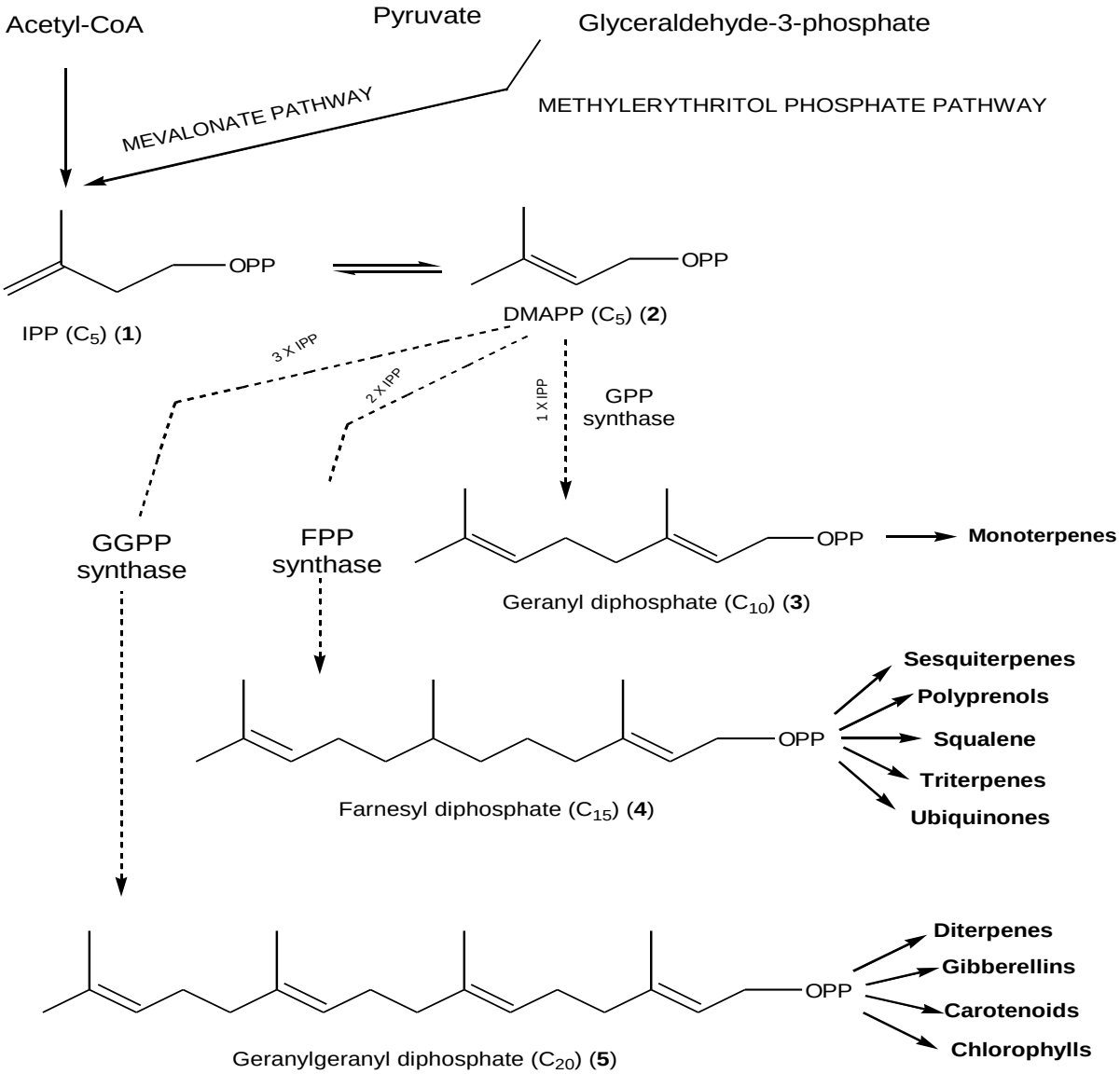
8.7 Miscellaneous Activities

Pharmacological studies carried out with essential oil and its oleoresin from *Schinus molle.* showed that this plant has hypotensive, an analgesic, antispasmodic and antidepressant activities [250-253]. In the investigation with heart wood of *A. agallocha* has showed sedative, anxiolytic property and hypersensitivity [254-256]. The significant antiallergic, anti-ulcerogenic, antipyretic, anaesthetic, anti-diabetic, anti-angiogenic and analgesic activities of *Cinnamomum cassia* essential oil and its oleoresin has been verified by some researchers [88, 211, 257-261]. The Hopea structures of *Dipterocarpaceae* are very interesting and showed interesting biological activity like antihepatotoxic and anti-HIV [210-225]. The existence of analgesic activity from *C. duckei* Dwyer oleoresin is observed by intra-peritoneal administration of acetic acid solution in mice. Carvalho *et al.* and its anxiolytic activity is evaluated in an ethological study in rats treated with *C. reticulate* oleoresin [262, 263]. *C. langsdorffii* oleoresin has great commercial and medical interest due to its antinociceptive [215, 231], antileishmanial, anti-ulcerogenic, antihistaminic, cicatrizing, gastro-protective, analgesic, skin perfusion, trypanocidal activities and other therapeutic properties [36, 39, 151, 227, 228, 264-268].

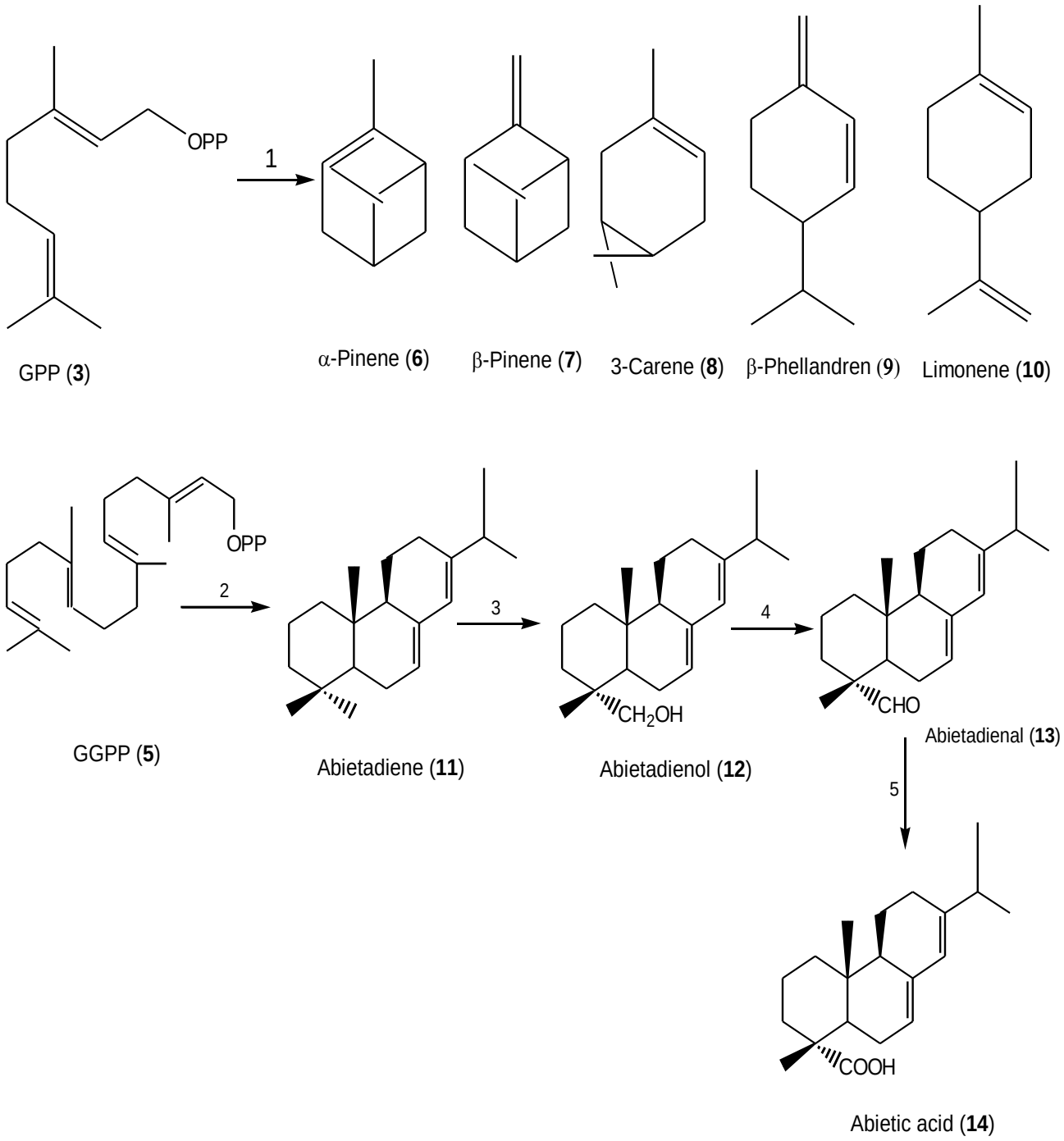
9. Uses

There has been an increasing interest in the use of essential oils and oleoresins of Aguaribay (*Schinus molle spp.*), Agarwood (*Aquilaria spp.)*, Cinnamon (*Cinnamomum spp.*), Dipterocarp (*Dipterocarpaceae spp.)*, Pine (*Pinus spp.*) and Copaiba (*Copaifera spp*) as functional ingredients in the pharmaceutical industry, perfume industry, food, drink additives and other chemical industries (household cleaning products, paintings, varnishes, rubber, insecticides, etc.) in recent years because they replace potentially harmful synthetic additives [23, 164, 226, 269-277]. A new active packaging, consisting of a label with cinnamon essential oil incorporated and attached to plastic packaging, is used to extend shelf-life of late-maturing peach fruit [278]. Gurjan oil is a good solvent for caoutchouc (unvulcanised rubber) which is applied to cloth to make it water-proof. This cloth resists insect-attacks. In Burma and Bangladesh Gurjan oil was mainly used for torches but its trade was limited due to the cheap price of kerosene. However, Gurjan oil from Singapore and Malaya was a common article of trade in Thailand. The oil produced in South India and Andaman Islands was traded in Europe for use in artworks. The principle of "family economic necessity" exempt extraction of NTFPs from any regulation when it is motivated by economic need for subsistence [278]. In 1996 it amounted to 64.5 million US$ or 38% of total exports. The exports value of non-timber forest products (NTFPs) the same year was 4.3 million US$ [273]. In Laos the forest and the timber is

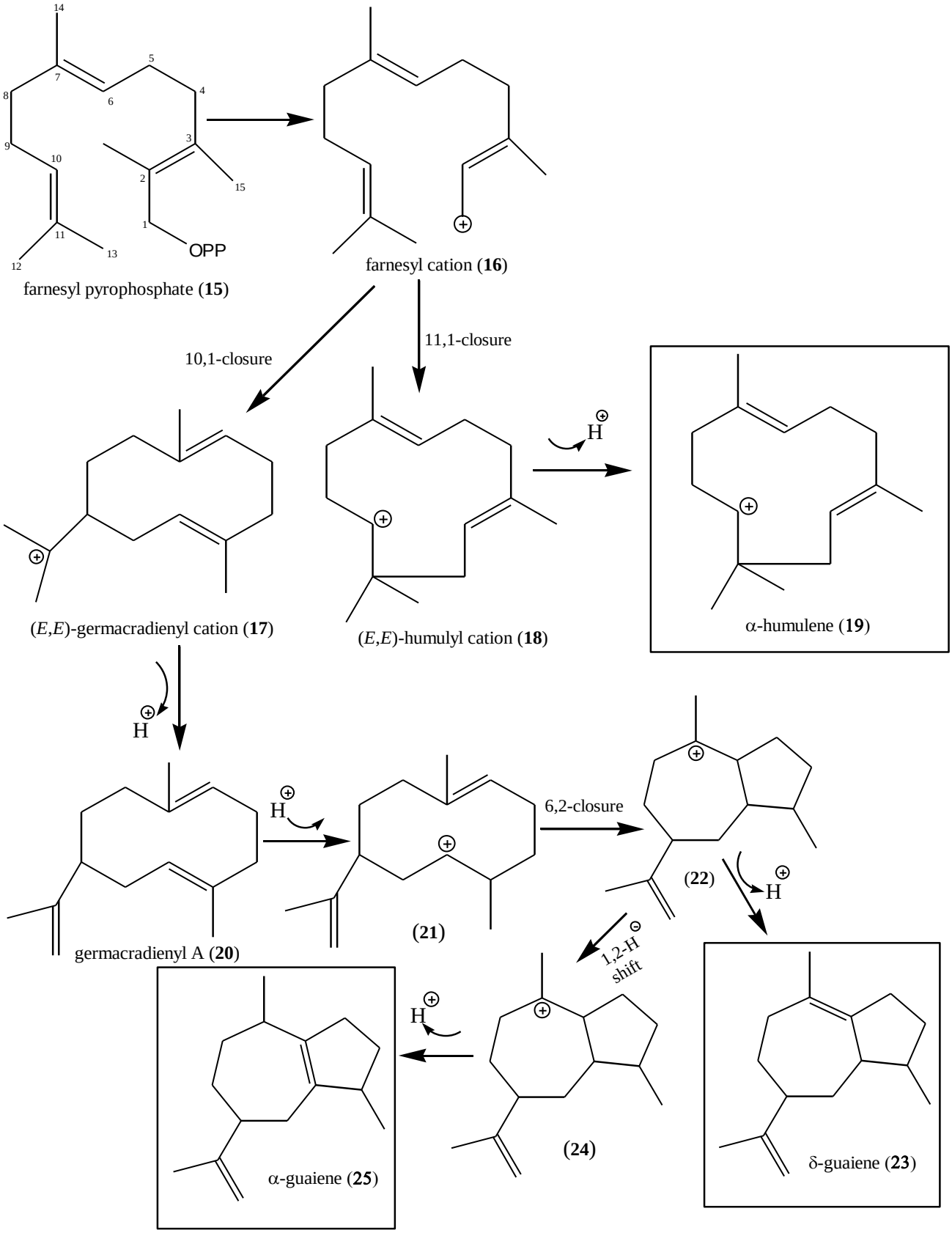
State owned, while local people have use rights [383]. The wontedly uses of Pine gum turpentine for chemical products, there are potential new uses as biofuels. The hindered nature of the structures of the major components of turpentine, α-pinene (**6**), β-pinene (**7**) and 3-carene (**65**), suggest that they might impart octane-enhancing properties in more efficient and cleaner burning high compression engines [379]. Copaiba oil is used as diesel-like fuels, Monti *et al*., and Oliveira *et al.* observed that copaiba oleoresin has potential for use in topical formulation, as a stimulant agent for the absorption of hydrophilic bioactive substances [349, 380]. Traditionally, these essential oils and oleoresins are used for their medicinal properties as a folk medicine to treat inflammation, tuberculosis, purgative, stomachic, fever, antispasmodic, antiviral, antiseptic, astringent, diuretic, rheumatism, pneumonia, anti-swelling, antidiarrheal, arthritis, cough, colds, asthma, leprosy, anorexia, headache, gout, balsamic, expectorant, masticatory, vulnerary, amenorrhoea, bronchitis, gingivitis, gonorrhea, ulcer, urethritis, wart, anti-hemorrhagic, aperient (mild laxative), cardiotonic, antidepressant, anti-emetic, sedative, dyspepsia, blood circulation disturbance , ring worm, leucorrhoea and other vaginal discharges [35, 139, 189, 230, 247, 253, 254, 262, 279-297]. Agarwood tissues are known to contain high levels of polysaccharides, polyphenolics and secondary metabolites, which make RNA extraction challenging [298]. Some studies suggested that cinnamon essential oils may improve useful in the battle against insulin resistance and type 2 diabetes mellitus, and various oils have been used in market as therapeutic agents for years without occurrence of significant adverse health effects [256, 260, 261, 299-302].



Scheme 1 General scheme of plant terpenoid biosynthesis.



Scheme 2 Outline of the biosynthesis of monoterpene olefins and abietic acid, the principal diterpenoid resin acid of grand fir oleoresin.



Scheme 3 Putative biosynthetic pathways for sesquiterpenes found in agarwood and cell suspension cultures.

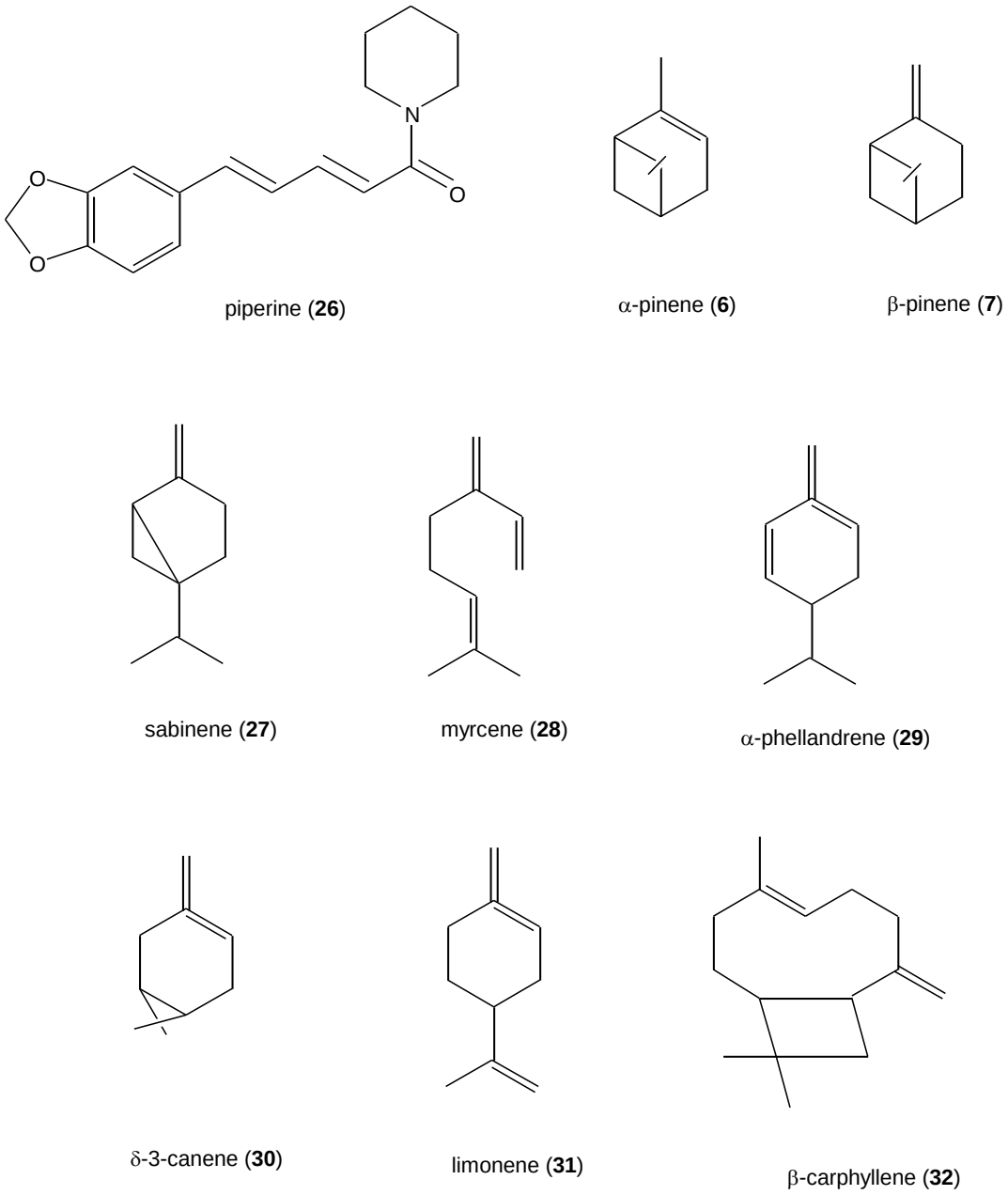
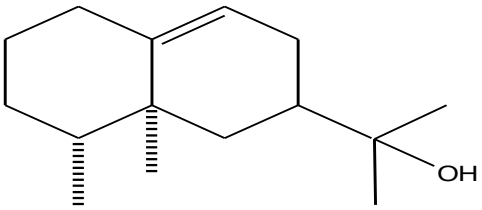
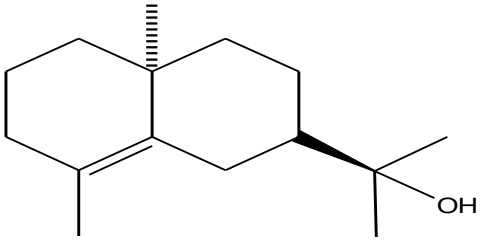


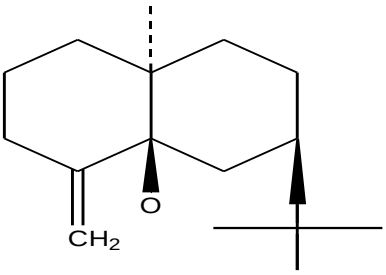
Fig. 1 Structural formulas of some main constituents of *Schinus molle spp***.**



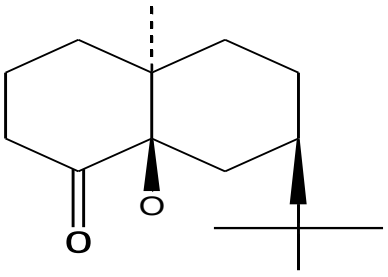
Jinkoh-eremol (**33**)



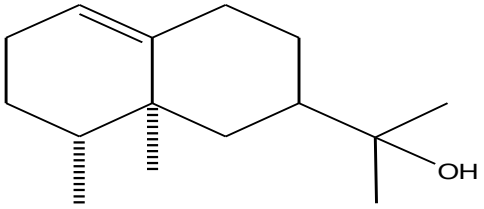
10-epi-γ-eudesmol (**34**)



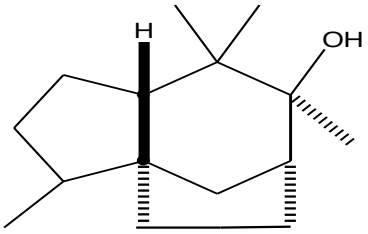
β-agarofuran (**35**)



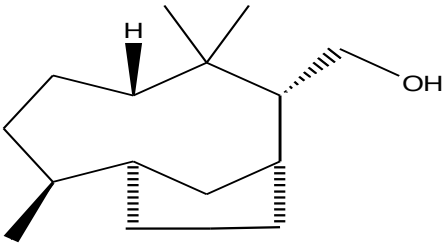
Nor-ketoagarofuran (**36**)



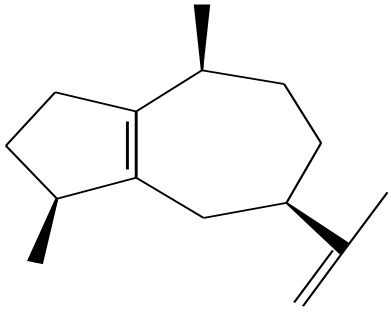
Kusunol (**37**)



Jinkohol (**38**)

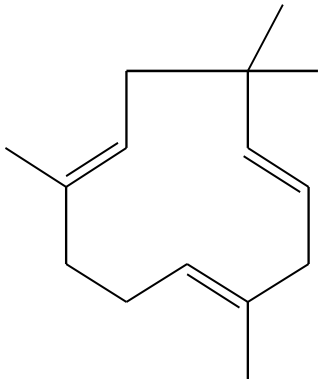


Jinkohol II (**39**)

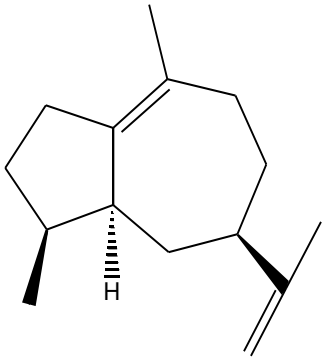


α-guaiene (**25**)

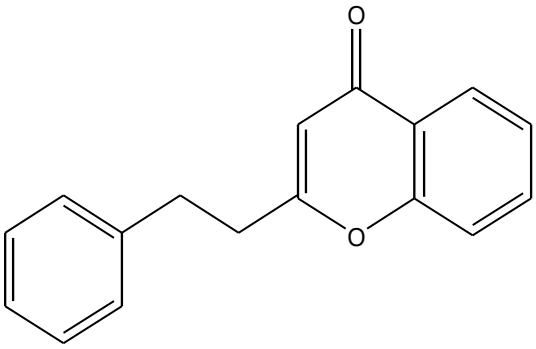
Fig. 2 Chemical structures of some *Aquilaria spp.*



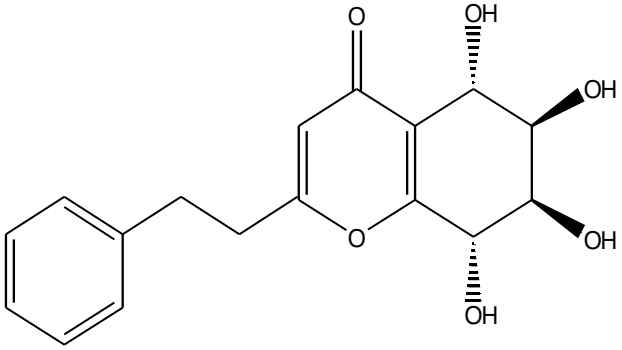
α-humulene (**19**)



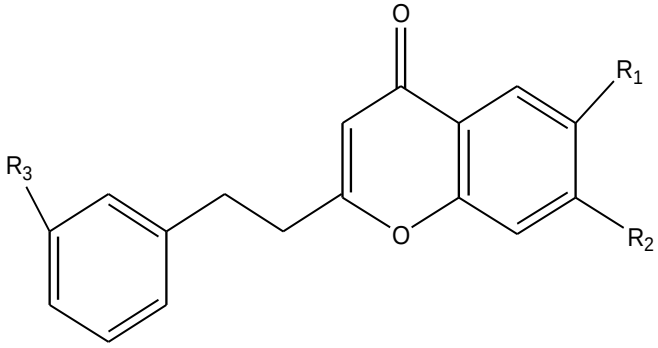
δ-guaiene (**23**)



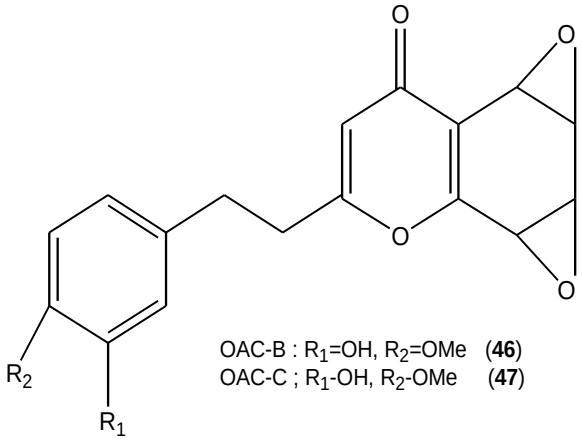
Flindersiachromone (**40**)



Agarotetrol (AH_1) (**41**)



AH_3 : R_1-OH, R_2-R_3-H (**42**)
AH_4 : R_1-OMe, R_2-R_3-H (**43**)
AH_5 : R_1=R_3=OMe, R_2=H (**44**)
AH_6 : R_1-R_2-OMe, R_3-H (**45**)



OAC-B : R_1=OH, R_2=OMe (**46**)
OAC-C ; R_1-OH, R_2-OMe (**47**)

Fig. 3 Chemical structures of sesquiterpenoids and chromone derivatives found in *Aquilaria spp.*

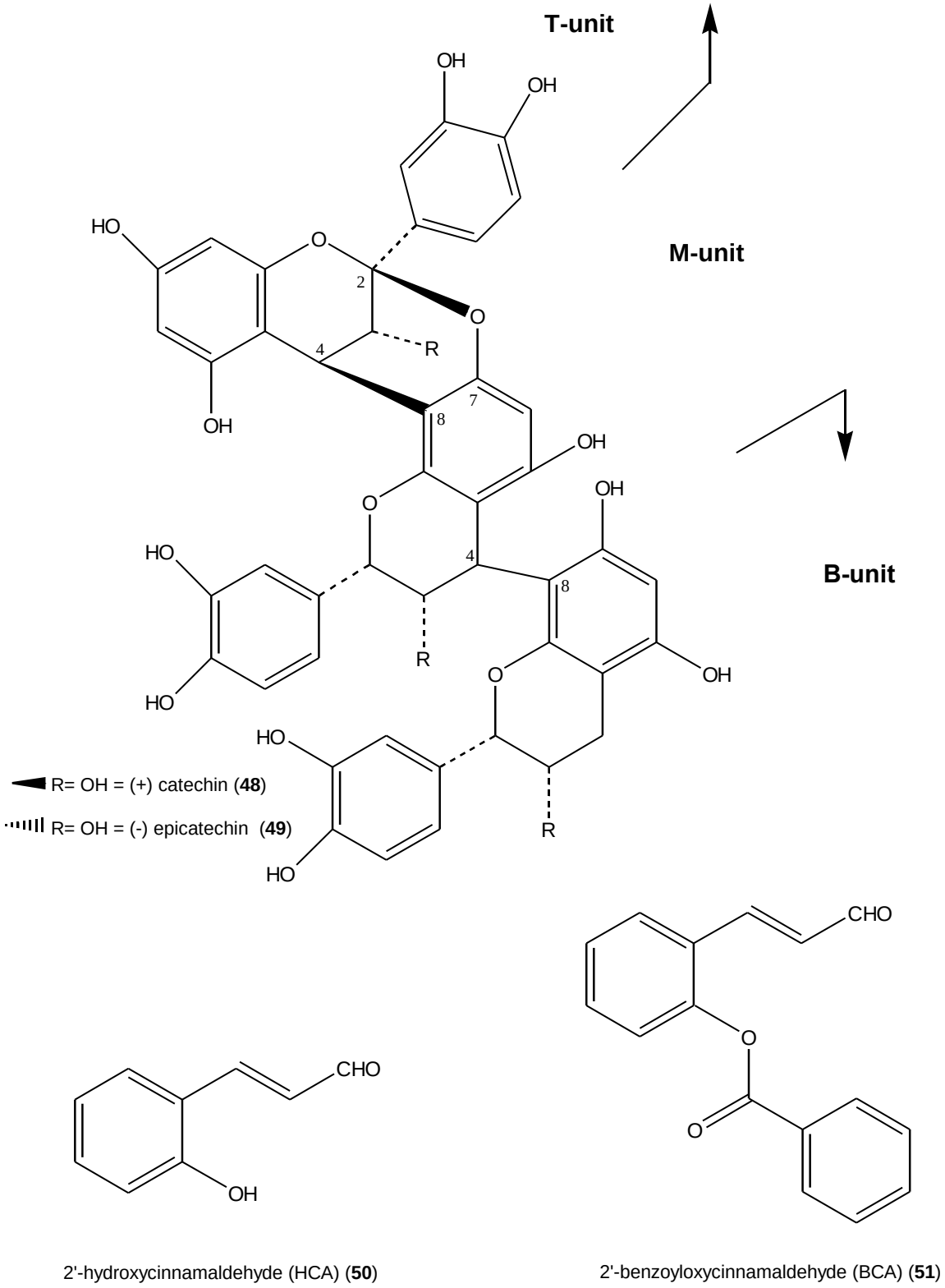
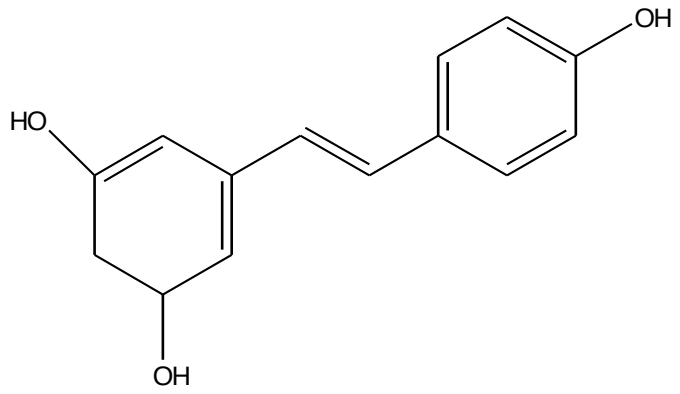
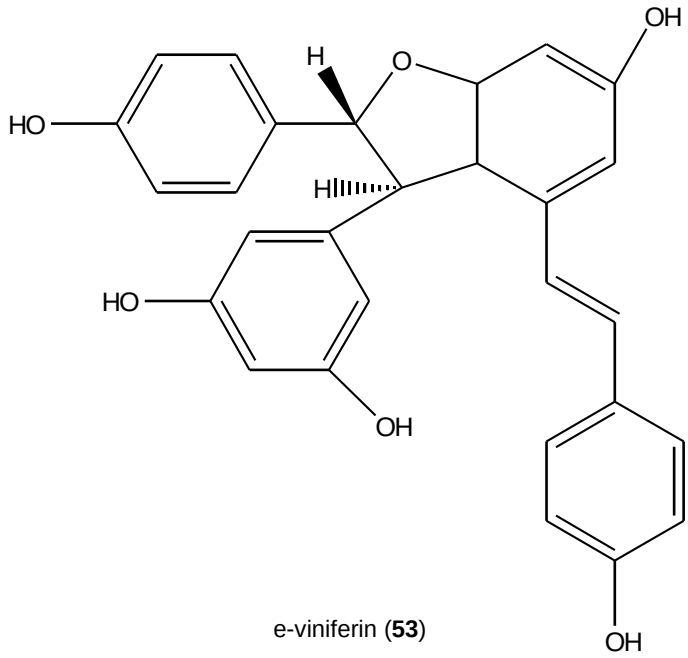


Fig. 4 Chemical structures of cinnamon oleoresin

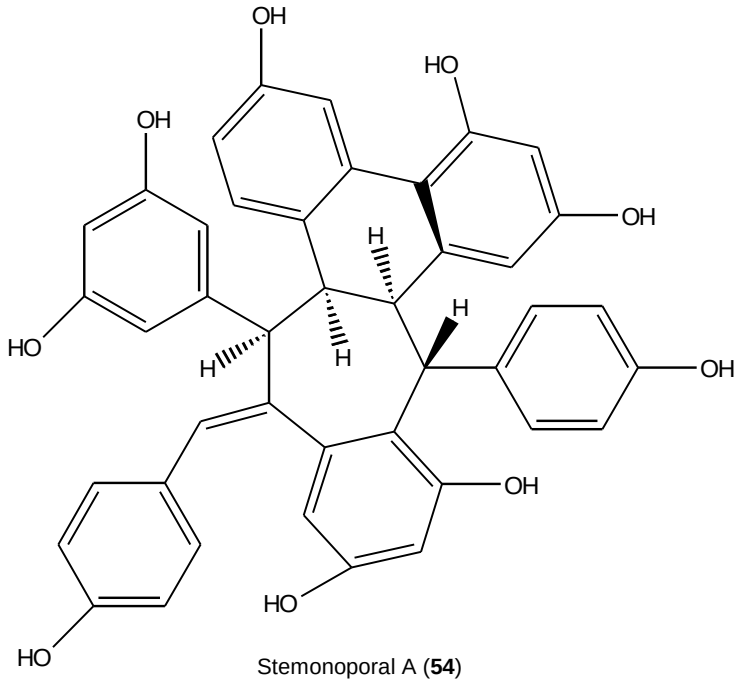


Resveratrol (**52**)

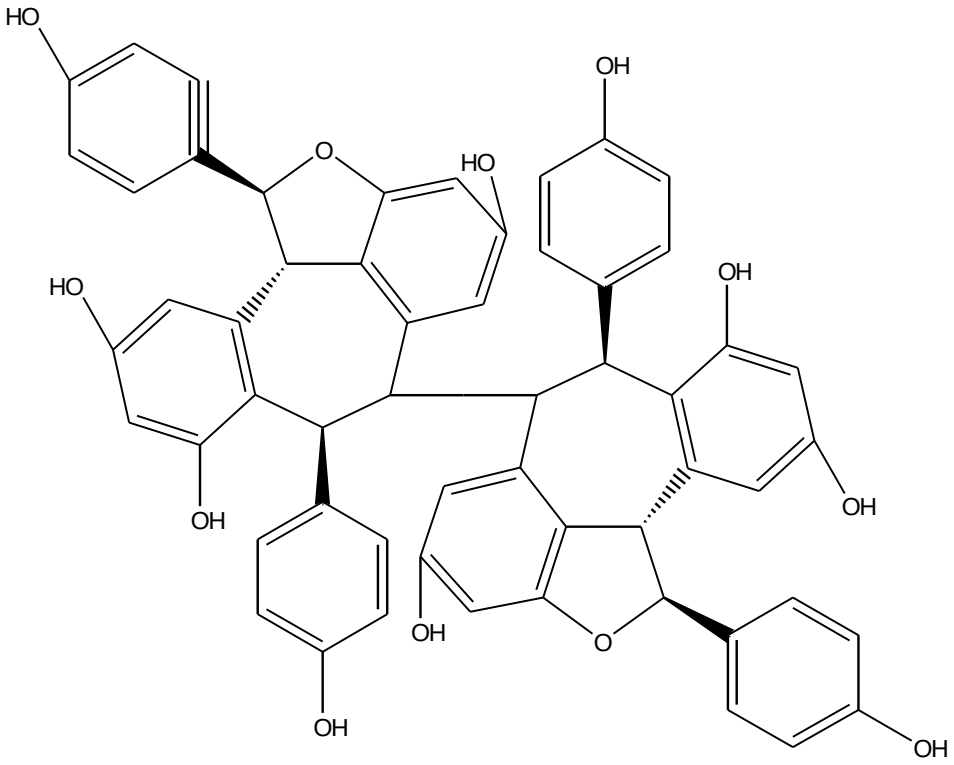


e-viniferin (**53**)

Fig. 5 Chemical structures of monomer resveratrol (**52**) and dimer resveratrol (**53**) compounds in *Dipterocarpaceae spp.*

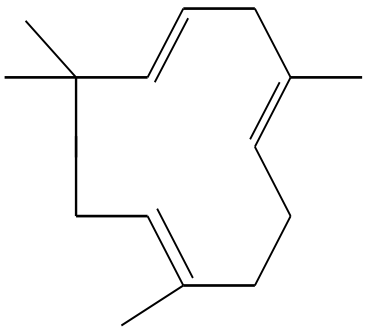


Stemonoporal A (**54**)

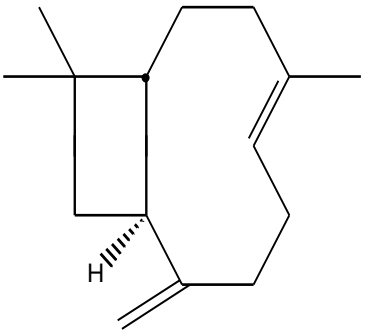


Vaticanol B (**55**)

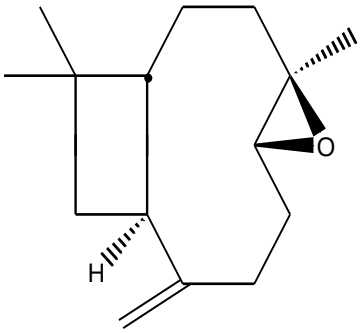
Fig. 6 Chemical structures of trimer resveratrol (**54**) and tetramer resveratrol(**55**) compouns in *Dipterocarpaceae spp.*



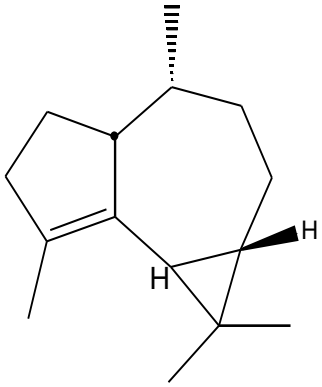
Humulene (**56**)



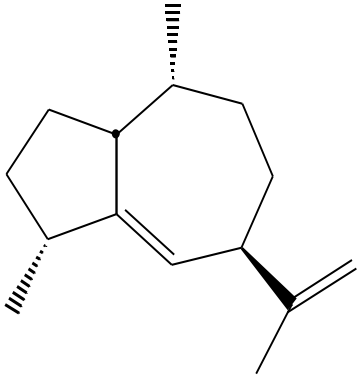
Caryophyllene (**57**)



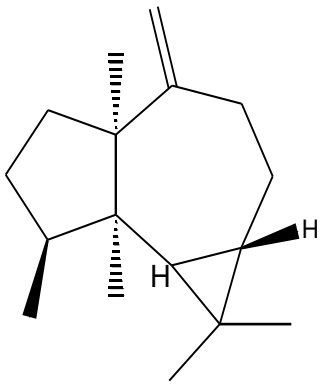
Caryophyllene oxide (**58**)



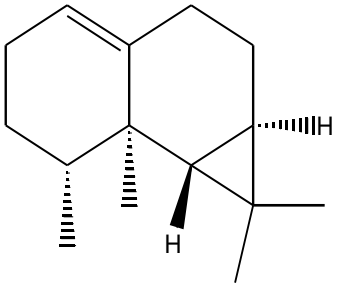
α-Gurjunene (**59**)



γ-Gurjunene (**60**)



Adoaromadendrene (**61**)



Calarene (**62**)

Fig. 7 Chemical structures isolated from dipterocarp oleoresins

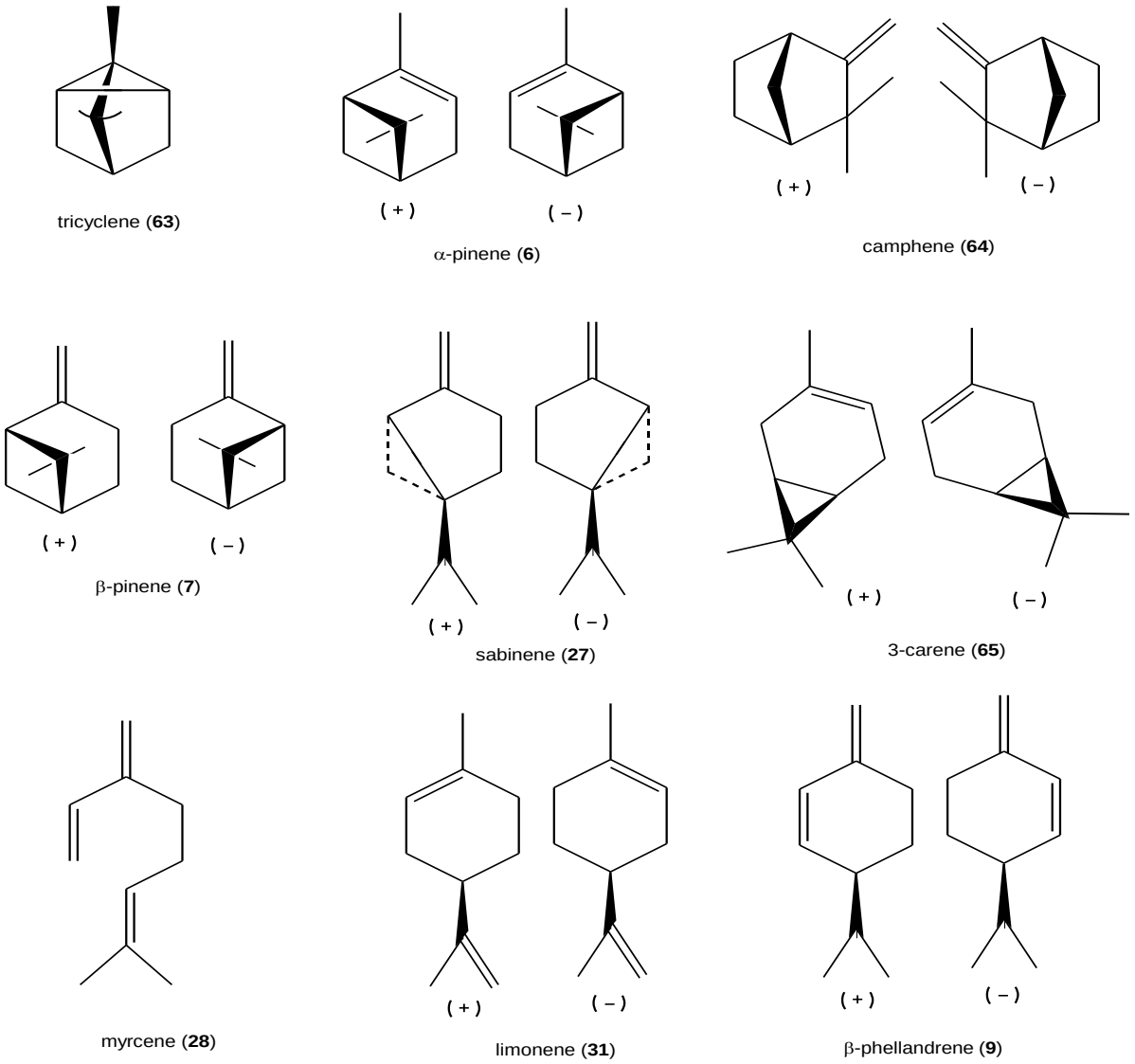


Fig. 8 The molecular structures of Pine oleoresin

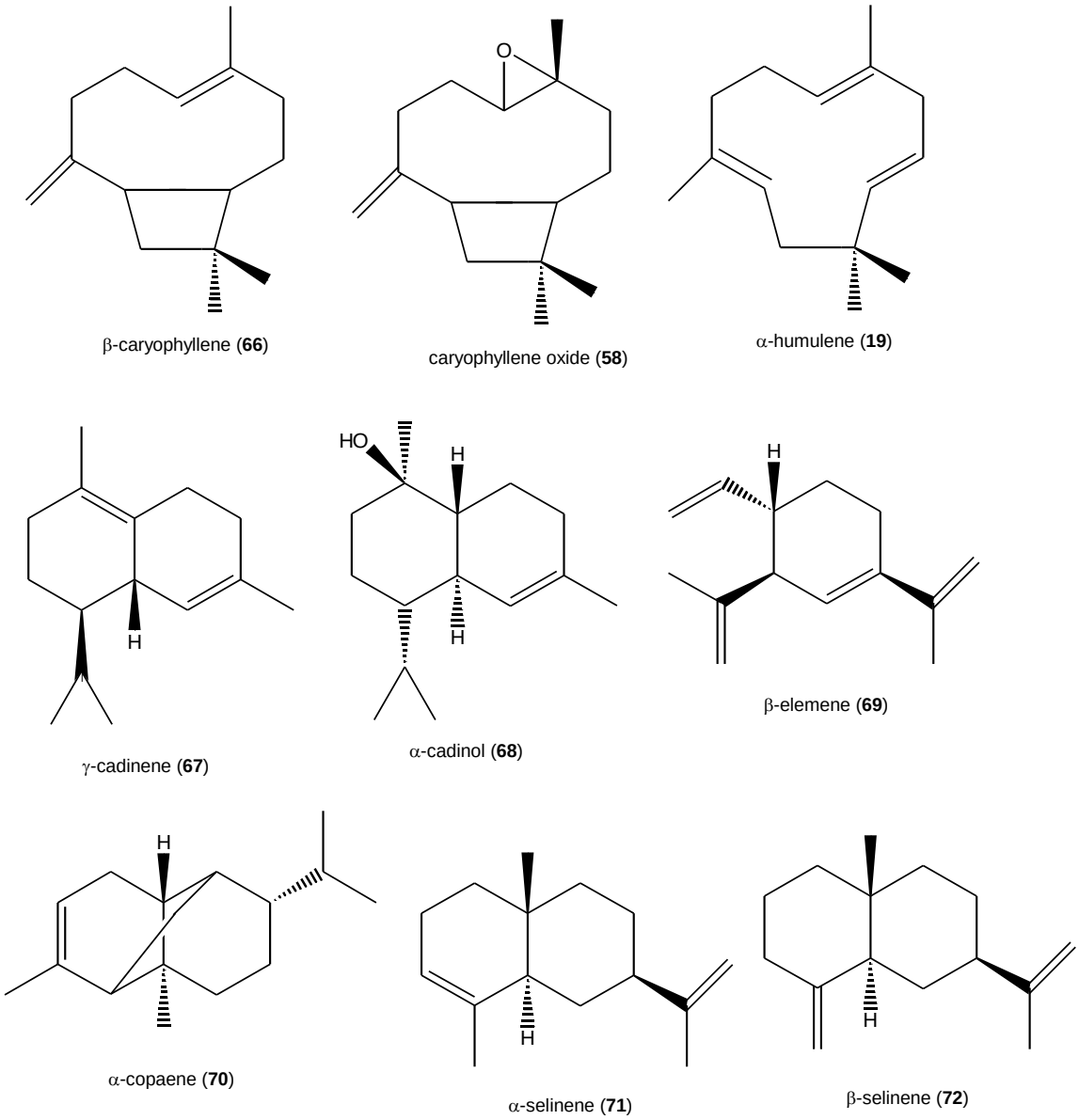


Fig. 9 Main sesquiterpenes detected in copaiba oleoresin.

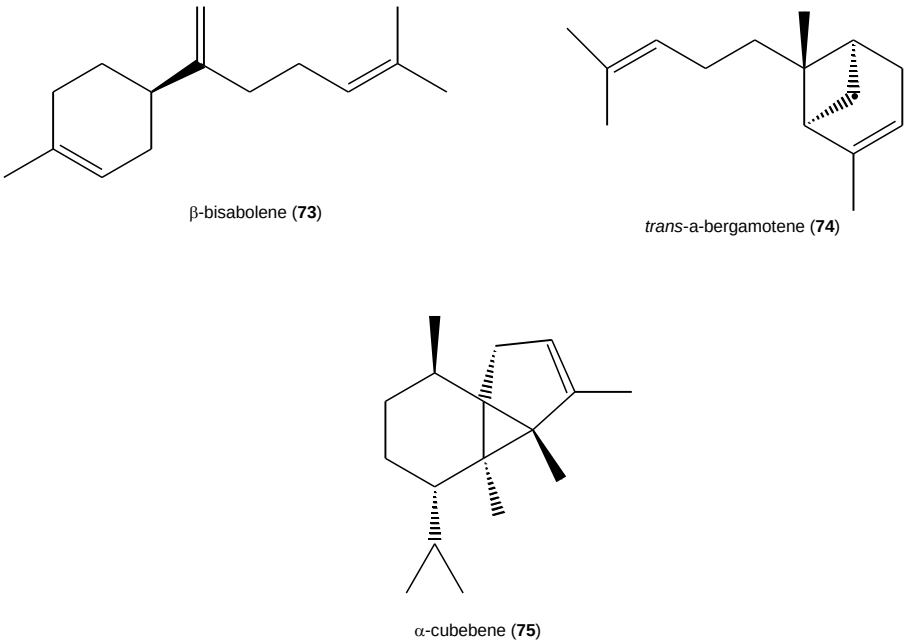


Fig. 10 Chemical structures of sesquiterpenes in copaiba oleoresin.

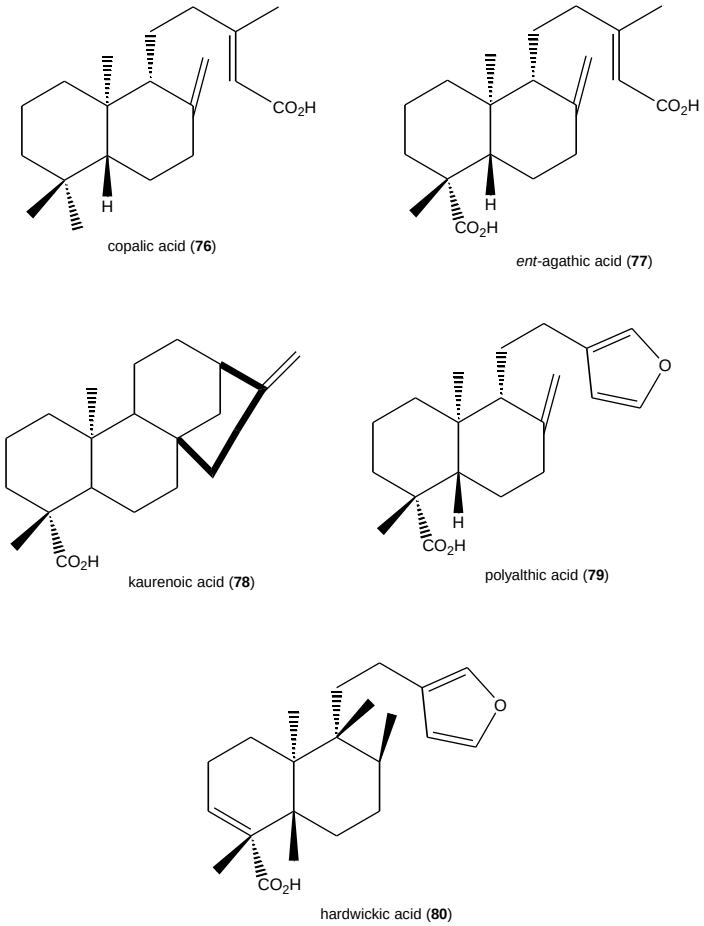


Fig. 11 Main diterpenes detected in copaiba oleoresin.

10. Conclusions

Although many papers have been published on the chemical composition of Aguaribay (*Schinus molle spp.*), Agarwood (*Aquilaria spp.)*, Cinnamon (*Cinnamomum spp.*), Dipterocarp (*Dipterocarpaceae spp.)*, Pine (*Pinus spp.*), and Copaiba (*Copaifera spp*) oleoresins and their essential oils, several questions remain unsolved, such as the fingerprint of the chemical composition of the different species and the presence of biomarkers, probably a combination of sesquiterpenes and diterpernic acids. Ethnopharmacological studies indicate many activities that are still not fully understood through pharmacological experiments. Also, the activities of the isolated compounds do not explain the strong activities of crude oleoresins. Indeed, several substances have being described, and new biological studies have been published that go some way to unraveling the action mechanism of the isolated sesquiterpenes and diterpenes. All these topics still require further investigation, as their oils are resources on which there is still much work to be done.

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